Implications of Distracted Driving on Start-Up Lost Time for Dual Left-Turn Lanes

David S. Hurwitz, A.M.ASCE[1]; Kevin P. Heaslip, M.ASCE[2]; Steven D. Schrock, M.ASCE[3]; Joshua Swake[4]; Patrick Marnell, S.M.ASCE[5]; Halston Tuss[6]; and Eric Fitzsimmons, A.M.ASCE[7]

Abstract: Previous research has found that distracted driving measurably increases driver response times to unanticipated roadway hazards. These instances are of particular consequence as they tend to be highly correlated with vehicle crashes resulting in property damage and/or injury. However, comparatively little attention has been allocated to quantifying the negative impacts of distracted driving on driver reaction to anticipated stimuli. This study empirically determined the impact of distracted driving on queue discharge rates at signalized intersections with protected left-turn phases for dual left-turn lanes. Observational studies were conducted at 11 intersection approaches at six signalized intersections in three states resulting in the observation of 844 distracted and 3,726 undistracted left-turning drivers. A statistical model was developed for the start-up lost time resulting from the average headways of the samples in each state. The difference in start-up lost times between queues comprised entirely of distracted or undistracted drivers ranged from 3.36 to 4.06 s in Kansas, 2.97 to 4.41 s in Oregon, and 2.25 to 5.14 s in Utah. **DOI:** 10.1061/(ASCE)TE.1943-5436.0000569. *© 2013 American Society of Civil Engineers.*

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Introduction

The implications of distracted driving have become a priority in transportation safety and driver behavior research. Evidence that an increase in driver response times to unanticipated roadway hazards can result from the practice of distracted driving has clearly motivated these efforts. Instances of unanticipated hazards are of particular consequence as they tend to be highly correlated with vehicle crashes. However, comparatively limited research has been conducted to quantify the negative impacts of distracted driving on driver reaction to anticipated stimuli, such as those presented by traffic-control devices. A collaborative research effort between Oregon State University, the University of Kansas, and Utah State University addresses the overarching research goal of determining the impact of distracted driving on driver response to anticipated stimuli. This research addresses this goal by empirically determining queue discharge behavior at signalized intersections with protected left-turn phases for dual left-turn lanes. A series of research hypotheses are developed in the next section to address the overall research goal.

[1]Assistant Professor, Oregon State Univ., 101 Kearney Hall, Corvallis, OR 97331 (corresponding author). E-mail: david.hurwitz@oregonstate.edu

[2]Assistant Professor, Utah State Univ., 233 Engineering, Logan, UT 84322. E-mail: kevin.heaslip@usu.edu

[3]Associate Professor, Univ. of Kansas, 2159B Learned Hall, Lawrence, KS 66045. E-mail: schrock@ku.edu

[4]Graduate Research Assistant, Oregon State Univ., 101 Kearney Hall, Corvallis, OR 97331. E-mail: swakej@onid.orst.edu

[5]Graduate Research Assistant, Oregon State Univ., 101 Kearney Hall, Corvallis, OR 97331. E-mail: marnellp@onid.orst.edu

[6]Graduate Research Assistant, Oregon State Univ., 101 Kearney Hall, Corvallis, OR 97331. E-mail: halston.tuss@gmail.com

[7]Lecturer/Postdoctoral Researcher, Univ. of Kansas, 2159A Learned Hall, Lawrence, KS 66045. E-mail: fitzsimmons@ku.edu

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Background

Theory and Calculation

To build the argument for the aforementioned research questions and to set the stage for the experimental design, a brief review of the literature relevant to distracted driving and driver performance is provided. The findings are presented in three focus areas: driver distraction types and impacts, start-up lost time and saturation headway, and left-turn capacity at signalized intersections.

Driver Distraction

Driving a vehicle is a complicated multitasking activity. When dealing with multiple tasks that require continuous and careful attention, a human brain cannot perform as it does when involved in individual tasks performed separately. The brain can only contribute to a limited number of tasks simultaneously, and once drivers attempt to multitask, their ability to do either task is degraded (Regan et al. 2008). The National Safety Council describes inattention as the state when "cognitive distraction contributes to a withdrawal of attention from the visual scene, where all the information the driver sees is not processed" (National Safety Council, Understanding the distracted brain: Why driving while using hands-free cell phones is risky behavior, unpublished report). More simply, distracted driving is any type of activity, commonly classified as manual, visual, or cognitive, that diverts the drivers' attention away from the driving task. Drivers that attempt to multitask are more prone to miss visual cues critical to safety and navigation (National

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Safety Council 2010). However, Klauer, et al. extended this definition further and explained that drivers attending to secondary tasks, driver drowsiness, or a nonspecific glance away from the roadway could also be sources of distraction. They found that the risk of a crash or a near crash increases every time the driver's eyes stay off the roadway for longer than 2 s (Klauer et al. 2006). Therefore, in-vehicle activities, such as dialing a cell phone, adjusting the radio, and reaching for objects, negatively impact the driver's ability to drive safely. Furthermore, even scanning the driving environment through the side and rear mirrors, which is a "safety enhancing activity," could increase the risk of a crash if it takes more than 2 s (Klauer et al. 2006).

Different sources of distraction and the way they affect driver performance have been the focus of previous research studies. The sources of driver distraction discussed in the literature are commonly in-vehicle distractions that break into two categories: nontechnology-based distractions, such as eating/drinking, smoking/smoking related, and passengers and technology-based distractions, such as cell phones, navigation systems, and other similar dashboard-related distractions (Regan et al. 2008).

Eating and drinking can be highly demanding activities involving several steps, diverting the drivers' attention away from the forward roadway to the vehicle interior for a significant portion of time. Similarly, smoking results in driver inattention and increases the risk of crash/near-crash (Regan et al. 2008). A pilot study investigating 2,919 vehicle crashes that involved distracted drivers in Virginia indicated that 6.3% of such crashes were attributable to eating, drinking, or smoking (Glaze and Ellis 2003).

The presence of passengers in the vehicle can also be a source of distraction resulting from either the passengers' distracting behavior or the conversation between the driver and the passengers. The extent to which the presence of passengers effects driving behavior, is a function of multiple parameters such as passengers' and driver age and gender, driver experience, the number of passengers, and their relationship with the driver (Regan and Mitsopoulos 2001, 2008). Various research studies have shown that the risk of being involved in a crash is considerably higher for young drivers, especially when accompanied by two or more young passengers (Regan and Mitsopoulos 2001). Several studies have found that conversing with the passengers may result in increased perception-reaction times and reduced speeds. However, the impacts of such conversation are not comparable to cell phone conversations, where the other person is not aware of the driving environment and the roadway situation (Regan et al. 2008). Drews et al. conducted research that found using a cell phone while driving was more risky than many other distracting activities drivers currently engage in; however, drivers perceived conversing on a cell phone to be an acceptable risk (Drews et al. 2010).

Cell phones have become a part of everyday life for millions of Americans. Newer smart phones allow users to check email, send text messages, and access the Internet. Smart phones allow for multitasking, and this has resulted in cell phone use as one of the main distractions that affect drivers (Edwards, M., Driver distraction and safety: Implications for telematic devices, unpublished report). Drews concluded that there was no doubt that text messaging while driving is a dual-task combination with inherently high risk for the driver and other traffic participants (Drews et al. 2010). The estimated risk of a crash while using a phone is four times higher than when phones are not used (McEvoy et al. 2005). Some states have attempted to counter in-vehicle cell phone use by enacting state-level laws prohibiting use of a cell phone or only allowing hands-free usage while driving. These steps toward cell phone awareness are positive ones, but the National Safety Council says "these laws give the false impression that using a hands-free phone is safe" (National Safety Council, Understanding the distracted brain: Why driving while using hands-free cell phones is risky behavior, unpublished report) when using a hands free device is almost as bad as using a hand-held device (Consiglio et al. 2003). A University of Utah study compared the use of cell phones with drunk driving. They compared the results of cell phone drivers and drunk drivers to baseline, or normal drivers, and concluded that drivers using a cell phone may exhibit greater impairments than legally intoxicated drivers (Strayer et al. 2003).

Dashboard activities performed by the driver, such as adjusting the vehicle stereo, adjusting the climate control, or reading a map or GPS unit can also cause drivers to be distracted and take their full attention off the road. According to Horrey and Lesch, not all drivers would allow distraction to interfere with the driving task. However, the amount of concurrent activities the driver was trying to accomplish would provide a higher likelihood of the driver being distracted (Horrey and Lesch 2009).

Perception Reaction Time

In the context of traffic engineering, perception reaction time (PRT) can be defined as the time needed for a driver to detect a target or event, process the information, make a decision as to how to respond, and, lastly, to initiate that reaction. Higher values (i.e., 1.5 or 2.5 s) are commonly used as estimations for PRT as these values cover most individuals in most situations. However, it is important to remember that PRTs are not fixed; they are a product of different human factors (AASHTO 2010).

According to Mannering et al.'s *Principles of Highway Engineering and Traffic Analysis*, start-up lost times occur due to an initial lag in the driver's response to the changing of a signal indication. This start-up lost time has a typical value of around 2 s. Furthermore, saturation headway is typically seen after the fourth vehicle in the queue (Mannering et al. 2009).

Start-Up Lost Time and Saturation Headway

Depending on the vehicle's position in a queue, different measures are used to determine the headway. For the first queued vehicle, headway refers to the time lapse between the activation of the green light and the time the front axle of the vehicle passes the stop line. For consecutive queued vehicles, headway refers to the time lapse between the vehicle's front axle and the axle of the proceeding vehicle crossing the stop line. Since the first driver proceeds through a full perception-reaction process, the first headway is typically longer and tends to reduce for the subsequent vehicles until it reaches a constant value after the fourth or fifth vehicle, which is referred to as the *saturation headway* (h).

The initial headways for the first four to five vehicles are usually above h s, by a value of Δ_i (for headway i). What is known as the *start-up lost time* (l_1) is achieved when these additional values are added:

$$l_1 = \Sigma \Delta_i \tag{1}$$

Research efforts focused mainly on the effects of driver distraction on start-up delay and headway because these factors directly influence the capacity of a signalized intersection.

Dual Left-Turn Lane Capacity

Dual left-turn lanes allow a higher volume of left-turning vehicles to traverse through the intersection than just one turn lane. The use of dual turn lanes allows for a maximum capacity increase because

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nearly twice as many vehicles can utilize the intersection per cycle, and the requirement of green time to meet the demand is less.

There have been differing opinions about whether the use of left-turn lanes is the most effective approach to adding left-turn capacity. Maze, et al. stated “the presence of a left-turn lane at a signalized intersection improves intersection safety and efficiency of operation” (Maze et al. 2004). However, Chang, et al. found that “the presence of left-turning vehicles at signalized intersections tends to increase crash potential, causing excessive delay and reduction of intersection capacity” (Chang et al. 1996). The results of these studies could be valid because it is difficult to evaluate the effects of traffic measurements in terms of the change in the number of traffic crashes at intersections because traffic crashes are unpredictable and rare events (Oh et al. 2010).

Research Hypotheses

The following hypotheses were established to address the research goal of determining what, if any, impact does distracted driving have on queue discharge characteristics and left-turn capacity at signalized intersections:

- $H_{O\,\mathrm{distraction}}$: There is no difference between the proportions of driver distraction types in different regions of the country;
- $H_{O\,\mathrm{headway}}$: There is no difference between the headway of each individual vehicle position (first, second, third, fourth, and fifth) of a distracted driver and an undistracted driver; and
- $H_{O\,\mathrm{startup\ lost\ time}}$: There is no difference between the start-up lost time of a queue composed of distracted drivers or undistracted drivers.

In this research study, the first headway is defined as the difference in time between the activation of the green left-turn arrow and the moment the front axle of the first vehicle in the queue crosses the stop line, while the subsequent vehicle headways are the difference in time between the front axles of two adjacent vehicles crossing the stop line. The vehicle start-up lost time is defined as the sum of the differences in time between each of the first five vehicle headways and the saturation headway.

Methodology

The methodology for this research study involved observations of six field locations in three states, which yielded a robust dataset of observations of visibly distracted and undistracted drivers. The following sections will detail the steps of the research methodology.

Site Selection

The experimental sites in each state were chosen by the research team due to their operational characteristics of the intersections matching the stated goals of the study. The requirements for the selection of an intersection were at least one dual left-turn lane and demand that resulted in queuing (queues of four to five vehicles could accumulate before the left-turn arrow was activated). Another requirement was that video data could be collected in an inconspicuous manner, so that the presence of the researcher would not adversely impact the behavior of approaching drivers. An equal number of sites were selected from each state to increase the potential diversity of driver behavior as well as intersection configuration. The following signalized intersections and approaches were selected for inclusion in the study:

1. Lawrence, Kansas (655 observations)
   - Iowa Street at 31st Street (southbound and easatbound)
   - Iowa Street at West 23rd Street/Clinton Parkway (southbound)
2. Corvallis, Oregon (1,320 observations)
   - NW Harrison Boulevard at Hwy 34 (westbound)
   - NW Circle Boulevard at Hwy 99W (northbound)
3. Logan, Utah (1,751 observations)
   - 1400 N at Main Street (northbound, southbound, eastbound, and westbound)
   - 400 N at Main Street (northbound and southbound)

Fig. 1 provides design drawings of the geometric configurations for the six study intersections. For several instances, multiple approaches were observed at the same intersection. While the study intersections span 11 approaches at six intersections in three states, all of the study sites were located in relatively smaller communities in close proximity to large public universities. As such, it is recommended that for future studies, the results of this study should be calibrated to local conditions before broad generalizations of driver behavior are proposed.

Video Data Collection

Data collection occurred on prevailingly good weather days, during daylight, and under dry pavement conditions. Data were collected on Tuesdays, Wednesdays, and Thursdays to replicate typical

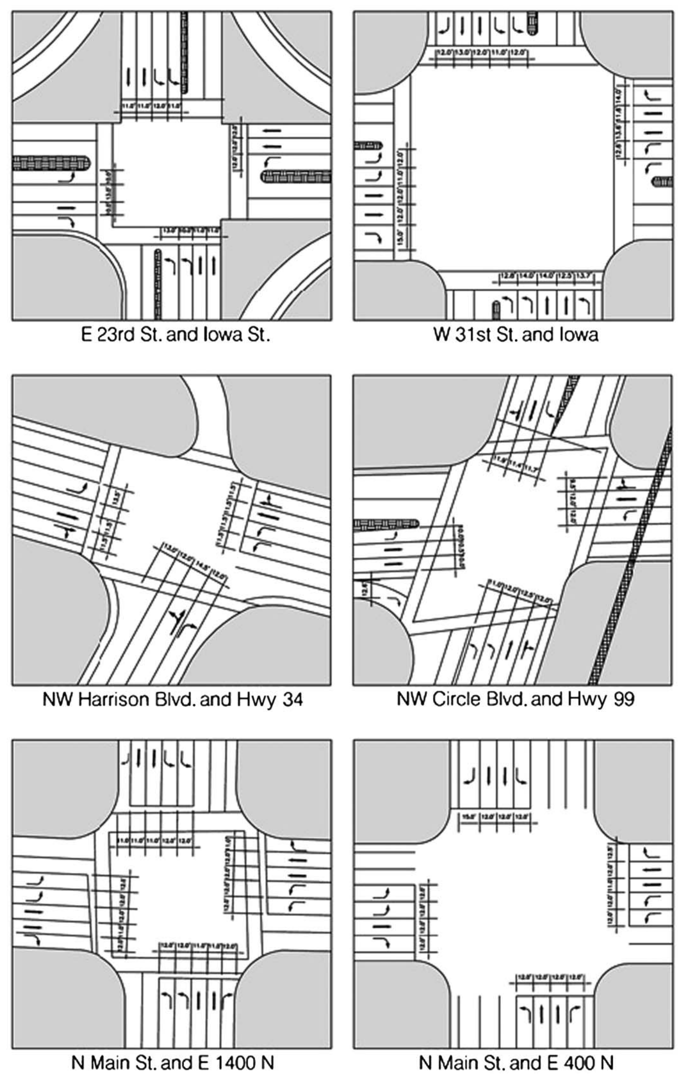

Fig. 1. Geometric configurations of observed intersections

weekday travel conditions and driver behavior. Effort by the research team was made to observe the locations during periods of time where queuing was more likely to occur as a means of increasing the sample per unit of observed time.

All field data were recorded by high-definition video cameras to aid in clearly determining distracted driver behaviors inside the vehicle compartment and identifying exactly when the left arrows were activated and when the front axle of vehicles crossed the approach stop line. Researchers in the field carefully positioned the camera equipment such that it would not be detected by the left-turning vehicles that were being observed.

While the video data collection provided a mechanism to observe drivers directly without influencing their behavior, it also posed a limitation for identifying certain types of distractions. Distractions could only be identified if they could be detected through visual inspection (e.g., talking on a hand-held cell phone). It was likely that some distractions were present but could not be detected through visual inspection of the video data (e.g., from listening to music).

Video Data Reduction

Video data were reduced by researchers on large high-definition LCD monitors at Oregon State University. To ensure consistency among researchers reducing the data, a single transcription template was developed with detailed instructions as to how the data was to be extracted and organized from the video. Observer reliability was maintained by requiring at least two research assistants transcribing an identical five minutes from every 60 minutes of transcribed video. If inconsistencies were detected, the entire hour was crosschecked until the observations of both researchers were in agreement.

Data were collected on every left-turning vehicle and driver in the inside and outside left-turn lane of the intersection approach during the observation period. Time-stamp data for the activation of the green arrow and the time the front axle crossed the stop line were recorded at a rate of 60 frames/s. The recorded data for individual vehicles and drivers including the travel lane (inside or outside), position in the queue (e.g., first, second, third, fourth, fifth, sixth), vehicle classification (heavy vehicle, bus, truck, passenger car, motorcycle, or bicycle), driver gender (male or female), and type of distraction (cell phone, eating/smoking, talking to passengers, other, undistracted, or could not determine). The distraction type was recorded if it transpired within 5 s of the onset of the green indication.

An important aspect of the transcription methodology was the process by which vehicle headways were determined. To accurately determine this value (time difference between the front axle of two successive vehicles to cross the same point), it was required that times be rounded to the nearest 0.01 s (by video time stamp). Fig. 2 displays two images of a vehicle observed in Oregon as it was reduced. Fig. 2(a) shows a light pickup in the outside left-turn lane, in the first position of a queue at the instant the left-turn green arrow was activated. Fig. 2(b) shows the same pickup at the moment the front axle crossed the stop line. The headway for the first vehicle was calculated as the difference between the activation of the green arrow and the time its front axle crossed the stop line. The headway for each subsequent vehicle was defined as the difference in time between the front axles of two sequential vehicles crossing the stop line.

Table 1 shows the breakdown of video hours collected at each observed intersection approach and the resulting numbers of distracted and undistracted drivers. As shown in Table 1, a total of 33 h of video, representing 704 cycles were collected in the field.

(a) (b)

Fig. 2. (a) Vehicle in outside left-turn lane at onset of the left-turn green arrow; (b) as vehicle entered the intersection (Photographs by Halston Tuss)

Table 1. Observed Left-Turn Vehicle Sample

City, state	Intersection	Approach	Video (h)	Distracted drivers	Undistracted drivers	Unable to determine
Corvallis, Oregon	Circle Boulevard at 99 West	Westbound	5	84	519	112
	Harrison Boulevard at 34	Northbound	7	93	801	43
Logan, Utah	400 North at Main	Northbound	1.5	24	110	16
		Southbound	1.5	159	361	0
	1400 North at Main	Northbound	2	48	312	106
		Southbound	2	96	512	0
		Eastbound	2	63	264	2
		Westbound	2	74	192	0
Lawrence, Kansas	Iowa at West 23rd Street	Southbound	5	87	279	20
	Iowa at 31st Street	Southbound	2	51	249	51
		Eastbound	3	65	127	15
Total:			33	844	3,726	365

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No less than 10 h were collected in each state resulting in a total sample of 4,935 drivers. Additional analyses of this data set are described in the following section.

Results and Analysis

A further analysis was performed on the data to test the aforementioned hypotheses. The process began by aggregating the data from the three states together and verifying observer reliability was maintained during the data reduction process. Due to the described video reduction technique, driver distraction could not be adequately classified by the research team for 365 observations. Therefore, the usable sample of vehicles was reduced to 4,570, which included 844 distracted drivers and 3,726 undistracted drivers. It was critical to initially examine the types of distracted driving behaviors captured in this study before the impacts of those behaviors on traffic stream parameters, such as headway and start-up lost time, could be illustrated.

Driver Distractions

Proportions of distracted driving were captured and categorized. Fig. 3 shows information regarding the overall proportion of distracted driving as well as the breakdown of distracted driving types on a per-state basis. The distracted driving types identified

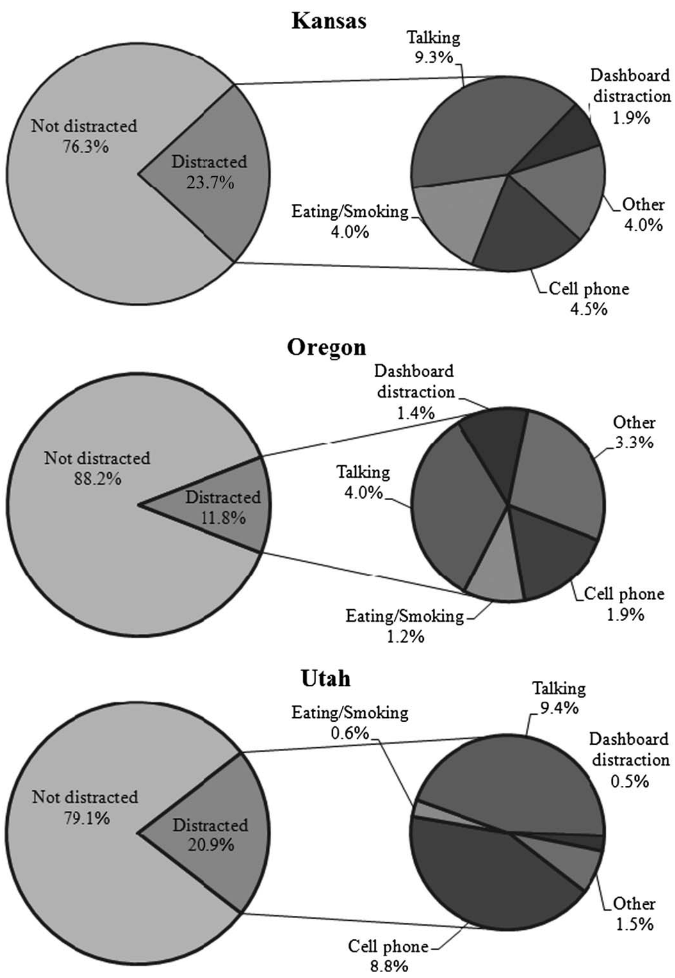

Fig. 3. Proportions of distracted driving types in Kansas, Oregon, and Utah

in this effort were eating/smoking, talking to passengers, cell-phone use, dashboard activities, and other.

As shown in Fig. 3, the distracted driving proportions were determined to be 23.7%, 11.8%, and 20.9% in Kansas, Oregon, and Utah, respectively. The proportion of distracted driving in Oregon was approximately half the proportion observed in Kansas and Utah. It should be noted that Oregon requires hands-free usage of cell phones while Kansas and Utah only have laws banning drivers from texting while driving. The result of a test for equality of proportions, utilizing Pearson's chi-squared test statistic, showed that there were statistically significant differences between the proportions of distracted drivers between Oregon and Utah, and between Kansas and Oregon ($P < 0.05$), but no significant differences were found between the proportions of distracted drivers in Kansas and Utah ($P = 0.30$). The most common occurrence of distracted driving observed in this study was related to talking with a passenger in the vehicle, while the least prevalent distraction was associated with dashboard distractions. A series of Chi-squared tests determined that all three distributions of distracted driving types were statistically different from one another ($P < 0.05$).

Headways

The second research question asked if there was a statistically significant difference between the mean headways of distracted and undistracted drivers for each of the first five vehicles in a standing queue entering an intersection at the onset of a protected green left-turn arrow. To address this research question, linear regression methods were used. Each state was assigned a dummy variable, distracted or not distracted, and the position in the queue. These variables were used in regression models as predictors for the headway, the dependent variable. An undistracted driver, in Oregon, in the first queue position was used as the reference level resulting in the following full model:

$$\begin{aligned}\text{Mean } h = {} & \beta_0 + \beta_1 * \text{Utah dummy} + \beta_2 * \text{Kansas dummy} \\ & + \beta_3 * \text{Distracted dummy} + \beta_4 * \text{Pos2 dummy} \\ & + \beta_5 * \text{Pos3 dummy} + \beta_6 * \text{Pos4 dummy} \\ & + \beta_7 * \text{Pos5 dummy}\end{aligned} \tag{2}$$

This model was compared to a reduced model with no terms for queue position:

$$\begin{aligned}\text{Mean } h = {} & \beta_0 + \beta_1 * \text{Utah dummy} + \beta_2 * \text{Kansas dummy} \\ & + \beta_3 * \text{Distracted dummy}\end{aligned} \tag{3}$$

The comparison was performed using an F-test, where null hypothesis is that $\beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$. This test showed overwhelming evidence to reject this hypothesis (P-value <0.05), meaning that the full model described in Eq. (2) better explains the variance in mean headway. Table 2 shows the values of the regression coefficients from the preferred full model. In all cases the lane position is significant (P-value <0.05) effecting the expected mean value of headway (when compared to the headway of a vehicle in position 1) by 0.11 s to −0.57 s.

The decision to include the impact of location (Kansas, Oregon, and Utah) in Eqs. (2) and (3) was made based on the fact that the proportion test showed a difference in the proportions of distracted drivers in the different states. To confirm this assumption, a reduced model was created with no terms for state:

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Table 2. Driver Headway Regression

Variable	Coefficient estimate	Standard error	t-value	P-value	Significance
Intercept	2.863	0.039	73.319	≪0.001	Yes
Kansas	−0.157	0.049	−3.200	0.001	Yes
Utah	−0.038	0.041	−0.942	0.346	No
Distracted	0.385	0.045	8.474	≪0.001	Yes
Position 2	0.110	0.045	2.444	0.015	Yes
Position 3	−0.177	0.051	−3.450	≪0.001	Yes
Position 4	−0.440	0.060	−7.398	≪0.001	Yes
Position 5	−0.577	0.071	−8.156	≪0.001	Yes

Note: Significance was defined as a confidence of 95% or greater (P-value <0.05).

$$\begin{aligned}\text{Mean } h = \beta_0 &+ \beta_3 * \text{Distracted dummy} + \beta_4 * \text{Pos2 dummy}\\ &+ \beta_5 * \text{Pos3 dummy} + \beta_6 * \text{Pos4 dummy}\\ &+ \beta_7 * \text{Pos5 dummy}\end{aligned} \tag{4}$$

This model was compared to the full model using an F-test, (null hypothesis is that $\beta_2 = \beta_3 = 0$). This test showed strong evidence to reject this hypothesis (P-value <0.05) showing that the full Eq. (2) with state better explains the variance in mean headway.

To examine the effect of individual distraction types, the full Eq. (2) was expanded to include dummies for each of the distraction types:

$$\begin{aligned}\text{Mean } h = \beta_0 &+ \beta_1 * \text{Utah dummy} + \beta_2 * \text{Kansas dummy}\\ &+ \beta_3 * \text{Pos2 dummy} + \beta_4 * \text{Pos3 dummy}\\ &+ \beta_5 * \text{Pos4 dummy} + \beta_6 * \text{Pos5 dummy}\\ &+ \beta_7 * \text{Cell phone dummy}\\ &+ \beta_8 * \text{Eating or smoking dummy}\\ &+ \beta_9 * \text{Talking dummy} + \beta_{10} * \text{Dashboard dummy}\\ &+ \beta_{11} * \text{Other dummy} + \beta_{12} * \text{Combination dummy}\end{aligned} \tag{5}$$

Table 3 shows the values of the regression coefficients from this model. Every distraction in this model had a significant increase on mean headway except the eating or smoking variable. The value of this increase varied from 0.16 s to 0.65 s.

Start-Up Lost Time

The start-up lost times were examined on a per-state basis so that geographic differences might be more readily examined. Eq. (1) provides the standard practice for calculating a start-up lost time (l_1). The application of Eq. (1) requires the determination of saturation headway (h). For this study, h was determined by calculating descriptive statistics for headways 6 through 12, factoring out any headway outside of a single standard deviation from the mean headway then calculating the new average headway. The saturation headways were calculated per approach, however the values were so similar within a single state that only a single value was used. The resulting value for the saturation headway was 1.92 s in Kansas, 2.09 s in Oregon, and 2.12 s in Utah. These values were used in the calculation of the actual start-up lost times presented in Fig. 4.

Fig. 4 shows a box plot of empirical data for the start-up lost times determined from standing, five vehicle queues containing anywhere from one to four distracted drivers. The condition of zero percent distracted driving represents a measure for the start-up lost time without any distracted drivers in the queue at the onset of the green arrow. The condition of 80% distracted driving represents the start-up lost time if four of the five vehicles in the standing queue were distracted. Table 4 supplements the start-up lost time data in Fig. 4 with sample sizes, means and standard deviations. The mean start-up lost times for queues with zero, one, or two distracted drivers are based upon reasonable sample sizes. It is important to note that only actual queues with these levels of distraction were used, significantly reducing the number of observations but providing confidence in the measures reported.

Increases in the percentage of distracted driving for vehicles in a standing queue in a dual left-turn lane resulted in varying increases

Table 3. Driver Headways Regression by Distraction Type

Variable	Coefficient estimate	Standard error	t Value	P-value	Significance
Intercept	2.858	0.039	73.319	≪0.001	Yes
Kansas	− 0.159	0.049	− 3.231	0.001	Yes
Utah	− 0.035	0.041	− 0.857	0.391	No
Cell phone	0.163	0.078	2.086	0.037	Yes
Eating/smoking	0.165	0.142	1.158	0.246	No
Talking	0.527	0.066	7.924	≪0.001	Yes
Dashboard	0.378	0.163	2.315	0.021	Yes
Other	0.533	0.109	4.889	≪0.001	Yes
Combination	0.655	0.333	1.969	0.048	Yes
Position 2	0.112	0.045	2.491	0.013	Yes
Position 3	− 0.170	0.051	− 3.315	<0.001	Yes
Position 4	− 0.431	0.059	− 7.243	≪0.001	Yes
Position 5	− 0.570	0.071	− 8.069	≪0.001	Yes

Note: Significance was defined as a confidence of 95% or greater (P-value <0.05).

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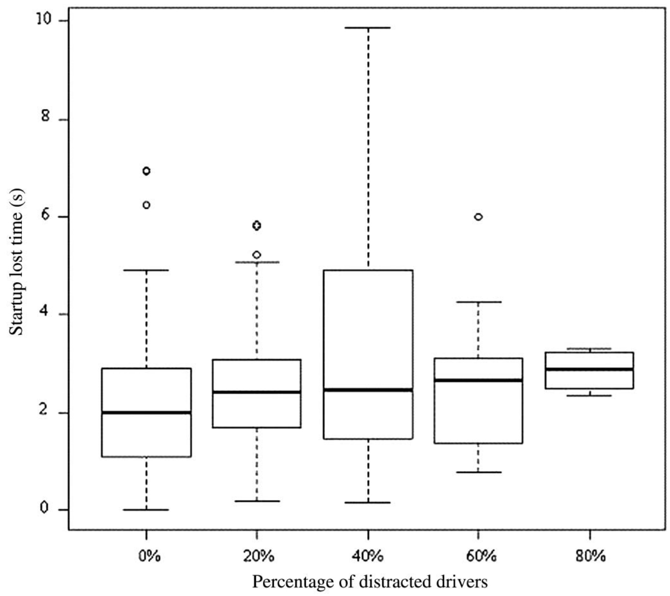

Fig. 4. Start-up lost time for five-vehicle queues in all states

Table 4. Descriptive Statistics for Fig. 4

Number of vehicles	0	1	2	3	4
Sample size	110	101	45	15	4
Mean (s)	2.16	2.48	3.22	2.58	2.86
Standard deviation (s)	1.39	1.27	2.40	1.39	0.45

in the corresponding start-up lost time. Through a visual inspection of the data, it appears that as the percentage of distracted drivers in the queue increases, so does the mean of the corresponding start-up lost times; however, the spread of the data is less consistent.

To verify this observation, a family-wise comparison from an ANOVA analysis with the Tukey Kramer honest significant difference was conducted between each level of distraction (zero, one, two, three, or four distracted drivers). No queues with five distracted vehicle were observed during this study. The results of these statistical tests are located in Table 5, which gives the P-values for each test.

The statistical tests provided partial evidence to support the notion that increased proportions of distracted driving result in an increased mean and variance of the observed start-up lost times. Statistically significant increases were observed at 95% confidence in the mean start-up lost times of zero distracted drivers and two distracted drivers ($P = 0.001$). Also, a suggestive result was indicated between two distracted drivers and one distracted driver ($P = 0.0616$). Additionally, statistically significant increases in variance were observed between zero distracted drivers and two distracted drivers ($P < 0.001$), one distracted driver and two distracted drivers ($P < 0.001$), two distracted drivers and three distracted drivers ($P = 0.031$), and two distracted drivers and four distracted drivers ($P = 0.018$).

Study Limitations

The results of this research study should be considered with the following four caveats in mind: (1) while the sample size of drivers observed is large enough to draw statistical significance, all of the observations took place in three relatively small towns near large

Table 5. Familywise Comparisons of the Mean Value of Start-Up Lost Time by Number of Distracted Divers in the Queue

	Familywise comparisons using Tukey Kramer honest significant difference		
Comparison of distracted driving	Estimated difference	Adjusted P-value	Significance difference
0 distracted versus 1 distracted	−0.317	0.576	No
0 distracted versus 2 distracted	1.061	0.001	Yes
0 distracted versus 3 distracted	−0.418	0.866	No
0 distracted versus 4 distracted	−0.702	0.902	No
1 distracted versus 2 distracted	0.744	0.062	No/ Suggestive
1 distracted versus 3 distracted	−0.100	0.999	No
1 distracted versus 4 distracted	−0.385	0.989	No
2 distracted versus 3 distracted	0.644	0.636	No
2 distracted versus 4 distracted	0.359	0.992	No
3 distracted versus 4 distracted	−0.285	0.998	No

Note: Significance was defined as a confidence of 95% or greater (P-value <0.05).

public universities, (2) while the data were collected such that drivers were unaware they were being observed, the research team could only detect distractions with a strong visual component (e.g., a person holding and talking on a cell phone), (3) In some instances distractions could not be adequately classified due to the presence of window glare or the occasional occlusion of vehicles in the outside lane by vehicles in the inside lane, and (4) the conclusions should not be extrapolated to other movements (e.g., single exclusive left-turn bays or left turns from a shared lane). As such, results should not be directly extrapolated to the entire population of drivers without an additional calibration process to local conditions since it is likely that all forms of distracted driving were not identified in the study sample.

Summary and Conclusions

This research effort sought to determine if the presence of distracted driving in the standing queue of left-turning vehicles at the onset of the green arrow in dual left-turn lanes negatively impacts the headways and associated start-up lost times. Through careful data collection and reduction, a sample of 844 distracted drivers and 3,726 undistracted drivers were observed in Kansas, Oregon, and Utah. Meaningful differences were identified, relating to the types and amounts of distracted driving observed in each state, as well as differences between the headways and start-up lost times of distracted and undistracted drivers. Several findings were produced, and are described here.

Driver Distraction

The proportion of observed distracted drivers differed between the three states in which data were collected. Drivers in Kansas and Utah were nearly twice as likely to be distracted compared to drivers in Oregon. The proportion of drivers observed in each of the five distraction categories differed between the three states in which data were collected. In particular, cell phone distractions were observed more frequently in Utah than Kansas or Oregon. Specifically, cell phone use in Utah was observed approximately eight times more frequently than in Oregon and two times more frequently than in Kansas. The most commonly observed driver distraction type across all three states was talking to a passenger.

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Headways

- Regression analysis found that distraction and queue position were both significant variables in predicting mean headway and
- It was estimated that a distracted driver's headway was 0.385 s greater than an undistracted driver's.

Start-Up Lost Time

- The saturation headway for vehicles in a dual left-turn lane was determined to be 1.92 s in Kansas, 2.09 s in Oregon, and 2.12 s in Utah and
- Increases in the number of distracted drivers in the first five vehicles of a standing queue in a dual left-turn lane result in an increase in the mean (up to 1.06 s) and standard deviation (up to 1.01 s) of empirically observed start-up lost times for five vehicle queues.

These data and the associated analysis should help to inform the current debate revolving around the exclusion of in-vehicle distractions. Current research supports the notion that the minimization or elimination of distractions will lead to fewer crashes. The potential improvement in the operational capacity at signalized intersections has been largely ignored. These data also contribute to the notion that we may need to consider regional calibration factors for the modeling of intersection capacity dependent on proportions of distracted driving.

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