Disentangling the Influence of Cell Phone Usage in the Dilemma Zone: An Econometric Approach

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Abstract

This paper focuses on developing an analysis framework to study the impact of cell phone treatment (cell phone type and call status) on driver behavior in the presence of a dilemma zone. Specifically, we examine how the treatment influences the driver manoeuvre decision at the intersection (stop or cross) and the eventual success of the manoeuvre. For a stop manoeuvre, success is defined as stopping before the stop line. Similarly, for a cross manoeuvre, success is defined as clearing the intersection safely before the light turns red. The eventual success or failure of the driver's decision process is dependent on the factors that affected the manoeuvre decision. Hence it is important to recognize the interconnectedness of the stop or cross decision with its eventual success (or failure). Towards this end, we formulate and estimate a joint framework to analyze the stop/cross decision with its eventual success (or failure) simultaneously. The study is conducted based on driving simulator data provided online for the 2014 Transportation Research Board Data Contest at http://depts.washington.edu/hfsm/upload.php. The model is estimated to analyze drivers' behaviour at the onset of yellow by employing exogenous variables from three broad categories: driver characteristics, cell phone attributes and driving attributes. We also generate probability surfaces to identify dilemma zone distribution associated with different cell phone treatment types. The plots clearly illustrate the impact of various cellphone treatments on driver dilemma zone behavior.

Keywords: Cell phone usage, Dilemma zone, driver behavior, unobserved factors

1. INTRODUCTION

1.1 Background

In the United States (US), crashes involving distracted drivers result in nearly 3,300 fatalities and 400,000 injuries annually (NHTSA, 2013; 2014). Of the fatal crashes involving distracted drivers, 12% are attributed to cell phone use at the time of crash. Evidence from earlier studies (Redelmeier and Tibshirani, 1997; McEvoy et al., 2005) suggests that concurrent cell phone use and driving are associated with greater crash risk. Moreover, cell phone use while driving has a negative impact on the driving performance, specifically in determining and identifying traffic events (Horrey et al., 2006; Ishigami and Klein, 2009). Thus, a driver while using a cell phone (talking or texting) might take longer to respond in unexpected situations on the road.

A 2011 Center for Disease Control and Prevention (CDC) study that compared distracted driving across several countries (including the US, Belgium, France, Germany, the Netherlands, Portugal, Spain, and the United Kingdom) found that more drivers in the US are likely to talk or text while driving compared to their counterparts in other countries (CDC, 2013). In the US, more than 90% of the population currently has cell phone subscription (the World Bank, 2014) and approximately 69% of the drivers have reported that they use cell phone while driving (CDC, 2013). Given the growing use of cell phones among younger individuals, it is not a surprise that policy makers are concerned about these trends. Of particular concern to traffic engineers is the effect of cell phone usage on response to traffic control devices. For example, increased reaction times due to cell phone usage might result in longer time to comprehend the message from traffic control devices thus resulting in unsafe situation at traffic signals.

Within the traffic signal design process, driver behavior in the dilemma zone has received significant attention (for example see Rakha et al., 2008; Hurwitz et al., 2011). In traffic signal design mitigating the impact of dilemma zone is a priority and traffic engineers are constantly seeking measures to reduce the problem associated with dilemma zone. In a dilemma zone, drivers are faced with the challenge of making decisions in response to the change of traffic signal from green to yellow. Coupled with the complexity of decision making in the dilemma zone, if the driver is using a cell phone, the driver's decision process might be affected resulting in dangerous conditions for the driver and other road users. Understanding how cell phone usage affects driver response in the presence of a potential dilemma zone is helpful in accommodating traffic signal design approaches and/or educating drivers about potential risks. While several research efforts have explored separately the impact of cell phone usage in the context of road safety (a detailed discussion is presented in the earlier literature section) and dilemma zone driving behavior, there has been little research that explores driver behavior in the dilemma zone using cell phones.

In this context, the objective of the current study is to develop an analysis framework to study the impact of cell phone treatment (cell phone type and call status) on driver behavior in the presence of dilemma zone. Specifically, we are interested in examining how cell phone treatment influences the driver manoeuvre decision at the intersection (*stop* or *cross*) and the eventual success of the manoeuvre. The analysis of driver performance while using a cell phone in a dilemma zone requires a substantial data collection effort. It would be impractical to compile such data in the real world. A driving simulator based data collection experiment will provide data on how drivers respond to traffic signal change while using cell phone in a dilemma zone. Employing such driver simulator based data, the current study explores the different types of cell phone use prevalent (hands free, headset or handheld) and distinct calling behavior (no call, incoming and outgoing call) on driver manoeuvre decision and its eventual success/failure. The study is conducted based on driving simulator data provided online for the 2014 Transportation Research Board Data Contest at http://depts.washington.edu/hfsm/upload.php.

The rest of the paper is organized as follows. Earlier research is presented in section 2 while positioning the current study in section 3. Section 4 provides details of the econometric model framework used in the analysis. Section 5 provides the data description. The model estimation results are presented in Section 6. Section 7 concludes the paper.

2. EARLIER RESEARCH

2.1 Background

A dilemma zone at a signalized traffic intersection refers to a stretch of road in proximity to the intersection where the drivers are indecisive in determining whether they should proceed or halt when a signal changes from green to yellow. This hesitation at the onset of yellow may lead to either red-light running violation or an abrupt stop at the intersection (Elmitiny et al., 2010). The indecisiveness might result in safety issues including but not limited to rear-end and right angle collisions (Hurwitz et al., 2012). While discussing the dilemma zone, it is important to recognize the alternative definitions of dilemma zone. In literature, two possible dilemma zone definitions exist – Type I and Type II. Type I dilemma zone, identified by Gazis et al. (1960) is described as possibility that a driver on seeing a yellow light is neither able to stop safely or cross the intersection due to intersection design parameters (for no fault of the driver). On the other hand, Type II dilemma zone refers to the possible presence of an indecision zone – stretch of the roadway segment – where drivers are unsure whether to stop or cross. Type I dilemma zone results from poor intersection design issues while Type II dilemma zone results from driver indecisiveness on the right course of action (while in the dilemma zone). In this research effort, we are focussed on Type II dilemma zone identification and improvement.

2.2 Previous Research

In this section, we briefly discuss safety literature along two streams: (a) research examining the impact of cell phone usage on motor vehicle collisions and (b) traffic signal design research in the context of dilemma zone.

2.2.1 Cell Phone Usage Research

Given the consequences involved, it is not surprising that several research efforts have examined the impact of cell phone usage on traffic safety. The studies examined data collected on the field or using driver simulators. The earlier literature can be classified along two major themes: (1) studies that found that cell phone usage worsened driver safety (irrespective of the driving task) and (2) studies that concluded that the complexity of cell phone task influenced the impact on road safety, specifically driver safety. In studies from the *first theme*, Redelmeier and Tibshirani, (1997) and McEvoy et al. (2005) concluded that use of cell phones quadruples the risk of motor vehicle collision. Other studies such as Strayer et al. (2003) and Rakauskas et al. (2004) studied the effect of cell phone conversation on driver performance using a driving simulator. The authors observed a drop in driving performances during these conversations. Studies not involving driving simulators also have found that conversing while driving worsens driver performance (Atchley and Dressel, 2004; Patten et al., 2004; Horrey et al., 2008; Strayer et al., 2003).

In literature from *second theme,* Klauer et al., 2006; Olson et al., 2009 based on their research on driver simulators concluded that collision risk increases for complex tasks such as texting and dialing while conversing on the cell phone was not associated with an increased crash risk. The authors suggest that complex tasks such as texting and dialing might cause the drivers to take their eyes off the road leading to increased risk (see Fitch et al., 2013; Olson et al., 2009). Most recently, Fitch et al. (2013) compared the cell phone usage risk for hand held, portable hands free and integrated hands free devices. In their analysis, the authors concluded that talking on the cell phone did not elevate collision risk levels; however, tasks that required interaction with the phone (of all types) resulted in elevated collision risk levels.

The major drawbacks of cell phone usage documented in literature include irregular speed and headway distribution (Rakauskas et al., 2004), failure to remember objects seen (Strayer et al., 2003), increased reaction times for unexpected events (Caird et al., 2008), reduced lane change behavior (Cooper et al., 2008), and missing traffic signage (Drews et al., 2004).

2.2.2 Dilemma Zone Research

The examination of dilemma zone and associated drivers' behaviour has started since the initial study by Gazis et al. (1960). Not surprisingly, because of the wide ranging implications for traffic signal design the impact of dilemma zone is a well-researched topic (see Moon and Coleman, 2003; Papaioannou, 2007; Rakha et al., 2008; Hurwitz et al., 2011). The two widely used techniques for examining the dilemma zone are: field data collection (Elmitiny et al., 2010; Gates and Noyce, 2010) and driving simulation (Rakha et al., 2008; Caird et al., 2007; Amer et al., 2010). Several earlier studies (Xiang et al., 2005) also used survey technique for investigating driver behaviour at dilemma zone.

Driver characteristics are the major focus of many of the existing studies in examining various aspects of dilemma zone. In terms of driver age, a number of studies argued that young drivers are more likely to drive aggressively compared to adult drivers in response to the yellow-light (Shinar and Compton, 2004; El-Shawarby et al., 2008). Research findings from earlier studies on driver behaviour at signalized intersection reveal that female drivers are more likely to stop at the onset of yellow compared to male drivers (Rakha et al., 2008). Moreover, male drivers are more likely to manifest aggressive action during a yellow-phase. In examining drivers' response to the yellow-phase, researchers have argued that perception-reaction time, drivers' travel time to intersection, vehicle acceleration and deceleration rate, vehicle's distance from the intersection at the onset of yellow and position in the traffic flow are several important indicators that affect the dilemma zone distribution (Liu et al., 2011; Rakha et al., 2008; Elmitiny et al., 2010; Papaioannou, 2007). Many of the earlier studies also investigate the influence of vehicular characteristics in analyzing various aspects of dilemma zone (Xiang et al., 2005; Gates et al., 2010; Gates et al., 2007) and argued that heavy vehicles are more likely to cross intersections aggressively and run red light compared to passenger vehicles. Among the roadway attributes, it was found that intersection layout, speed limit and gradient affect drivers' decision at signalized intersection (Liu et al., 2011).

Overall, from the review, it is evident that there are no studies that examine the influence of cell phone usage in the dilemma zone. The current study addresses this gap by analyzing driver behavior data at the onset of yellow compiled using a driver simulator.

3. CURRENT STUDY

The current research makes a three-fold contribution to the literature on impact of cell phone usage on dilemma zones. ***First***, we formulate and estimate a joint framework to analyze the stop/cross decision with its eventual success (or failure) simultaneously. ***Second***, the model is estimated to analyze drivers' behaviour at the onset of yellow by employing a comprehensive set of exogenous variables. *Finally*, we generate probability surface to identify dilemma zone distribution associated with different cell phone treatment types.

Using the data from driving simulator, we propose to evaluate the success (or failure) of driver's decision at the onset of yellow as a two level process. At the *first level*, we examine driver's decision upon the recognition of yellow onset whether s/he will stop prior to the stop line or cross the intersection. The decision process is influenced by the distance from the stop line, velocity at yellow onset, individual demographics (such as age and gender), the cell phone type treatment (headset or handheld) and call status (no call, incoming call and outgoing call). The decision process assumes the form of a logit model with two alternatives – stop and cross. In the *second level*, depending on the manoeuvre decision made, we examine the success or failure of driver's action at the onset of yellow. For a *stop* manoeuvre, success is defined as stopping before the stop line. Similarly, for a *cross* manoeuvre, success is defined as clearing the intersection safely before the light turns red. For example, if the driver decides to stop, s/he will proceed to reduce the speed and come to a halt prior to the stop sign. Hence, in this overall decision process there are separate success (or failure) processes for drivers with stop and cross manoeuvres i.e. all drivers stopping are analyzed through a stopping success rate model and all drivers crossing are examined through a crossing success model. This approach yields two additional logit models. The decision process in the second level is also influenced by the same set of exogenous variables influencing the stop/cross model. Thus the model system proposed has three binary decision processes.

The eventual success or failure of the driver's decision process is dependent on the factors that affected the manoeuvre decision in the first place. Hence it is important to recognize the interconnectedness of the stop or cross decision with its eventual success (or failure). For example, if the driver is predominantly occupied by cell phone conversation the loss of judgement in deciding whether the driver will stop or proceed will also affect the eventual success (or failure) of the decision. To accommodate for such potential interconnectedness, it is beneficial to consider the impact of observed and unobserved factors on decision to stop (or cross) and the success of manoeuvre. Accommodating for the impact of observed factors is relatively straightforward within the traditional discrete models. For example, if the distraction of the presence of cell phone has an impact, it can be accommodated as an observed attribute. However, presence of cell phone cannot capture the level of distractedness which is possibly a factor of the driver. Hence, it is useful to account for such unobserved factors. The process of incorporating the impact of unobserved factors across choice processes poses methodological challenges. Essentially, accommodating the impact of unobserved factors recognizes that the dimensions of interest are realizations from the same joint distribution. Traditionally, in econometric literature, such joint processes are examined using simulation based approaches that stitch together the processes through common unobserved error terms (see Eluru and Bhat, 2007 for examples in safety literature). Ignoring the presence of such potential jointness may lead to biased and inconsistent parameter estimates (Chamberlain, 1980; Eluru and Bhat, 2007; Washington et al., 2003) in modeling the determinants of driver behavior in the dilemma zone. Hence, in our analysis, we focus on developing modeling approaches that address these challenges. We propose to develop a framework to jointly model drivers' stop/cross decision at the onset of yellow-phase with its eventual success (or failure). The structure of the model framework is described subsequently.

4. ECONOMETRIC MODEL STRUCTURE

The modeling of stop/cross and subsequent success/failure events is undertaken in our model system using a generalized extreme value framework. Let q $(q = 1,2,\ldots,Q)$ be an index to represent individuals, k $(k = 1,2)$ be an index to represent the manoeuvres stop and cross, and j $(j = 1,2)$ be an index to represent the success (= 1) and failure (= 2) of the manoeuvres. Further, to accommodate the possibility of multiple records per person, let t $(t = 1,2, \dots, T)$ represent the different records for individual q. Then, the equation system for modeling the manoeuvre decision and its success (or failure) in the usual binary logit model formulation may be written as follows:

$$u^*_{qkt} = (\beta'_k + \gamma'_k)x_{qt} + \eta_q + \varepsilon_{qkt} \,, \tag{1}$$

Equation (1) is associated with the propensity for alternative k (=1, 2) u^*_{qkt} for an individual q at choice occasion t, and x_{qt} is an $(M \times 1)$-column vector of attributes associated with individual q (for example, gender, age, distance to stop line at yellow onset *etc*.) at the t^{th}choice occasion and β_k and $\gamma_k$represent the corresponding $(M \times 1)$-column vector of mean coefficients and standard deviation' respectively. η_q captures unobserved factors that simultaneously impact manoeuvre decision and subsequent success or failure for individual q[1]. ε_{qkt} is an idiosyncratic random error term assumed to be identically and independently standard Gumbel distributed across individuals' manoeuvre decision alternative k.

$$y^*_{qjt} = (\alpha'_j + \theta'_k)x_{qt} \pm \eta_q + \xi_{qjt} \,, \tag{2}$$

Equation (2) is associated with y^*_{qkt} being the propensity for alternative j (success or failure) for individual q at the t^{th} choice occasion. α_k and $\theta_k$represent the corresponding $(L \times 1)$-column vector of mean coefficients and standard deviation, respectively. ξ_{qjt} is an idiosyncratic random error term, assumed identically and independently standard Gumbel distributed for individual q and alternative j. η_q term generates the dependency between equation (1) and (2). The $\pm$ sign in front of η_q in the success or failure category equation (2) indicates that the correlation in unobserved individual factors between the manoeuvre decision and its success (or failure) may be positive or negative. To determine the appropriate sign, one can empirically test the models with both '$+$' and '$-$' signs independently. The model structure that offers the superior data fit is considered as the final model.

In examining the model structure of stop/cross event (in Equation 1) and success/failure of the manoeuvre decision (in Equation 2), it is necessary to specify the structure for the unobserved vector γ_k, θ_k, and η_q. In this paper, it is assumed that all these vectors are independent realizations from normal population distributions. Thus, conditional on γ_k, θ_k and η_q, the probability of an individual q corresponding to the manoeuvre k at the t^{th}choice occasion is given by:

$$P_{qkt}|\big(\gamma_k,\, \eta_q\big) = \frac{exp\big((\beta'_k + \gamma'_k)x_{qt} + \eta'_q\big)}{\sum_{p=1}^{2} exp\big((\beta'_p + \gamma'_p)x_{qt} + \eta'_q\big)} \tag{3}$$

Similarly, the probability of individual q representing the success and failure j corresponding to the manoeuvre k at the t^{th} choice occasion is given by (conditional on η_q):

$$R_{qjt}|\big(\theta_k, \eta_q\big) = \frac{exp\big((\alpha'_j + \theta'_k)x_{qt} \pm \eta'_q\big)}{\sum_{p=1}^{2} exp\big((\alpha'_p + \theta'_p)x_{qt} \pm \eta'_q\big)} \tag{4}$$

Thus the likelihood function for the joint probability expression can be expressed as:

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[1] In unordered models typically η_q term would also require an alternative specific suffix. However, in two alternatives cases (as is in our context) this is not required as one of the alternatives is considered as a base with utility 0. Hence, we deliberately dropped the suffix for the ease of discussion.

$$L_q = \int_{\eta} \prod_{t=1}^{T} \prod_{k=1}^{2} \prod_{j=1}^{2} \left[\left(P_{qkt} | (\gamma_k, \eta_q) \right) \left(R_{qjt} | (\theta_k, \eta_q) \right) \right]^{\omega_{qkt} \lambda_{qjt}} d\eta_q \quad (5)$$

where, ω_{qkt} is dummy with $\omega_{qkt} = 1$ if individual q correspond to the manoeuvre k at the t^{th}choice occasion and 0 otherwise and λ_{qjt} is dummy with $\lambda_{qjt} = 1$ if individual q correspond to the alternative j at the t^{th}choice occasion and 0 otherwise.

$$L = \sum_{q} L_q \quad (6)$$

All the parameters in the model are then consistently estimated by maximizing the logarithmic function of L presented in equation 6. The parameters to be estimated in the model are: β_k, α_j and υ. To estimate the proposed model, we apply Quasi-Monte Carlo simulation techniques based on the scrambled Halton sequence to approximate this integral in the likelihood function and maximize the logarithm of the resulting simulated likelihood function across individuals (see Bhat, 2001; Eluru and Bhat, 2007; Eluru et al., 2008; Yasmin and Eluru, 2013 for examples of Quasi-Monte Carlo approaches in literature). The model estimation routine is coded in GAUSS Matrix Programming software (Aptech 2015).

5. DATA COMPILATION, SAMPLE FORMATION AND ASSUMPTIONS

The study is focused on the success and failure of the driver`s manoeuvre (stop or cross). Towards this end, we simultaneously examine the manoeuvre decision process as well the subsequent success and failure process. The dataset, after deleting the familiarization and the records for which the drivers had to restart, consisted of 850 records of 49 drivers from the original dataset of 1,157 driver visits. The dependent variable generation required obtaining driver manoeuvre decision and their subsequent success/failure. Hence, we derived three dependent variables – (1) stop / cross variable, (2) for stopping vehicles – success/ failure, and (3) for crossing vehicles – success/failure.

From the dataset of 850 driver visits, we have categorized the driver manoeuvres in the following two groups: 1) Stop – the visits for which vehicle's velocity was zero, and 2) cross – the visits for which vehicle's velocity was not zero. Subsequently, we determined the success and failure of the manoeuvres as follows.

For stopping drivers

- Success: Vehicle's velocity was zero and vehicles stopped before or on the stop line (distance from stop line is "positive")
- Failure: Vehicle's velocity was zero and vehicles stopped after passing the stop line (distance from stop line is "negative")

For crossing drivers

- Success: "Remaining yellow phase at the stop line ≥ 0" and "velocity at the stop line ≥ 15th percentile velocity at the onset of yellow"[2]

[2] The dataset does not provide a direct indication of whether the driver successfully crosses the intersection. Hence, we needed to make a reasonable assumption. To that extent, we used the 15th percentile velocity condition. In traffic design, the all red time for the intersection is determined allowing a vehicle moving at a 15th percentile velocity to

- Failure: "Remaining yellow phase at the stop line < 0" or "velocity at the stop line < 15th percentile velocity at the onset of yellow"

The first row panel of Table 1 offers a summary of the sample characteristics of the driver manoeuvre and the subsequent success and failure conditions. From the sample characteristics, it is evident that more drivers (64.3%) decided to stop at the onset of yellow. More interestingly, we observe that success rate among the drivers who decided to stop (89.9%) is much higher compared to those who decided to cross (58.4%). Further, the second row panel of Table 1 offers a summary of the sample characteristics of explanatory variables in the estimation dataset. From the descriptive analysis, we observe that the sample represents young drivers more than other group of drivers (37%). Moreover, proportion of male drivers are somewhat more than female drivers (male 52.9% versus female 47.1%). We can also observe that the mean velocity of the vehicles at the green to yellow transition is 42 mph while the mean velocity at the stop line is 15 mph.

6. EMPIRICAL ANALYSIS

6.1 Variables Considered

In our analysis, we categorized the available exogenous variables in three broad categories: Driver characteristics (including driver age and driver gender), Cell phone attributes (including cell phone and call type), and Driving attributes (including elapsed time from the onset of yellow to a 10% acceleration change, acceleration direction, minimum acceleration after acceleration pedal change, difference in maximum and minimum acceleration after acceleration pedal change, velocity at green to yellow, distance from stop line at green to yellow and velocity at stop line). It should be noted here that in our final model specification we have also considered several interactions of cell phone attributes with driver characteristics and driving attributes. In the final specification of the model, typically parameters significant at the 90% confidence level are retained. However, to account for the smaller sample size, we also retained a small set of marginally significant parameters in the current study context.

6.2 Model Specification and Overall Measures of Fit

The empirical analysis involves the estimation of two models: (1) a model for decision to stop or cross and the result of the corresponding manoeuvre without any dependency across the decisions and (2) a joint model that recognizes the presence of unobserved factors in manoeuvre decision and its subsequent success or failure while also accounting for the dependency between the manoeuvre decision and its subsequent success or failure. In both models, there are three components: (1) a binary logit model for the decision to stop or cross, (2) a binary logit model for success and failure in stopping, (3) a binary logit model for success and failure in crossing. The difference in the two frameworks results from how the three components are connected. In the first model, these three components are treated as independent models yielding the Independent Binary Logit models (IBL model). In the joint model we recognize that these are decisions made by the same individual across multiple repetitions thus allowing for unobserved correlation across the choices at an individual level. The joint model takes the form of joint panel correlated error

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successfully cross the intersection. Hence, in our analysis, we consider the vehicles that entered the intersection (i.e. crossed the stop line) prior to the end of red and are moving at a velocity ≥ 15th percentile velocity as "success".

components binary logit model (PECBL model) for manoeuvre and binary logit models for success/failure in stopping and crossing. A likelihood ratio (LR) test comparison is performed between the IBM and PECBL model to identify if there are significant error correlations present among the stop/go decision and success/failure in stopping or crossing. The LR test statistic is computed as $2[LL_U - LL_R]$, where LL_U and LL_R are the log-likelihood of the unrestricted and the restricted models, respectively. The log-likelihood (LL) value at the convergence for the IBM model is -713.1 (with 34 parameters) and for the PECBL model is -577.9 (with 38 parameters). The enhanced LL value for the PECBL model with fewer parameters clearly indicate the superiority of the PECBL model. A comparison employing other comparison matrices such as Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) also provide the same comparison results. In summary, the comparison between the independent and joint models confirms that a joint model of the manoeuvre and subsequent success/failure decisions is superior to separate binary logit models. The results highlight the presence of unobserved factors in the manoeuvre decision and its subsequent success or failure models while also showing significant presence of joint unobserved factors affecting the manoeuvre decision and its subsequent success or failure.

6.3 Estimation Results

In presenting the effects of exogenous variables in the model specification, we will restrict ourselves to the discussion of the PECBL model. Table 2 presents the estimation results. For the ease of presentation, the decision to Stop/Cross component and Success/Failure of manoeuvres component are discussed separately. The estimates for common unobserved components in joint model specification are presented in the last row panel of Table 2.

6.3.1 Decision to Stop/Cross Component

<u>Driver Characteristics:</u> With respect to driver characteristics, we found that age impacted the decision to stop. In our analysis, the age variable was categorized as young (age 18-25), middle aged (age 30-45) and older individuals (age 50-60). The results indicate that older drivers are more likely to cross the intersection compared to the middle aged driver. Further, the effect of young age is significant with the interaction of the incoming call. The negative sign of the interaction term indicates that young drivers are less likely to cross the interaction while receiving an incoming call. Compared to male drivers, female drivers are more likely to cross or drive through the intersection while making no call or while in an outgoing call.

<u>Cell Phone Attributes:</u> Finding regarding the effect of cell phone type on stop/cross decision indicates that drivers using headset are more likely to drive through the intersection compared to those drivers using other types of cell phone. The result might be explained by the fact that drivers conversing or answering phones by using headset have more control over the vehicle and thus can drive with a higher mean vehicular speed (Patten et al., 2004) to drive through the intersection compared to those who use hand held phone. Interestingly, none of the call type variables are found to directly affect drivers' decision in the stop/cross decision component of the joint model. As is discussed above, call type interacted with driver attributes does influence the decision process.

<u>Driving Attributes:</u> Among driving attributes, several variables are found to impact the decision of stop/cross in the current study context. The results reveal that the likelihood of crossing increases with an increasing elapsed time from the onset of yellow until the 10% acceleration change. The driving attributes representing acceleration pedal change direction indicates a lower likelihood of

crossing the intersection when the acceleration pedal change direction is “release”. Minimum or maximum acceleration after acceleration pedal change has no significant effect on stop/cross decision in the current study context. However, the difference in the maximum and minimum acceleration after acceleration pedal change shows significant effect in the presence of an outgoing call. The result indicates a lower likelihood of crossing with an increasing value of acceleration differences, specifically while the driver is answering an outgoing call.

Higher velocity when the light first turns from green to yellow shows a positive relation with the crossing decision of drivers, an effect also observed in several previous studies (Chang et al., 1985; Papaioannou, 2007; Gates et al., 2007; Elmitiny et al., 2010). Similar to earlier studies (Elmitiny et al., 2010), our study also found that drivers are less likely to drive through the intersection if they are at a higher distance from stop line when the light first turns from green to yellow. This is particularly so for no call condition indicating that drivers are likely to respond more intuitively when they are not on a call.

6.3.2 Success/Failure of Manoeuvres Component

The estimation results of the success/failure of manoeuvres component of the joint model are discussed in this section by variable groups. Last two column panels of the corresponding stop and cross manoeuvres in Table 2 represent the effect of exogenous variables on failure relative to the base category (success).

<u>Driver Characteristics:</u> The impacts of driver age indicate that young drivers are more likely to fail both in the stopping and crossing manoeuvres relative to other group of drivers. The result is perhaps indicative of aggressive driving behaviour of young drivers at the proximity of intersection, specifically at the yellow-light onset (Chang et al., 2012; Shinar and Compton, 2004; El-Shawarby et al., 2008). The coefficient corresponding to driver gender reflects lower likelihood of failure for crossing decision of female drivers compared to their counterparts. At the same time, we found that female driver answering incoming call are also less likely to fail in stopping manoeuvre. These results are perhaps indicating more cautious driving of female drivers compared to male drivers (Shinar and Compton, 2004; Tarawneh and Tarawneh, 2002; Liu et al., 2011).

<u>Cell Phone Attributes:</u> Drivers are more likely to succeed in stopping manoeuvre if they are using headset for conversing. On the other hand, if they are answering an incoming call by using their headset, they are more likely to fail in stopping. In the event of an incoming call by using handheld cell phone while driving, drivers are also more likely to fail in driving through the intersection presumably due to the slower reaction time (Consiglio et al., 2003; Burns et al., 2002). Moreover, handheld phones are more physically demanding (Matthews et al., 2003) which might further deteriorate the driving performance. In terms of call type, the likelihood of stop failure is lower for both the no call and outgoing call situations compared to incoming call situation. On the other hand, likelihood of crossing failure is higher while drivers are answering an outgoing or an incoming call relative to the no call situation.

<u>Driving Attributes:</u> Among the driving attributes, the results indicate that the likelihood of failure while driving through the intersection decreases with an increasing elapsed time from the onset of yellow to 10% acceleration change. The indicator “release” of acceleration pedal change direction for no call condition has a negative coefficient presumably indicating lower perception-reaction time for this group of driver (El-Shawarby et al., 2008). In crossing, the likelihood of failure is lower for “depressed” indicator in acceleration pedal change. The likelihood of failure for stopping

increases with higher value of minimum acceleration after acceleration pedal change. Drivers decided to stop are more prone to brake heavily and are usually have difficulties in selecting deceleration rate, which in turn might result in improper or failure in stopping manoeuvres (Li, 2009).

Driving attributes representing higher velocity when traffic light turns from green to yellow shows a lower likelihood of failure for crossing manoeuvres, as is expected. Drivers are less likely to fail in stopping if they are in a higher distance from stop line when the light first turns from green to yellow. But, they are more likely to fail in crossing with a higher distance from stop line at the onset of yellow. Moreover, the positive correlation of failure is also observed for no call condition. Of course, the reader needs to consider this effect in conjunction with the incoming and outgoing call effects described earlier. In our model estimates, higher velocity at the stop line reveals a higher likelihood of failure in stopping.

6.3.3 Unobserved Effects

In our model structure, two types of unobserved effects are considered: (1) unobserved effects within the manoeuvre decision (γ_k) and its subsequent success or failure (θ_k) and (2) common unobserved effects between manoeuvre decision and its subsequent success or failure (η_q). The results for the three vectors (γ_k, θ_k and η_q) are presented in the last panel of Table 2. The first and second terms indicates the presence of unobserved heterogeneity in the stop manoeuver equation and cross failure equation, respectively. The unobserved effect was not significant in the stop failure equation.

In estimating η_q terms both the positive and negative signs on the η_q terms are considered in equation 2 for all k (stop and cross decision). In our model estimation, we found statistically superior result for positive sign for stop and crossing manoeuvres. The significance of η_q parameters as presented in the two rows of Table 2 confirm our hypothesis of the presence of common unobserved factors affecting stop/cross manoeuvre and the subsequent success/failure conditions. Moreover, the positive sign of these terms highlight the presence of positive correlations due to common unobserved individual elements between the decision to stop/cross and the subsequent failure in manoeuvres. Further, accounting for these correlations allow us to enhance the estimates of the other variables in the model.

6.4 Model Illustration

We apply the developed model to generate probability surfaces as a function of distance from stop line and velocity at yellow onset while controlling for various other exogenous variables. To illustrate the impact of the various cell phone treatment types that were statistically significant in the model estimation, probability surfaces specific to the treatment types are generated. The surfaces were generated for the three probability values – cross, stop failure and cross failure. The reader would note that one can easily generate the corresponding probabilities for stop, stop success.

For ease of presentation, we fix the values for a subset of the independent variables and illustrate the variability for cell phone treatment, distance and velocity variables. The surfaces are plotted for a hypothetical female, young driver, median value in the dataset for all continuous variables (except distance and velocity at yellow onset).

- <u>Stop/cross</u> – The model estimates yield three different cell phone effects. These are represented as Figure 2a-2c. The results clearly highlight how under no call the probability of crossing drops with higher distance and lower speeds. The area shaded as 0.4-0.6 provides the illustration of the ***dilemma zone*** where the likelihood of the two manoeuvres are nearly equally likely. Between incoming and outgoing call states, we observe that a larger dilemma zone is present for incoming calls.

- Stop Failure - The model estimates yield three different cell phone effects. These are represented as Figure 3a-3c. The no call scenario indicates a high rate of failure as the distance from stop line is close to 0 for all cell phone treatments; however, with increasing distance from the stop line, the probability of failure drops for No call while the rate of drop is much smaller for Call scenario with incoming call being the most likely for failure. The figure illustrates how a young female driver's capability to stop is reduced due to cell phone operation.
- Cross Failure - The model estimates yield three different cell phone effects. These are represented as Figure 4a-4c. The no call scenario has the lowest failure rate (as indicated by large area with failure lower than 1). The handheld scenarios with incoming and outgoing calls have increased failure to cross with nearly similar profiles. Again, these figures illustrate the effect of handheld device on crossing behavior.

It is quite interesting that we see impact of headset on stop failure and handheld device on cross failure process. The reader would note that the figures provided are only a sample of the various illustrations that can be generated based on the independent variables in the models. Adding more variables would have made it harder to present and discuss the results.

7. CONCLUSIONS

Cell phone use while driving has a negative impact on the driving performance, specifically in determining and identifying traffic events. Given the proliferation of cell phone use while driving, traffic signal design has become a challenge for transportation professionals. Coupled with the complexity of decision making in the dilemma zone, if the driver is using a cell phone, the driver's decision process might be affected resulting in dangerous conditions for the driver and other road users. Understanding how cell phone usage affects driver response in the presence of a potential dilemma zone is helpful in modifying traffic signal design approaches and/or educating drivers about potential risks. Towards that end, the objective of our research effort is to contribute to the identification of dilemma zones for drivers using cell phones at the presence of a yellow signal. The study is based on driving simulator data provided online for the 2014 Transportation Research Board Data Contest at http://depts.washington.edu/hfsm/upload.php. Our research explores the different types of cell phone use prevalent (hands free, headset or handheld) and distinct calling behavior (no call, incoming and outgoing call) by employing exogenous variables from three broad categories: driver characteristics, cell phone attributes and driving attributes.

We proposed a simultaneous framework to study decision manoeuvre at the onset of yellow and subsequent success/failure of the manoeuvre. We generated three binary dependent variables - stop/cross, stop failure, and cross failure. For a stop manoeuvre, success was defined as stopping before the stop line. Similarly, for a cross manoeuvre, success was defined as clearing the intersection safely before the light turns red. The eventual success or failure of the driver's decision process is dependent on the factors that affected the manoeuvre decision in the first place. Hence it is important to recognize the interconnectedness of the stop or cross decision with its eventual success (or failure). Thus, the dependent variables were jointly modeled using a panel error component structure that stitches the three binary logit models with correlation for unobserved components at an individual level.

The model developed performed substantially better than the independent binary logit models. The enhanced model fit provides credence to our assumption that factors that influence the decision manoeuvre also affect the success of the decision manoeuvre. In addition to the impact of a host of demographic variables, the model estimation results highlighted the influence of cell phone treatment, distance and velocity from stop line at onset of yellow on the decision process and it success or failure. The model applicability was illustrated by generating probability plots for various scenarios. The plots clearly illustrated the impact of various cellphone treatments on three dependent variables. Specifically, the plots highlighted how the use of cell phones increases the probability of failure in different manoeuvre decision at the onset of yellow. Moreover, the developed plots can be customized for every individual based on his/her exogenous variables allowing us to generate dilemma zone plots for distance and velocity while controlling for cell phone treatments.

To be sure, the study is not without its limitations. The applicability of the model frameworks relies heavily on the variable definitions. Any inaccuracy in the dependent variable will reduce the accurateness of the models. Further, in datasets with few records (such as 49 drivers) obtaining statistically significant parameters is a challenge. The proposed approach provides a methodology to be employed by policy makers to identify success and failure of the decision manoeuvres at a traffic signal. Our effort serves as a starting point for a larger data collection effort that will allow for more specific policy recommendations. Finally, the econometric models developed are reduced form models and do not explicitly consider the complex physical processes at hand and their impact on the drivers. The econometric models provide association relationship between the dependent variables and independent variables (not causality).

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Table 1: Sample Characteristics of Driving Manoeuvres and Explanatory Variables

Dependent Variables				
Categories	**Stop**		**Cross**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Success	492	89.945	177	58.416
Failure	55	10.055	126	41.584
Total	547	64.353	303	35.647

Explanatory Variables	
Variables	**Sample Characteristics**
Categorical Explanatory Variables	**Percentage**
Driver age	
Young (age 18-25)	37.059
Middle-aged (age 30-45)	35.176
Older (age 50-60)	27.765
Driver gender	
Female	47.059
Male	52.941
Cell phone type	
Handheld	33.647
Headset	32.588
Hands free	33.765
Call Type	
No call	33.529
Outgoing call	33.412
Incoming call	33.059
Acceleration pedal change direction	
Released	21.529
Depressed	4.353
Ordinal Explanatory Variables	**Mean**
Elapsed time from the onset of yellow to 10% acceleration change (sec)	0.164
Minimum acceleration after acceleration pedal change (ft/s^2)	-15.761
Difference in maximum and minimum acceleration after acceleration pedal change (ft/s^2)	24.643
Velocity at green to yellow (mph)	42.502
Distance from stop line at green to yellow (100's ft)	2.040
Velocity at stop line (mph)	15.083

Table 2: Estimation Results of Joint Model

Variables	Decision to Stop/Cross Component of the Joint Model		Success/Failure of Manoeuvres Component of the Joint Model			
	Driver Manoeuvre		Stop		Cross	
	Cross (Stop is base)		Failure (Success is base)		Failure (Success is base)	
	Coef	t-stat	Coef	t-stat	Coef	t-stat
Constant	-4.859	-3.673	2.731	1.297	3.185	1.046
Driver Characteristics						
Driver age (Base: Middle-aged)						
Young	–	–	0.684	1.308	0.738	1.102
Young*Incoming call	-1.600	-3.679	–	–	–	–
Older	0.996	1.290	–	–	–	–
Driver gender (Base: Male)						
Female	–	–	–	–	-1.276	-2.049
Female*No call	0.870	1.965	–	–	–	–
Female*Outgoing call	1.062	2.383	–	–	–	–
Female*Incoming call	–	–	-2.480	-3.402	–	–
Cell Phone Attributes						
Cell phone type (Base: Hands free)						
Handheld	–	–	–	–	–	–
Handheld*Incoming call	–	–	–	–	0.891	1.346
Headset	0.380	1.761	-0.841	-1.237	–	–
Headset*Incoming call	–	–	1.985	2.236	–	–

Call Type						
No call	–	–	-2.202	-1.700	–	–
Outgoing call	–	–	-1.500	-2.522	13.365	4.107
Incoming call	–	–	–	–	12.261	3.754
Driving Attributes						
Elapsed time from the onset of yellow to 10% acceleration change (sec)	3.302	4.723	–	–	-0.487	-1.367
Acceleration pedal change direction						
Released	-2.467	-5.365	–	–	–	–
Released*No call	–	–	-1.724	-1.636	–	–
Depressed	–	–	–	–	-1.569	-1.782
Minimum acceleration after acceleration pedal change (ft/s^2)	–	–	0.145	2.727	–	–
Difference in maximum and minimum acceleration after acceleration pedal change (ft/s^2) *Outgoing call	-0.066	-5.698	–	–	–	–
Velocity at green to yellow (mph)	0.126	3.592	–	–	-0.436	-6.175
Distance from stop line at green to yellow (100's ft)	-0.462	-1.074	-1.009	-1.416	4.598	5.297
Distance from stop line at green to yellow (100's ft)*No call	-0.534	-3.353	–	–	5.679	3.726
Velocity at stop line (mph)	–	–	0.626	7.803	–	–
Error component - Stop	2.122	5.204	–	–	–	–
Error component – Cross Failure	–	–	–	–	1.243	2.978
Common unobserved component - Stop and Stop Failure	–	–	0.740	2.540	–	–
Common unobserved component - Cross and Cross Failure	–	–	–	–	0.736	1.741

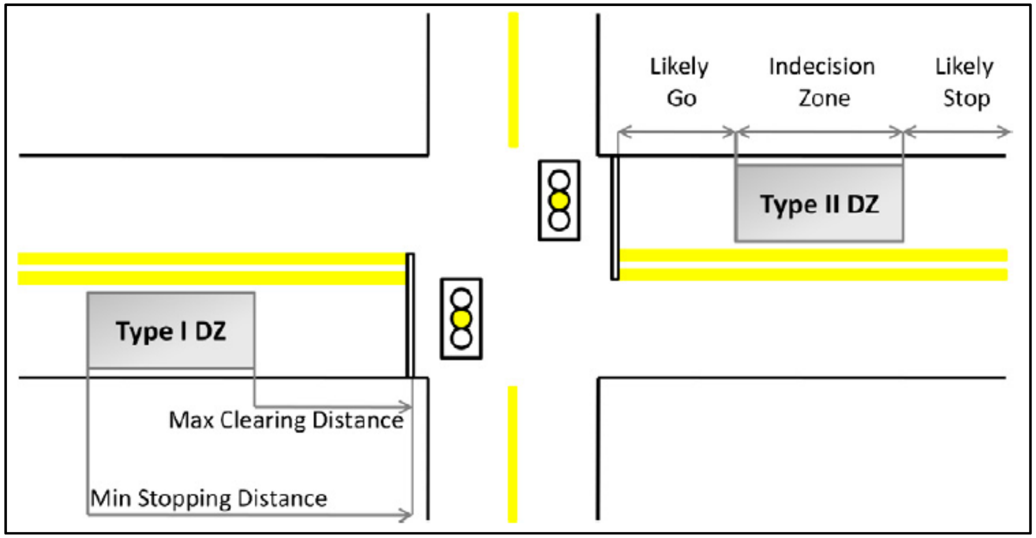
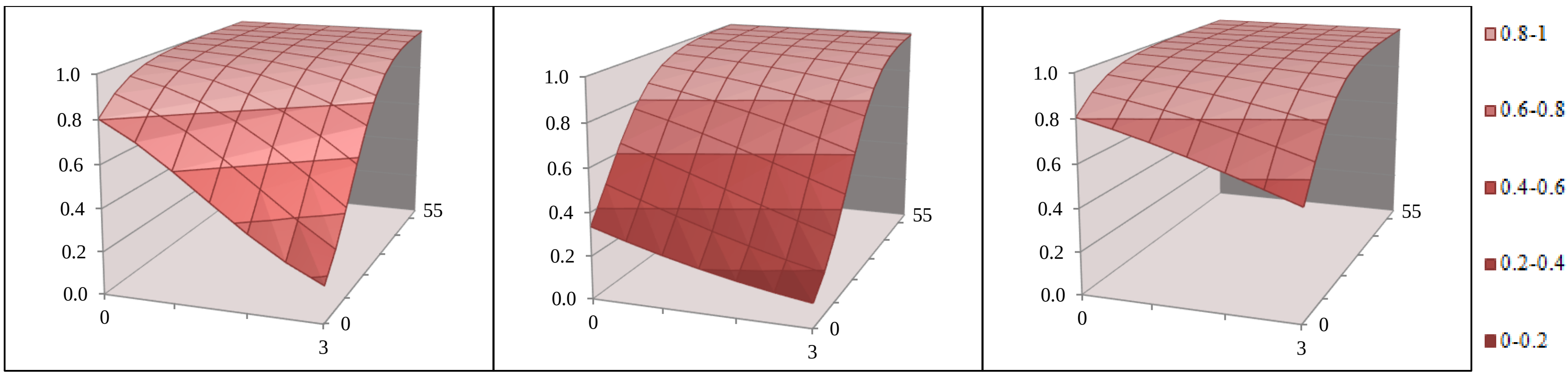


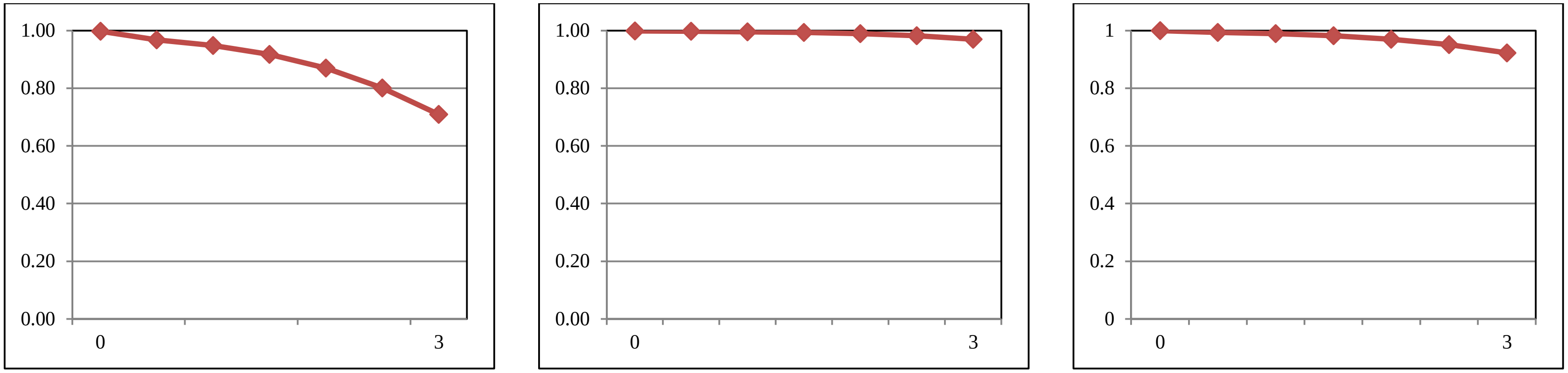
Figure 1: Depicting Type I and II Dilemma Zones (Source: Hurwitz et al., 2012)



(2a) No call (2b) Headset and Incoming call (2c) Headset and Outgoing call

X-axis (Length): Distance from stop bar at the green to yellow (100's ft); Y-axis (Depth): Velocity at green to yellow (mph); Z-axis (Height): Probability

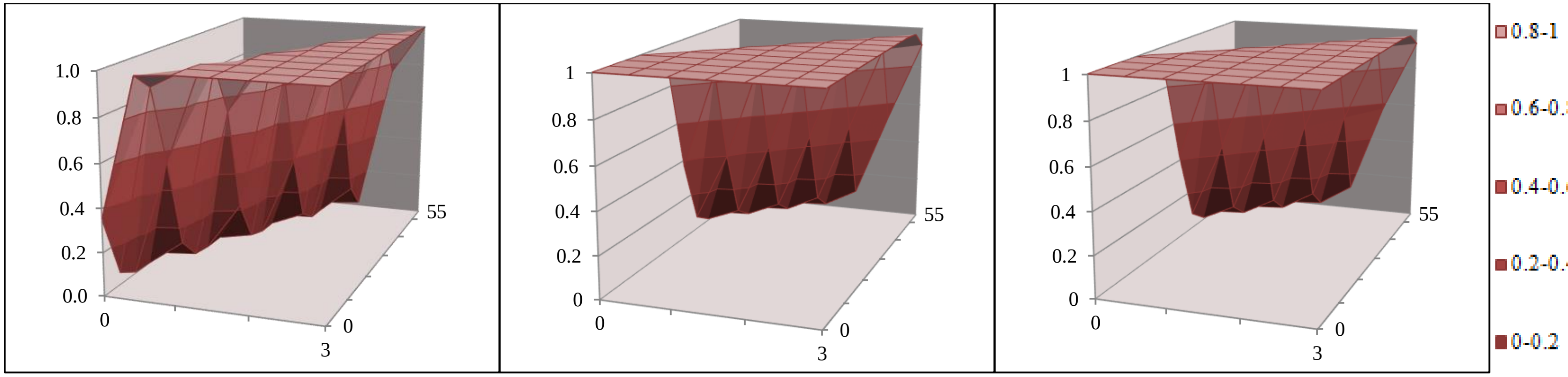
Figure 2: Probability of Decision to Cross as a Function of Distance from Stop Line and Velocity at Onset of Yellow



(3a) No call (3b) Headset and Incoming call (3c) Headset and Outgoing call

X-axis: Distance from stop bar at the green to yellow (100's ft); Y-axis: Probability

Figure 3: Probability of Failure to Stop (for Drivers Choosing to Stop) as a Function of Distance from Stop Line



(4a) No call (4b) Handheld and Incoming call (4c) Handheld and Outgoing call

X-axis (Length): Distance from stop bar at the green to yellow (100's ft); Y-axis (Depth): Velocity at green to yellow (mph); Z-axis (Height): Probability

Figure 4: Probability of Failure to Cross (for Drivers Choosing to Cross) as a Function of Distance from Stop Line and Velocity at Onset of Yellow