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Abstract: This paper presents the analysis results of driver responses during a yellow phase, based on field observations of 1123 drivers collected with a specially-designed system from six signalized intersections of high crash frequency in Maryland. By classifying drivers into aggressive, conservative, and normal groups based on their responses (i.e., stop or pass) and the distances to the stop line when the signal turns yellow, the statistical tests with the ordered-probit model clearly indicate some critical factors and their impacts on a driver's decision at intersections. Such factors include average traffic flow speeds, traffic volume rate, the green split, the number of through and crossing lanes in the target approach, signal coordination, the difference between a vehicle's approaching speed and the average traffic flow speeds, a driver's gender, age, talking over cell phone or not, a vehicle's type and model, and etc. The research findings for this study offer the basis for responsible agencies to identify underlying factors contributing to aggressive maneuvers at signalized intersections which often cause traffic crashes, and to develop improvement strategies, such as customized driver education and intelligent safety protection systems.

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Dear Editor,

Greetings!

Thank you very much for your time and efforts spent in the re-review process and we also express our great appreciation to the reviewers for the time they has taken in reviewing our paper as well as the valuable suggestions they offered. The manuscript "**AN EMPIRICAL STUDY OF DRIVER RESPONSES DURING THE YELLOW SIGNAL PHASE AT SIX MARYLAND INTERSECTIONS**" (Manuscript No. TEENG-666) has been revised in response to the review comments.

The files attached in this submission include:

(1) Revised Manuscript;

(2) Response to Reviewer Comments;

(3) Copyright Transfer Agreement form signed by the authors;

Regarding to Copyright Transfer Agreement form, I will mail it to ASCE if the original form is required.

Please contact me using the email yueliu1980@gmail.com should you have any problems.

Best Regards.

Yours sincerely,

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AN EMPIRICAL STUDY OF DRIVER RESPONSES DURING THE YELLOW SIGNAL PHASE AT SIX MARYLAND INTERSECTIONS

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ABSTRACT: This paper presents the analysis results of driver responses during a yellow phase, based on field observations of 1123 drivers collected with a specially-designed system from six signalized intersections of high crash frequency in Maryland. By classifying drivers into aggressive, conservative, and normal groups based on their responses (i.e., stop or pass) and the distances to the stop line when the signal turns yellow, the statistical tests with the ordered-probit model clearly indicate some critical factors and their impacts on a driver's decision at intersections. Such factors include average traffic flow speeds, traffic volume rate, the green split, the number of through and crossing lanes in the target approach, signal coordination, the difference between a vehicle's approaching speed and the average traffic flow speeds, a driver's gender, age, talking over cell phone or not, a vehicle's type and model, and etc. The research findings for this study offer the basis for responsible agencies to identify underlying factors contributing to aggressive maneuvers at signalized intersections which often cause traffic crashes, and to develop improvement strategies, such as customized driver education and intelligent safety protection systems.

CE Database Subject Headings: Signalized intersection; Driver behavior; Yellow signal phase; Ordered-probit model; Statistical tests.

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INTRODUCTION

Improving traffic safety has increasingly been regarded as one of the priority transportation issues in most states. Over the past decades, intersection related crashes constituted about 30 percent of the total crashes on Maryland state routes (e.g., 34% in 2002 and 35% in 2003). Among those, about 20 percent involved red-light running, which caused either rear-end or side-crash collisions (MDSHA, 2003). A tremendous amount of resources have been invested on improving the safety and efficiency at signalized intersections. Although programs such as driver education, red-light camera deployment, and operational improvements to roadway geometry have all contributed to a safer driving environment, significantly reducing traffic signal related crashes remains a challenging task. One of the main areas deserved further research is to better understand various factors that may significantly affect an individual's decision during a yellow phase at signalized intersections (Xiang et al., 2005).

Driver responses at signalized intersections have been investigated along with the dilemma zone issue in the literature since its initial study by Gazis et al. (1960). They indicated that incompatibility frequently exists between a driver's desire to comply with the yellow-phase indication and the encountered constraints. Olson and Rothery (1961) conducted field observations at five intersections and found that drivers tend to take advantage of the long yellow phase and view it as an extension of the green phase. Their research concluded that driver behavior does not seem to be affected by the yellow-light phase duration, especially since most motorists do not even know the typical phase duration. Another type of dilemma associated with a driver's decision making, termed as "Type-II Dilemma" was proposed to accommodate the problem of indecision when both stopping and passing maneuvers can be executed. Zeeger et al. (1978) also proposed a method, termed "option zone," where 90% of the vehicles stop and 10% go under various traffic conditions. Liu et al. (2007) presented the results of an empirical study on dilemma zones for different driver groups at signalized intersections using a specially designed video-based system. Their empirical results revealed the dynamic nature of the dilemma zone often varies with the behavior of the driving population, and also concluded that the commonly used practice of extending the yellow phase duration may not be effective.

In studying a driver's response to the yellow-light phase, Van der Horst and Wilmink (1986) indicated that such a process is governed by a multitude of factors, including driver attitude and emotional states, the crossing ability before the red phase, consequence of stopping and passing, interactions with other drivers, and the vehicle approaching speed. They used extensive numerical analyses to illustrate the complex decision-making process and its relations with associated factors. Their employed parameters were also adopted in later studies by Milazzo et al. (2002), Shultz et al. (1998), and the Green Book (AASHTO, 2001).

In classifying driver responses during the yellow phase and identifying potential affecting factors, Shinar and Compton (2004) observed more than 2000 drivers over a total of 72 hours at six intersections. They concluded that male drivers are more likely than female drivers in taking aggressive actions; senior drivers in comparison with young drivers are less likely to manifest aggressive driving patterns during a yellow-light phase; the presence of passengers was associated with lower rates of aggressive driving; and the likelihood of taking aggressive actions increases with the driver's value of time.

It has also been recognized in the literature that a driver's response to a yellow-light phase may vary with some other factors such as talking on the phone or not. For instance, Patten et al. (2004) investigated the impacts of mobile-phone usage on drivers from the perspective of cognitive workload and attention resource allocation, and reported that the reaction time of most drivers increases significantly during the use of cellular phones. Caird et al. (2005) used a driving simulator to measure the performance of 77 participants (older and younger drivers) while approaching signalized intersections during a yellow phase. Xiang et al. (2005) performed an extensive investigation of driver responses under different populations and vehicle characteristics. Based on the survey results, they classified driver behaviors into several distinct patterns, and found that a driver's stopping/passing behavior was affected by multiple factors, such as gender, age, and the use of cellular phones. El-Shawarby et al. (2007) characterized driver behavior at the onset of a yellow-phase transition on high-speed intersection approaches using field data from 60 test subjects. Their study concluded the impact of age and gender factors on driver behavior and consequently on the dilemma zone distributions. Gates et al. (2010) investigated the influence of vehicle type on various aspects of driver behavior in a dilemma zone, including brake response time, deceleration rate, and red-light-running occurrence. A very recent study by Amer et al. (2010) introduced a state-of-the-art Behavioral Model (BM) that offers a tool to simulate the driving behavior after the onset of a yellow indication.

RESEARCH SCOPE AND OBJECTIVE

Despite the promising accomplishments reported in the literature, much remains to be addressed on this subject, especially on the following critical issues:

- The impacts of other affecting factors unrelated to individual characteristics such as signal control features, vehicle mechanical dynamics, intersection geometric features, and average traffic flow characteristics on driver behavior have not been adequately analyzed. The complex interactions between those factors and their collective impacts on drivers have neither been addressed yet.
- The data collection process in most existing studies was conducted in a driving simulator or implemented through strictly controller field experiments. Driver behavior extracted from such environments could be biased due to the lack of considering its interaction with surrounding traffic environment.
- Due to the constraints of the sample size and the measurement method, key factors affecting the behavior of different driving populations remain unclear.

The research results presented in this paper attempt to address the above issues from the following aspects:

- Collecting detailed information on the characteristics of drivers, roadway geometric features, congestion levels, average traffic flow speeds, vehicle dynamics, and vehicle types and performances through a specially designed video-based system with properly synchronized far-side and near-side cameras.
- Classifying drivers into three groups: “aggressive”, “conservative”, and “normal”, based on the critical distance to the stop line and their stop/go decisions at the onset of yellow-phase transition.
- Employing a multi-step, discrete statistical test to explore the complex interrelations between a driver’s response (i.e., discrete in nature) to an intersection yellow phase, characteristics associated with individual driver and vehicle performance, traffic environments, and key intersection geometric features.
- Serving as the basis for traffic safety professionals to design more effective safety improvement strategies, based on a better understanding of various factors that may affect a driver’s decision during a yellow phase.

DATA COLLECTION

With assistance from the Office of Traffic and Safety of Maryland State Highway Administration, this study selected six intersections of high crash frequency (MD193 at MD201-WB, MD650 at Metzerott Rd.-NB, Randolph Rd. at Glenallan Rd.-WB, MD410 at Belcrest Rd.-WB, MD410 at Adelphi Rd.-WB, and MD193 at Mission Dr.-WB) for field data collection. Those selected sites are located in both urban and rural areas, and are not close to any special facilities, e.g., schools, bars, or military bases.

Note that one of the foremost critical issues for investigating driver behavior is to design a reliable field data acquisition system. This is due to the fact that all behavioral related data, such as speed and acceleration rates, need to be measured at sufficiently high level of accuracy and precision. Failure to do so may render either misleading or inconclusive results even with a large sample of observations. We have designed a cost-effective tool for this study to reliably observe the complex interaction process between a driver's response during the yellow phase and a variety of contributing factors. The key idea of the proposed system is to superimpose reference lines over the video image, allowing us to measure a vehicle's travel times between these lines sequentially to obtain the vehicular speed change profile during the yellow phase and other behavioral related data.

As shown in Fig. 1, the entire system for field data collection includes the following components:

- Two DVD video cameras placed at the locations with precisely measured distances from the intersection at variable time-elapse rates of up to 30 frames per second; one camera was placed at the far side along the roadway segment to monitor the speed change of each approaching vehicle trapped in a yellow phase, while the other was placed near the stop line for collecting individual vehicle-related information and intersection control features;
- Two or three observers stationed at the stop line, responsible for recording individual driver characteristics and activities such as a driver's gender, age level, passengers in vehicle or not, talking over cell phone, vehicle type and model;
- Several rewritable DVD video disks to facilitate computer operations and to save the video tape conversion time;
- An adjustable tripod to allow a flexible setup of the camera orientation;
- Orange cones, placed at an identical spacing along the roadway before the survey period as the "reference points" for camera calibration and video benchmarking that offer the information for computing the change of vehicle speeds. The procedures for optimizing the distance between reference points and validation of the measurement accuracy can be found in Liu et al. (2006);
- A frame-by-frame video editing computer program (see Fig. 2), which must be able to:
    1. Read the video file directly from the video disk without any converting or capturing job;
    2. Superimpose reference lines onto the video image to form a "speed trap" for measurement;
    3. Slice the video footage into a small set of segments (up to a frame) to facilitate future analysis;

4. Record the necessary timestamps;
5. Synchronize the far-side and near-side videos so as to match the speed change profile of each target vehicle with associated traffic condition factors, intersection geometry factors, control features, vehicle performances, and individual driver-related characteristics (Liu et al., 2006).

Insert Figure 1 here

Insert Figure 2 here

With the specially design video-based system, the research team has collected a total of 56 near-side and far-side videos for 30 morning peak hours (7:00-8:00AM) and 26 evening peak hours (3:30-4:30PM) over a more than two-month period from May 15th to July 31st, 2005. All videos were taken during weekdays under good weather condition and visibility. A total of more than 3000 samples were extracted from the collected videos. To ensure the data reliability, the research team compared each sample from the stop-line observers, near-side videos, and far-side videos. Only after the three sources were well matched, we then included this sample in the analysis dataset. Also, for some ambiguous characteristics such as driver age, we first classified the driving population into several age groups in our laboratory experiments and trained our field observers to have consistent classifications of various sample individuals. Such a pre-training process enables all field observers to produce the consistent results. Through the aforementioned procedure, only 1123 individual driver responses were finally accepted for use in the analysis. The key information associated with each intersection is shown in Table 1, and all collected variables are organized into the following groups for further analysis:

- **Intersection related factors**: yellow phase duration, cycle length, number of through lanes in the target approach, number of cross lanes by the target approach, green split of the target approach (the ratio of green time to the cycle length), speed limit of the target approach, signal coordination or not with the next intersection, and visibility of the next intersection's signal.
- **Traffic characteristics**: average speed per cycle and average flow rate per lane per cycle in the target approach.
- **Driver characteristics**: pass or stop decision, lane position selected by the driver, vehicles in platoon or not, gender and age of drivers, passenger in vehicle or not, and driver talking on cell phone or not.
- **Vehicle characteristics**: vehicle's type (sedan, SUV, pick-up, sports car, van, truck, or bus) and vehicle's model (US, Japan, Europe, or Korea)

- **Vehicle dynamics**: distance-to-stop-line, expected time-to-stop-line ,and the approaching speed when drivers perceive the commencement of a yellow phase, speed change before and after the yellow phase, average acceleration/deceleration rates during the yellow phase, and average perception-reaction time of the driving population (Liu et al., 2006).

Insert Table 1 here

METHODOLOGY

This study has collected a total of 1,123 observations of individual driver responses during the yellow phase at six intersections with the aforementioned data collection system. It should be noted that driver behavior and characteristics at signalized intersections are not uniformly distributed. Thus, for convenience of analysis, this study has first classified the driving population into three distinct patterns: “aggressive”, “conservative”, and “normal”, based on their response during a yellow phase, and then evaluate their complex interrelations with those field observed factors.

Classification of driver’s response

To facilitate the analysis, we first classified all observed driver decisions into three distinct groups: aggressive, normal, and conservative. The classification is based on the assumption that there exists a critical distance (d_c) perceived by a normal driver at each intersection when noticing the beginning of a yellow phase. A driver, if neither aggressive nor conservative, is most likely to take the stop action if the current location to the stop line (x_d) is longer than the perceived critical distance (d_c). By the same token, a driver may choose to pass the intersection during the yellow phase if the perceived d_c is longer than x_d . Note that such a critical distance, d_c , is not directly observable from the field data (i.e., either $x_d < d_c$, or $x_d > d_c$) and it may vary with individual driver characteristics and surrounding conditions, such as intersection geometric features and traffic volume. Hence, this study has employed a discrete choice model for estimating the average d_c for driving populations at each intersection (see Appendix A for details). A summary of the definition for each driving group is listed below, and the resulting critical distances as well as the distribution of driving population at each intersection are shown in Table 2 and 3.

- "Conservative drivers" – Drivers who took the stop action even though they could have proceeded through the intersection during the yellow phase (i.e., the driver makes a stop even the distance to the stop line x_d is less than the critical distance, d_c);
- "Normal drivers" – Drivers who took the stop action when $x_d > d_c$ or the pass action when $x_d < d_c$;
- "Aggressive drivers" – Drivers who aggressively passed the intersection during the yellow phase even though they were quite far away from the stop line ($x_d > d_c$).

Insert Table 2 here

Insert Table 3 here

Based on the above classification results, this study has further performed the analysis of speed differences among driving groups at each intersection. As shown in Table 4, at all the observed intersections, the aggressive driver group usually executes an approaching speed about 10-20% higher than the average traffic flow speed, while the conservative driver group averagely exhibits an approaching speed about 10-15% lower than the average traffic flow speed, which confirm the assumption of characteristic discrepancies among different driving groups.

Insert Table 4 here

Notation for associated factors

To facilitate the statistical analysis, Table 5 presents the notations for all field observed factors, which will be used in the hereafter presentation.

Insert Table 5 here

The statistical model

The dependent variable is used to characterize drivers, based on their decisions during a yellow phase, as one of the following three groups: conservative stop, normal, or aggressive pass. Since the dependent variable is discrete in nature, this study has employed the ordered-probit model to investigate the impacts of associated variables on the resulting driving responses.

The core concept of an ordered-probit model for a dependent variable of three classes can be presented with the following latent regression expression (Greene and Hensher, 2003):

$$y^* = \beta' x + \varepsilon$$

Where, y^* is unobservable, its observable outcomes are:

$$y = 1 \text{ if } y^* \le 0$$

$$y = 2 \text{ if } 0 < y^* \le \mu_1$$

$$y = 3 \text{ if } \mu_1 < y^*$$

The unknown parameter μ_1, representing the boundaries between ordered responses will be estimated along with β' (the vector of parameters for explanatory variables). ε is the error term, which is assumed to be normally distributed with cumulative distribution denoted by $\Phi(\cdot)$. We have the following probabilities:

$$\Pr ob(y = 1) = \Phi(0 - \beta' x) - 0$$

$$\Pr ob(y = 2) = \Phi(\mu_1 - \beta' x) - \Phi(0 - \beta' x)$$

$$\Pr ob(y = 3) = 1 - \Phi(\mu_1 - \beta' x)$$

A graphic depiction of the relationship between the probability and the observed outcomes is shown in Fig. 3.

Insert Figure 3 here

The unobservable latent variable y^*, in the above model is the difference between the estimated distance to the stop line and the threshold value d_c. The independent variables are all observable and potentially associated factors.

Multi-step statistical tests

The statistical test with the ordered-probit model for all associated factors consists of three steps. The focus of Step-I analysis is to identify critical traffic environmental factors, which serve as the set of background variables for Step-II and Step-III analyses. The list of variables for Step-I test is shown below:

- **Step-I**:

- *Dependent variable – one of the following responses: "conservative stop", "normal", and "aggressive pass"*
- *Independent variable set –* ***AVGSPEED****,* ***VOLUME****,* ***PLATOON****,* ***SPLIT****, and* ***MIDL*** *(Test-1)*

Based on the identified background factors, the analysis at Step-II is to investigate the impact of the following factors on the response of drivers during the yellow phase. All tests performed at Step-II and the included factors are also shown below:

- **Step-II**:
  - *Test-2 – significant traffic background variables +* ***intersection related variables [****yellow phase duration (****YD****) + cycle length (****CYCLE****) + number of through lanes (****THRUL****) + number of cross lanes (****CROSSL****) + speed limit sign being posted or not (****POST****) + speed limit value (****SPL****) + coordination with next intersection (****COOR****)]*
  - *Test-3 – significant traffic background variables +* ***individual vehicle dynamics variables [****a vehicle's approaching speed when the yellow starts (****I_SPEED****)* ***or*** *the difference (in percent)between each individual driver's speed and the average traffic flow speed (****PER_ABOVE****)]*
  - *Test-4 – significant traffic background variables +* ***individual driver related variables [****gender variable (****MALE****) + young driver variable (****YOUNG****) + senior driver variable (****SENIOR****) + variable for passengers or not (****PASSENGER****) + talking-on-phone variable (****PHONE****)]*
  - *Test-5 – significant traffic background variables +* ***individual vehicle related variables*** *[****SEDAN****,* ***VAN****,* ***SUV****,* ***PU****,* ***SPORTCAR****,* ***TRUCK****,* ***JAP****,* ***US****,* ***EUR]***
  - *Test-6 – global test of all significant variables identified through tests 1-5 to finalize the list of critical factors on driver's decision making process*

It should be noted that some factors, though shown insignificant during individual tests in Step-II, could collectively reveal significant impacts on a driver's response. To capture those possible hidden behavior, we performed Step-III analysis to explore the compound impacts of individual and vehicle related factors on a driver's response. To prevent the multicollinarity problem, each multiplication of individual driver and vehicle related factors is tested at one time with all significant traffic background variables, intersection related variables, and vehicle dynamics variables. All tests performed at Step-III include:

- **Step-III**:
    - *Test-7 to Test-76 – significant traffic background variables + significant intersection related variables + significant individual vehicle dynamics variables +* ***[individual driver related variables * individual vehicle related variables]***

The flowchart for performing the proposed multi-step tests is illustrated in Fig. 4.

Insert Figure 4 here

ANALYSIS RESULTS AND FINDINGS

The results of Test-1 in Table 6 show the impacts of Step-I factors on a driver's decision during the yellow phase. A positive and significant coefficient for the average traffic flow speed implies that drivers are more likely to take aggressive passing actions in response to the observed yellow phase during the high-speed traffic conditions. This seems to justify the need to place speed enforcement at high-speed intersections so as to improve traffic safety. A negative coefficient for the traffic volume and green splits indicates that drivers tend to be self-restrained during the conditions of high volume or long green time, and are less likely to take the aggressive-pass action during the yellow phase.

Test-2 shown in Table 6 presents the estimated impacts of intersection related factors on the response of drivers during the yellow phase. As expected, factors exhibited statistical significant signs include: the number of through and crossing lanes in the target approach, and signal coordination. A negative sign for the number of through lanes, ***THRUL*** (-.187), and a positive sign for the required crossing lanes, ***CROSSL*** (.112) imply that drivers in a major intersection approach of multiple lanes are more likely to take non-aggressive responses during a yellow phase. This may be due to the collective impacts of various factors, such as experiencing a higher volume (as reflected in the same estimation), having a longer green duration, and thus showing less desire to take the risk during the yellow phase.

In contrast, drivers in the minor approach of a major-minor intersection tend to take a more aggressive action during the yellow phase. Also revealed is the fact that good signal coordination (***COOR***: .228) between adjacent intersections tends to encourage drivers to take aggressive actions during the yellow phase. This may be due to the deficiency of traditional signal progression models which focus mostly on maximizing the operational efficiency of intersections, but not minimizing the total number of vehicles trapped in the dilemma zones. Other factors such as the yellow phase duration, the cycle length, and posted speed limit do not exhibit any significant impact on a driver's decision during a yellow phase among those available sample observations.

Insert Table 6 here

Test-3 is focused on investigating the impact due to an individual vehicle's approaching speed, while Test-4 is mainly on evaluating the response differences due to the gender and age factors. Also included in the evaluation are the impacts due to the presence of passengers, talking over the cell-phone, vehicle types, and vehicle made (Test-5). Although the estimated relations are not consistent across all six observed intersections due to the difference in sample size, their statistical indications have revealed the following interesting relations:

- Drivers having their approaching speeds higher than the average flow speed are more likely to behave aggressively when encountering a yellow phase (***PER_ABOVE***: 4.160/p-value < .001, see Test-3 in Table 6);
- Male drivers are more likely to take aggressive actions when approaching the yellow phase (***MALE***: .652/p-value = .063, see Test-4 in Table 6);
- Young drivers tend to take aggressive actions when approaching the yellow phase (***YOUNG***: .925/p-value = .004, see Test-4 in Table 6), but senior drivers are more likely to be conservative (***SENIOR***: -.977/p-value = .083, see Test-4 in Table 6);
- Drivers talking on phone tend to take conservative actions when approaching the yellow phase (***PHONE***: -1.087/p-value = .039, see Test-4 in Table 6);
- Drivers in vans tend to take conservative actions when approaching the yellow phase (***VAN***: -.851/p-value = .021, see Test-5 in Table 6);
- Drivers in sports cars tend to take aggressive actions when approaching the yellow phase (***SPORTCAR***: 1.263/p-value = .009, see Test-5 in Table 6);
- Drivers in Japan made cars exhibited the pattern of taking aggressive decisions during the yellow phase (***JAPAN***: .666/p-value = .021, see Test-5 in Table 6).

Test-6 performs a global analysis of all individually significant factors identified through Tests 1-5 to finalize the list of factors that exhibit critical impacts on driving behavior. Note that the variables ***SENIOR*** and ***VAN*** are dropped from the list due to their insignificance at a 0.10 level, and all significant variables in Test-6 are listed in the last column of Table 6.

Step-III analysis results, shown in Table 7, reveal significant compound impacts of individual and vehicle related factors on a driver's response during the yellow phase. For examples, the number of passengers that exhibits a negative but insignificant sign when the test is based on all samples (see Test-4 in Table 6) shows different and significant relations when the samples were divided by gender. As indicated in Table 7, female drivers tend to be conservative when having passengers (***FEMALE*PASSENGER***: -1.057/p-value < .001, see Test-26), but not for male drivers. Similar discrepancies also exist between young and senior drivers with passengers. Also, it is noticeable that the estimation results have revealed the following additional behavioral patterns:

- Young male drivers tend to be more aggressive than other male drivers when a encountering the yellow phase (see tests 7-9);
- Young female drivers tend to take aggressive actions when encountering the yellow phase, while senior and middle-age female drivers tend to take conservative actions under the same situation (see tests 23-25);
- Both female and senior drivers with passengers tend to take conservative actions when encountering the yellow phase (see tests 26 and 51);
- Female drivers talking over phone tend to take conservative actions when encountering the yellow phase, but not male drivers (see tests 11 and 27);
- Senior and middle-age drivers talking over phone tend to take conservative actions when encountering the yellow phase, but not young drivers (see tests 39, 52, and 65);
- Female van-drivers tend to take conservative actions when encountering the yellow phase, but not male drivers(see tests 13 and 29);
- Senior and middle-age drivers in vans tend to take conservative actions when encountering the yellow phase ,but not young drivers (see tests 41, 54, and 67);
- Male drivers in SUVs tend to take aggressive actions when encountering the yellow phase, but not female drivers (see tests 14 and 30);
- Female and young drivers in sports cars tend to take aggressive actions when encountering the yellow phase (see tests 32 and 44);
- Male drivers in Japan-made cars are likely to take aggressive actions when encountering the yellow phase, but not female drivers (see tests 19 and 34);

- Young drivers in Japan-made cars tend to take aggressive actions when encountering the yellow phase, but not senior and middle-age drivers (see tests 47, 60, and 73);
- Female drivers in US-made cars tend to take conservative actions when encountering the yellow phase, but not male drivers (see tests 20 and 35);
- Young drivers in US-made cars tend to take aggressive actions when encountering the yellow phase, but not senior and middle-age drivers (see tests 48, 61, and 74);
- Female drivers in European and Korean made cars tend to take conservative actions when encountering the yellow phase, but not male drivers (see tests 21-22 and 36-37);
- Senior and middle-age drivers in European and Korean made cars tend to take conservative actions when encountering the yellow phase, but not young drivers (see tests 49-50, 62-63, and 75-76).

Insert Table 7 here

POTENTIAL APPLICATIONS OF THE RESEARCH RESULTS

Note that the above relations between driver responses during a yellow phase and related factors are based on more than 1000 field observations at six intersections. Some of these reported relations are likely to vary at different intersections in different regions. However, the above empirical information offers some valuable information for understanding the complex interrelations between the decision of drivers and all contribution factors. The estimation results can be used in classifying the distribution of driving populations at a target intersection, and in identifying some factors that may cause drivers to act aggressively in response to the yellow phase. More importantly, with some additional modeling work, traffic safety engineers can design effective strategies to counter traffic signal related crashes, especially for those associated with dilemma zones. For instance, one can:

- Enhance traditional signal timing models for possible reduction of aggressive driving related factors identified in this study without losing the operational efficiency. Based on the significant factors identified in this paper, one can develop a series of quantitative models to predict a driver's decision (aggressive pass, normal pass, normal stop, or conservative stop) in response to the yellow phase and the number of aggressive drivers potentially trapped in the dilemma zone during each signal cycle. Such models can be incorporated into the traditional signal control framework to improve the intersection safety;

- Propose driver education guidelines based on the behavioral findings in this study to depress aggressive maneuvers during the yellow phase. For example, integration of the research results with vehicle incident reports will disclose the interrelation between vehicle characteristics, aggressive driving maneuvers, and signal related incidents. Such valuable information will be critical to the design of customized driver educational plans;
- Develop a driver response prediction model to support the dilemma zone protection system, as shown in Fig. 5. During a yellow phase, the system will track the target driver, and the expected model will concurrently predict the response of the target driver, based on measurable factors (e.g. traffic environmental factors and individual vehicle dynamics). The system will activate the warning message and extend the all-red phase to prevent any read-end collision or side-crash if the target driver is computed to be trapped in the dilemma zone and predicted to take the aggressive passing maneuver.

Insert Figure 5 here

CONCLUSIONS AND RECOMMEDATIONS

This study has observed the behavior of 1123 drivers in response to an encountered yellow phase and their surrounding traffic conditions at six signalized intersections. To contend with the difficulty in measuring driver responses during the relatively short yellow phase, this study has developed a video-based system that enables users to track an individual driver's speed change during the yellow phase before reaching the intersection. The comprehensive field data obtained with such a reliable system offers the basis for this study to profile the behavior of drivers during the yellow phase and to identify various associated factors.

Based on the decision of each individual driver during a yellow phase and the field observed information, this study has further classified the driving populations into aggressive, normal, and conservative groups. Using an ordered-probit model and a multi-step statistical analysis procedure, this study has successfully identified the underlying factors that may have significant impacts on the response of drivers at signalized intersections. The compound impacts of multiple factors on the decision of drivers during a yellow phase have also been evaluated.

In summary, through extensive field observations and statistical analyses, this study has reached the following tentative conclusions:

- Driving populations at most signalized intersections, based on their responses during the yellow phase, can be classified into three distinct groups: aggressive, normal, and conservative.
- A variety of factors may affect a driver's decision on taking an aggressive or a conservative action during the yellow phase. Examples of factors include: average traffic flow speed, green splits, traffic volume, signal coordination, number of approach lanes, talking on the phone or not, vehicle type, age, and gender.
- The speed of a vehicle approaching the intersection in comparison with the average flow speed seems to be the best indicator for identifying the aggressive level of a driver.
- The intersection geometric features may affect a driver's response to the encountered yellow phase. For example, drivers on the minor street are more likely to take an aggressive pass decision during a yellow phase due to the allocated short green phase.
- A coordinated signal system may encourage drivers to take an aggressive passing decision during the yellow phase.
- Some behavioral variables could have significant compound impacts on a driver's response during the yellow phase. For example, male drivers in SUVs tend to take aggressive actions when approaching the yellow phase, but not female drivers.
- Understanding the behavioral discrepancy between different driving populations and the critical contributing factors is essential for researchers and responsible agencies to design of safety improvement strategies

However, it should be mentioned that all above reported findings are exploratory in nature and much remains to be investigated due to the complex interactions between drivers, their experienced traffic conditions, and the large number of potentially related factors. In view of the increasing demand for improving traffic safety, further research along the followings lines will be essential:

- Conducting comprehensive speed profile analyses with appropriate traffic sensors at all major intersections plagued by crashes so as to verify the distribution of driving populations;
- Performing an in-depth driving population classification for intersections experiencing a high crash frequency with the video-based approach developed in this study;
- Refining the set of contributing variables and the test procedures proposed in this study to avoid the possibility of obtaining false positive results due to the inclusion of so many variables, and estimate the

distribution of various driver responses to the yellow-light phase with more data from intersections of different geometric features and driving populations;

- Performing extensive analyses on the compound impacts of multiple variables on the response of drivers under various traffic conditions; and
- Applying all the research findings in developing a set of intersection safety evaluation models, and test their effectiveness in identifying underlying factors that cause a high crash frequency at some intersections.

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Appendix: A binary logit model for estimating the perceived critical distance (d_c)

Each driver approaching the yellow phase with a given distance-to-stop-line must judge between the two alternatives: a = accept the distance for the clearing the intersection; and r = reject the distance for making a stop. A driver, in his or her decision situation, d , will expect a specific utility from that decision. This utility can be regarded as a combination of safety and delays incurred by the driver. We regard the total utility, U_{ad} , as an additive combination of a deterministic term, V_{ad} , and a random term ε_{ad} :

$$U_{ad} = V_{ad} + \varepsilon_{ad} \quad (1)$$

$$U_{rd} = V_{rd} + \varepsilon_{rd} \quad (2)$$

We assume that the deterministic component, V_{ad} , can be computed as a linear utility function:

$$V_{ad} = \alpha + \beta_1 x_{ad1} + \beta_2 x_{ad2} + \ldots + \beta_K x_{adK} \quad (3)$$

$$V_{rd} = \alpha + \beta_1 x_{rd1} + \beta_2 x_{rd2} + \ldots + \beta_K x_{rdK} \quad (4)$$

Where:

$\alpha, \beta_1, \beta_2, \ldots, \beta_K$ = parameters;

x_{adk} = value of the k^{th} attribute in decision d in case of acceptance;

x_{rdk} = value of the k^{th} attribute in decision d in case of rejection;

K = number of attributes.

The random component ε_{ad} includes all influencing factors that cannot be evaluated precisely. We assume here that the drivers, on average, make rational decisions; that is, they make those decisions that provide the highest utility for them. Thus, the probability $p_a(t)$ of acceptance of a distance-to-stop-line by a driver to clear the intersection is:

$$p_a(t) = p(U_{ad} > U_{rd}) = p(\varepsilon_{rd} - \varepsilon_{ad} \le V_{ad} - V_{rd}) \quad (5)$$

For the random component ε_{ad} , we assume a Gumbel distribution (Ben-Akiva and Lerman, 1987). Then the difference $\varepsilon_d = \varepsilon_{rd} - \varepsilon_{ad}$ has a logistic distribution:

$$F_{\varepsilon_d}(x) = \frac{1}{1+e^{-\mu x}} \tag{6}$$

Where, μ is a parameter of the distribution. Therefore, Eqns. (5) and (6) can be written as:

$$p_a(t) = F_{\varepsilon_d}(V_{ad} - V_{rd}) = \frac{1}{1+e^{-\mu(V_{ad}-V_{rd})}} \tag{7}$$

As for attributes, in this study, we used only the distance-to-stop-line as the major factor affecting a driver's decision to pass or stop. Therefore, Eq. (7) becomes:

$$p_a(t) = \frac{1}{1+e^{\alpha+\beta x_d}} \tag{8}$$

Now, to derive the critical distance-to-stop-line, d_c, for a driver either to clear the intersection or to make a stop, we can consider $p_a(t)$ (a function of the distance-to-stop-line) as a statistical density function for a random variable D. Then, the critical distance-to-stop-line is defined as the median of this random variable D, that is, d_c is the value of D, for which:

$$\int_0^{d_c} p_a(t)dt = 0.5 \tag{9}$$

Finally, the parameters α and β are estimated by a maximum likelihood technique with the likelihood function:

$$L(\alpha,\beta) = \sum_{d=1}^{n}\left[\ln\left(\frac{1}{1+e^{\alpha+\beta x_d}}\right) + \alpha + \alpha y_d + \beta x_d - \beta y_d x_d\right] \tag{10}$$

Where, $y_d = 1$ if a driver in situation d accepted a distance to pass; and 0 if a driver in situation d rejected a distance to make a stop; n = number of observed decisions (pass or stop); x_d = a vehicle's distance-to-stop-line when the yellow phase starts.

The maximization of $L(\alpha,\beta)$ reveals values for α and β in Eq. (8). Since this is the distribution function of a logistic distribution, Eq. (9) can be solved for d_c as the mean of this distribution, which is:

$$d_c = \frac{\alpha}{\beta} \tag{11}$$

REFERENCES

1. Amer, A., Rakha, H., and El-Shawarby, I. A Behavioral Modeling Framework of Driver Behavior at the Onset of a Yellow Indication at Signalized Intersections. Proceedings of the 89th Annual Meeting of the Transportation Research Board [CD-ROM]. Washington DC. January 10-14, 2010.
2. American Association of State Highway and Transportation Officials [AASHTO]. AASHTO GREEN BOOK - A Policy on Geometric Design of Highways and Streets (4th Edition). American Association of State and Highway Transportation Officials, 2001.
3. Ben-Akiva, M., Lerman, S.R. Discrete Choice Analysis. Mass. Institute of Technology Press. Cambridge, MA, 1987.
4. Caird, J. K., S. L. Chisholm, C. J. Edwards and J. I. Creaser. The Effect of Amber Light Onset Time on Older and Younger Drivers' Perception Response Time (PRT) and Intersection Behavior. Proceedings of the 84st Annual Meeting of the Transportation Research Board [CD-ROM]. Washington DC. January 9-13, 2005.
5. El-Shawarby, I., Rakha, H., Inman, V. W. and Davis, G. W. Age and Gender Impact on Driver Behavior at the Onset of a Yellow Phase on High-Speed Signalized Intersection Approaches. Proceedings of the 86th Annual Meeting of the Transportation Research Board [CD-ROM]. Washington DC. January 21-25, 2007.
6. Gates, T. J. and Noyce, D., Dilemma Zone Driver Behavior as a Function of Vehicle Type. Proceedings of the 89th Annual Meeting of the Transportation Research Board [CD-ROM]. Washington DC. January 10-14, 2010.
7. Gazis, D., Herman, R., and Maradudin, A. The problem of the amber signal light in traffic flow. Operations Research, 8(1), 112-132, 1960.
8. Greene, W., and Hensher, D. A latent class model for discrete choice analysis contrasts with mixed logit. Transportation Research Part B, 37(8), pp. 681-698, 2003.
9. Liu, Y., Chang, G.L., Tao, R., E. Tabacek, and T. Hicks, Measuring the response of drivers to a yellow phase with a video based approach. Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering. pp. 578-583, Chicago, Illinois, USA, August 13-16, 2006.
10. Liu, Y., Chang, G.L., Tao, R., E. Tabacek, and T. Hicks. Empirical observations of dynamic dilemma zones at signalized intersections. Transportation Research Record, 2035, 122-133, 2007.
11. Maryland State Highway Administration [MDSHA]. Maryland Traffic Safety Facts (2003). Retrieved November 22, 2008, from www.sha.state.md.us/Safety/oots/Factbook2003April15.PDF, 2003.
12. Milazzo II, J., Hummer, J., Rouphail, N., Prothe, L., and McCurry. The effect of dilemma zones on red light running enforcement tolerances. Proceedings of the 81st Annual Meeting of the Transportation Research Board [CD-ROM]. Washington DC. January 13-17, 2002.
13. National Highway Traffic Safety Administration [NHTSA]. Methodology study of the consumer braking information initiative, Retrieved November 22, 2008, from http:// www.nhtsa.dot.gov/CARS/PROBLEMS/studies/brakes/Phase2/COVER.html, 1998.
14. Olson, P., and Rothery, R. Driver Response to the Amber Phase of Traffic Signals. Operations Research, 9(5), 650-663, 1961.
15. Patten, C., Kircher, A., Östlund, J., and Nilsson, L. Using mobile telephones: cognitive workload and attention resource allocation. Accident Analysis and Prevention 36 (3), pp. 341-350, 2004.
16. Shinar, D., and Compton, R. Aggressive driving: an observational study of driver, vehicle, and situational variables. Accident Analysis and Prevention 36 (3), 429-437, 2004.
17. Shultz, G., and Babinchak, M. Methodology study for the consumer braking information initiative, Final Report, NHTSA.99.658 3-1, 1998.
18. Van der Horst, R., and Wilmink, A. Drivers' decision-making at signalized junctions: an optimization of yellow-light timing. Traffic Engineering & Control, 27(12), 615-622, 1986.

19. Xiang, H., C.S. Chou, G.L. Chang, and R. Tao. Observations and classification of Drivers Responses during Yellow-Light Signal Phase. Proceedings of the 84th Annual Meeting of Transportation Research Board [CD-ROM]. Washington DC. January 9-13, 2005.

20. Zegeer, C.V., and R.C. Dean. Green-extension systems at high-speed intersections. ITE Journal, 48(11), 19-24, 1978.

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Table 1. Survey intersection characteristics

Intersections*	1	2	3	4	5	6
Cycle length (seconds)	150	150	120	150	150	150
Yellow phase duration (seconds)	4.5	5	4	4.5	5	5.5
Target approach green split	0.387-0.491	0.603	0.450-0.718	0.316	0.248	0.785
Speed limit (mph)	40	40	35	35	35	45
Number of through lanes in target approach	4	3	3	2	2	3
Number of cross lanes by the target approach	3	3	2	5	5	4
Coordination with next signal	Yes	No	Yes	Yes	No	No
Next signal visibility	Yes	No	Yes	Yes	No	No
Number of observations	292	360	77	128	150	116

*Intersection indices (1-6) refer to: MD193 at MD201, MD650 at Metzerott Rd., Randolph Rd. at Glenallan Rd., MD410 at Belcrest Rd., MD410 at Adelphi Rd., and MD193 at Mission Dr respectively.

Table 2. The estimated average critical distance, d_c, for the driving populations at each intersection

Surveyed Intersections	Yellow Duration(sec)	Cycle Length (sec)	Critical distance d_c (ft)
193@201	4.5	150	234ft
650@Metzerott	5	150	205ft
Randolph@Glenallan	4	120	269ft
410@Belcrest	4.5	150	200ft
410@Adelphi	5	150	177ft
193@Mission	5.5	150	278ft

Table 3. Distribution of driving populations at each intersection

Surveyed Intersections	Total Samples	Aggressive Pass	Normal	Conservative Stop
193@201	292	4% (13)	89%(260)	7% (19)
650@Metzerott	360	8% (28)	81%(292)	11% (40)
Randolph@Glenallan	77	8% (6)	84%(65)	6% (6)
410@Belcrest	128	5% (6)	90%(115)	5% (7)
410@Adelphi	150	7% (10)	83%(125)	10% (15)
193@Mission	116	8% (9)	84%(97)	8% (10)
Summary	1123	6% (72)	85%(954)	9% (97)

Table 4. Speed difference analyses among driving groups

Surveyed Intersections	Group	Average Speed/Std. (mph)	Percentage Above Average Traffic	Paired-t Ratio
193@201	Aggressive	41.05/5.03	+16.0%	6.314
	Normal	35.39/5.13	0%	0.108
	Conservative	32.35/3.37	-8.6%	-6.290
650@Metzrott	Aggressive	38.74/7.36	+13.5%	5.540
	Normal	34.13/6.92	0%	-0.564
	Conservative	30.00/5.29	-12.1%	-7.644
Randolph@Glenallan	Aggressive	52.25/7.43	+13.8%	8.126
	Normal	45.91/4.59	0%	-0.728
	Conservative	40.81/6.30	-11.1%	-8.903
410@Belcrest	Aggressive	38.09/8.44	+15.3%	9.353
	Normal	31.19/7.16	-5.6%	-3.668
	Conservative	29.55/7.08	-10.6%	-13.679
410@Adelphi	Aggressive	38.70/6.48	+21.5%	6.014
	Normal	30.49/5.13	-4.3%	-2.990
	Conservative	27.21/4.94	-14.6%	-8.769
193@Mission	Aggressive	54.40/6.70	+12.0%	11.396
	Normal	44.15/6.36	-9.1%	-7.402
	Conservative	41.00/5.57	-15.6%	-7.886

Table 5. Notation for factors observed during field experiments

Traffic environment related variables	
Cycle-based average traffic flow speed	AVGSPEED (mph)
Cycle-based lane flow rate	VOLUME (veh/hr/lane)
Vehicle in platoon or not	PLATOON (1 – Yes, 0 – No)
Green split	SPLIT
Lane position of the vehicle	MIDL (1 – inner lane, 0 – not inner lane)
Intersection related variables	
Yellow phase duration	YD (seconds)
Cycle length	CYCLE (seconds)
Number of through lanes	THRUL
Number of cross lanes	CROSSL
Speed limit sign posted or not	POST (1 – Yes, 0 – No)
Speed limit value	SPL (mph)
Signal coordinated or not	COOR (1 – Yes, 0 – No)
Individual vehicle dynamics variables	
Approaching speed when the yellow phase starts	I_SPEED (mph)
Percentage of vehicles above the average traffic flow speed	PER_ABOVE
Individual driver related variables	
Driver's gender	MALE (1 – Yes, 0 – No)
Driver's age (< 26 years old – Young, > 46 years old - SENIOR)	YOUNG (1 – Yes, 0 – No) SENIOR (1 – Yes, 0 – No) MIDDLE (1 – YOUNG – SENIOR)
Passenger in vehicle or not	PASSENGER (1 – Yes, 0 – No)
Driver on cell phone or not	PHONE (1 – Yes, 0 – No)
Individual vehicle related variables	
Vehicle is Sedan or not	SEDAN (1 – Yes, 0 – No)
Vehicle is SUV or not	SUV (1 – Yes, 0 – No)
Vehicle is Pick-up or not	PU (1 – Yes, 0 – No)
Vehicle is Sports car or not	SPORTCAR (1 – Yes, 0 – No)
Vehicle is Van or not	VAN (1 – Yes, 0 – No)
Vehicle is Truck or not	TRUCK (1 – Yes, 0 – No)
Vehicle is Bus or not	BUS (1 – Yes, 0 – No)
Vehicle is made in US or not	US (1 – Yes, 0 – No)
Vehicle is made in Japan or not	JAP (1 – Yes, 0 – No)
Vehicle is made in Europe or not	EUR (1 – Yes, 0 – No)
Vehicle is made in Korean or not	KOR (1 – Yes, 0 – No)
Dependent variables	
Driver's response patterns	GROUP (1 – conservative stop, 2 – normal, 3 – aggressive pass)

Table 6. Estimation results of step I and II tests

	Parameter Coefficient [P value] (Sample Size)	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Final List of Significant Variables
Background Variable Set – Traffic Environmental Factors	C	3.426 [<.001]	3.779 [<.001]	4.248 [<.001]	4.889 [<.001]	4.191 [<.001]	6.034 [<.001]	
	AVGSPEED [+]	.0382 [<.001]	.0392 [<.001]	.0401 [<.001]	.0346 [<.001]	.0440 [<.001]	.0185 [.045]	×
	VOLUME[-]	-.307E-02 [<.001]	-.307E-02 [<.001]	-.309E-02 [<.001]	-.325E-02 [<.001]	-.331E-02 [<.001]	-.992E-03 [.073]	×
	SPLIT[-]	-2.199 [<.001]	-2.261 [<.001]	-2.217 [<.001]	-1.804 [<.001]	-2.226 [<.001]	-2.627 [<.001]	×
	MIDL[-] (570)	-.247 [.213]						dropped in test 1
	PLATOON[-] (268)	-.521 [.408]						dropped in test 1
Intersection Related Variables	YD[+]		.0725 [.643]					dropped in test 2
	CYCLE[-]		-.508-02 [.422]					dropped in test 2
	THRUL[-]		-.187 [.009]				-.0898 [.034]	×
	CROSSL[+]		.112 [.003]				.0501 [.053]	×
	POST[-] (497)		-.0174 [.863]					dropped in test 2
	SPL[-]		-.0289 [.198]					dropped in test 2
	COOR[+] (497)		.228 [.019]				.367 [.038]	×
Individual Vehicle Dynamics Variables	I_SPEED[+]			.113 [<.001]			.064 [.030]	×
	PER_ABOVE[+]			4.160 [<.001]			3.432 [<.001]	×
Individual Driver Related Variables	MALE[+] (750)				.652 [.063]		.216 [.089]	×
	YOUNG[+] (591)				.925 [.004]		.647 [.054]	×
	SENIOR[-] (163)				-.977 [.083]		-.441 [.211]	dropped in test 6
	PASSENGER[-] (192)				-.609 [.378]			dropped in test 4
	PHONE[-] (118)				-1.087 [.039]		-0.816 [.050]	×
Individual Vehicle Related Variables	SEDAN[+] (540)					.0378 [.667]		dropped in test 5
	VAN[-] (150)					-.851 [.021]	-.382 [.115]	dropped in test 6
	SUV[-] (225)					-.222 [.316]		dropped in test 5
	PU[+] (94)					.609 [.221]		dropped in test 5
	SPORTCAR[+] (81)					1.263 [.009]	0.745 [.063]	×
	TRUCK[-] (26)					-.246 [.693]		dropped in test 5
	JAP[+] (445)					.666 [.021]	.331 [.011]	×
	US[-] (559)					-.252 [.541]		dropped in test 5
	EUR[-] (80)					-.725 [.354]		dropped in test 5

Note: Significance tests are performed at the 0.10 level; Cells highlighted represent the significant variables in a test.

Table 7. Estimation results of the Step III analysis (Compound Variables)

Test #	Compound Impact of Variables	Coef.	P-Value	Test #	Compound Impact of Variables	Coef.	P-Value
7	MALE and YOUNG	.787	[<.001]	42	YOUNG and SUV	.199	[.185]
8	MALE and SENIOR	-.433	[.005]	43	YOUNG and PU	.916	[<.001]
9	MALE and MIDDLE	.107	[.314]	44	YOUNG and SPORTCAR	1.551	[<.001]
10	MALE and PASSENGER	.249	[.170]	45	YOUNG and TRUCK	.509	[.426]
11	MALE and PHONE	.643	[.154]	46	YOUNG and BUS	.127	[.913]
12	MALE and SEDAN	.028	[.774]	47	YOUNG and JAP	.822	[<.001]
13	MALE and VAN	.237	[.126]	48	YOUNG and US	.361	[.001]
14	MALE and SUV	.707	[<.001]	49	YOUNG and EUR	.059	[.820]
15	MALE and PU	.613	[.035]	50	YOUNG and KOR	.046	[.904]
16	MALE and SPORTCAR	.984	[<.001]	51	SENIOR and PASSENGER	-1.023	[<.001]
17	MALE and TRUCK	-.246	[.393]	52	SENIOR and PHONE	-1.041	[<.001]
18	MALE and BUS	-.104	[.876]	53	SENIOR and SEDAN	-.424	[.018]
19	MALE and JAP	.705	[<.001]	54	SENIOR and VAN	-1.648	[<.001]
20	MALE and US	.166	[.074]	55	SENIOR and SUV	-1.469	[<.001]
21	MALE and EUR	.293	[.221]	56	SENIOR and PU	.150	[.658]
22	MALE and KOR	.610	[.369]	57	SENIOR and SPORTCAR	.207	[.730]
23	FEMALE and YOUNG	.272	[.022]	58	SENIOR and TRUCK	-.604	[.379]
24	FEMALE and SENIOR	-1.394	[<.001]	59	SENIOR and BUS	-.105	[.928]
25	FEMALE and MIDDLE	-.934	[<.001]	60	SENIOR and JAP	-.329	[.153]
26	FEMALE and PASSENGER	-1.057	[<.001]	61	SENIOR and US	-.756	[<.001]
27	FEMALE and PHONE	-1.200	[<.001]	62	SENIOR and EUR	-1.579	[<.001]
28	FEMALE and SEDAN	-.028	[.817]	63	SENIOR and KOR	-1.638	[<.001]
29	FEMALE and VAN	-1.615	[<.001]	64	MIDDLE and PASSENGER	-.318	[.050]
30	FEMALE and SUV	-1.419	[<.001]	65	MIDDLE and PHONE	-1.108	[<.001]
31	FEMALE and PU	.089	[.957]	66	MIDDLE and SEDAN	-.068	[.594]
32	FEMALE and SPORTCAR	1.343	[<.001]	67	MIDDLE and VAN	-1.097	[<.001]
33	FEMALE and BUS	-.162	[.922]	68	MIDDLE and SUV	-.14E-02	[.993]
34	FEMALE and JAP	-.169	[.182]	69	MIDDLE and PU	.129	[.676]
35	FEMALE and US	-.837	[<.001]	70	MIDDLE and SPORTCAR	-.128	[.744]
36	FEMALE and EUR	-.996	[.047]	71	MIDDLE and TRUCK	-.399	[.271]
37	FEMALE and KOR	-.780	[.004]	72	MIDDLE and BUS	-.244	[.795]
38	YOUNG and PASSENGER	-.331	[.110]	73	MIDDLE and JAP	-.180	[.203]
39	YOUNG and PHONE	.569	[.237]	74	MIDDLE and US	-.424	[<.001]
40	YOUNG and SEDAN	.233	[.024]	75	MIDDLE and EUR	-.668	[.011]
41	YOUNG and VAN	.130	[.508]	76	MIDDLE and KOR	-.599	[.087]

Note: Significance tests are performed at the 0.10 level; Cells highlighted represent the significant variables in a test.

Figure 1
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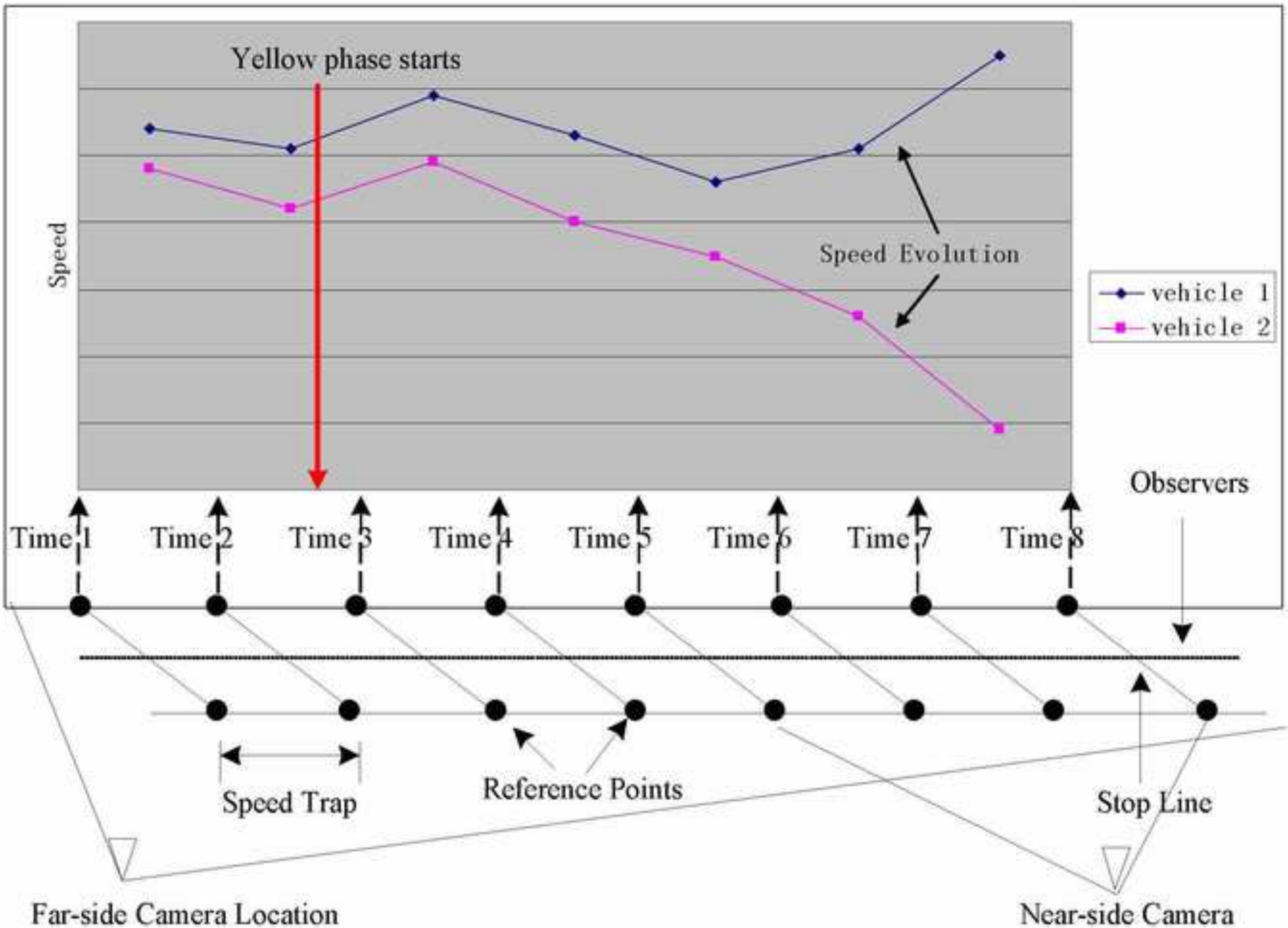

Fig. 1. A graphic illustration of the video-based data collection system – design and components

Figure 2
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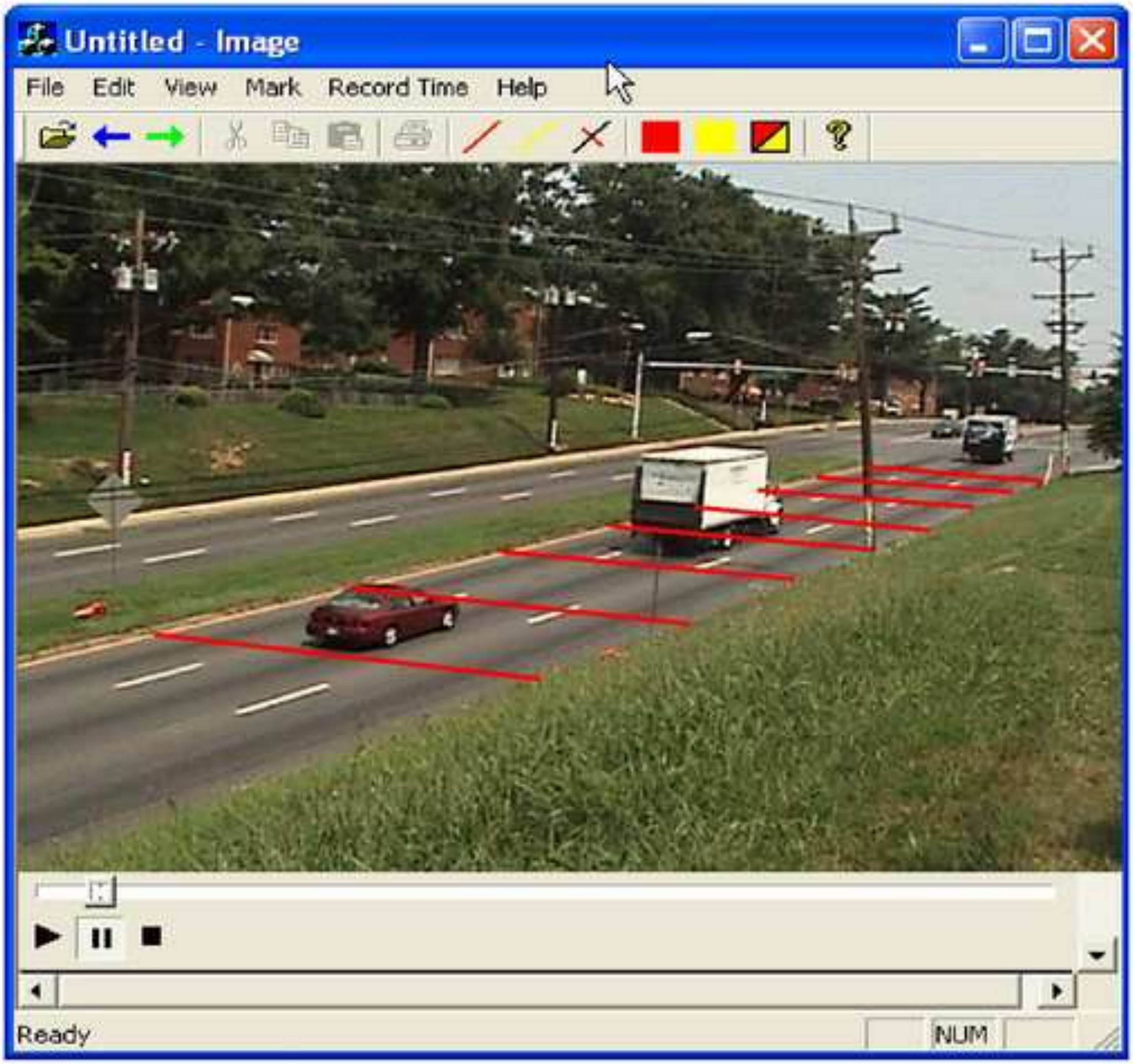

Fig. 2. The developed frame-by-frame video editing computer program

Figure 3
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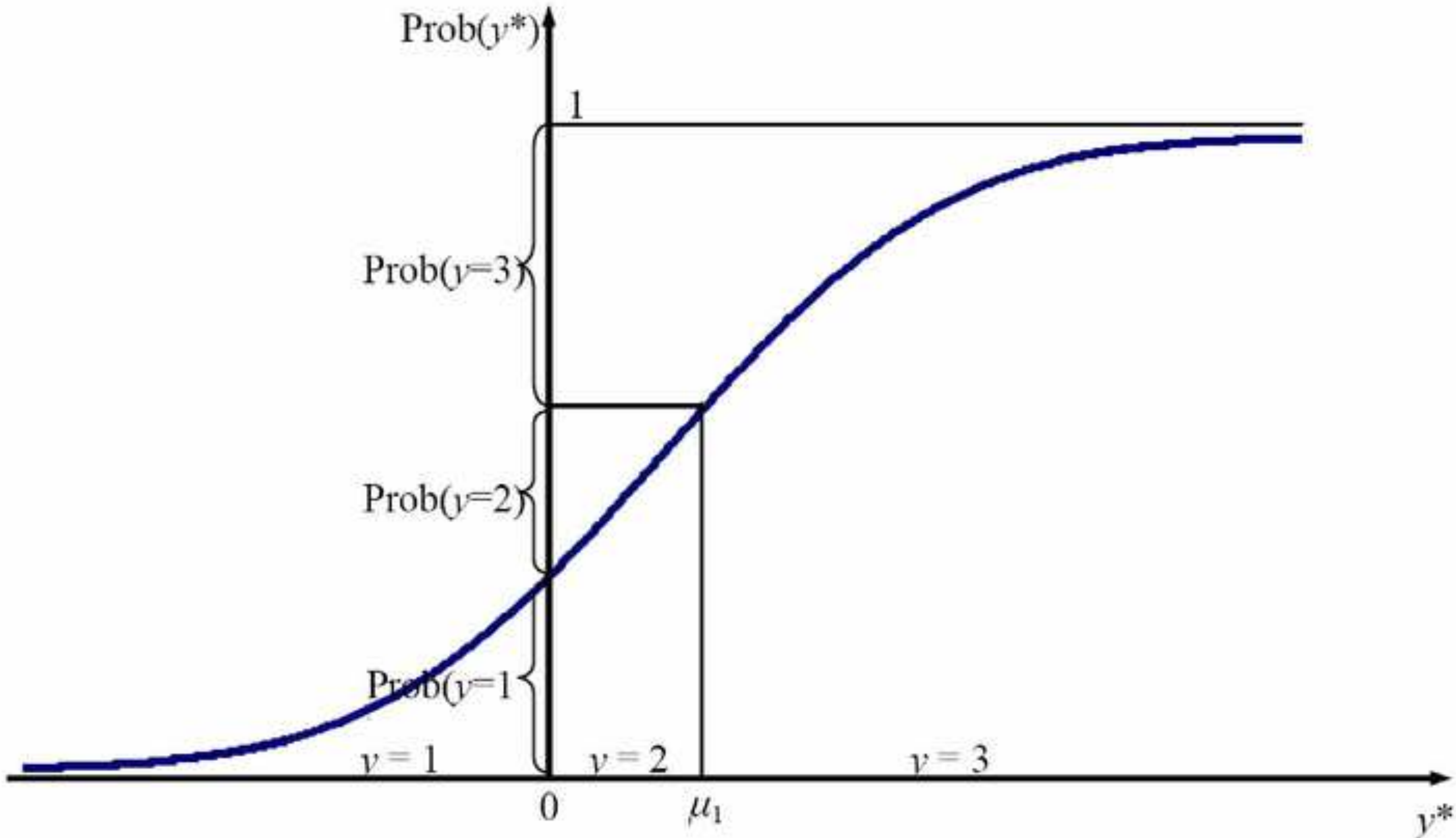

Fig. 3. An illustration of the probability distribution in an ordered-probit model

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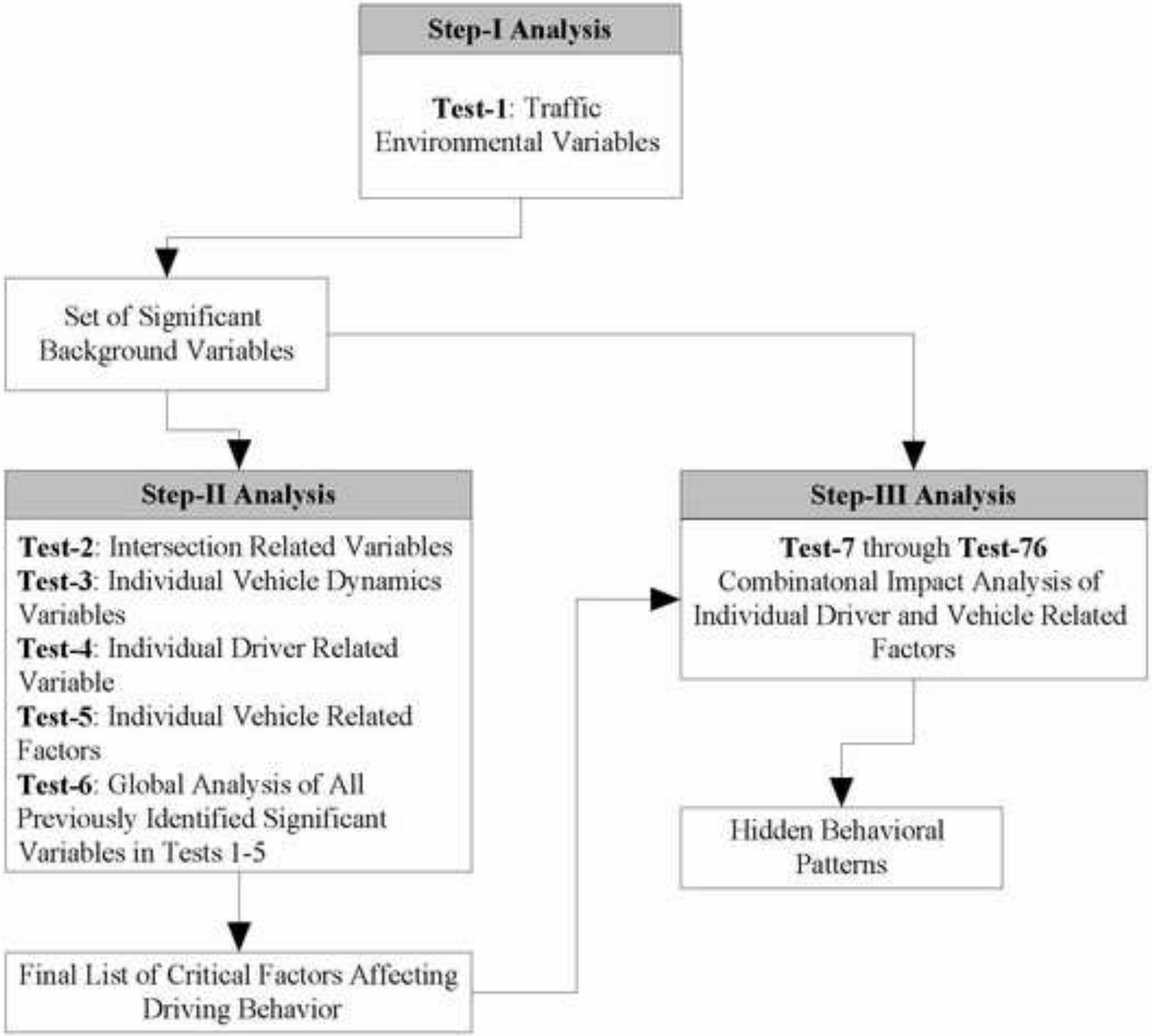

Fig. 4. The multi-step statistical test procedure with the ordered-probit model

Figure 5
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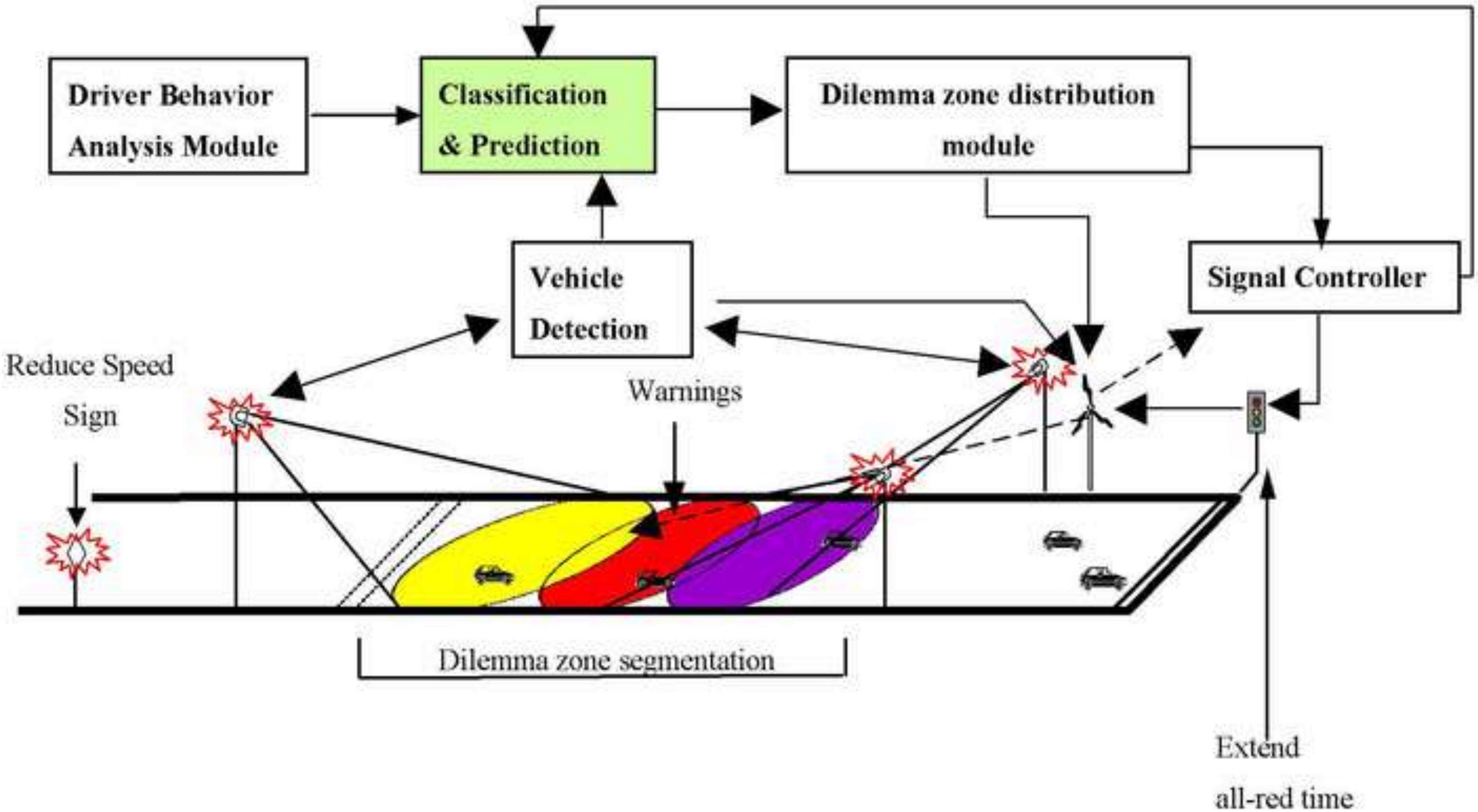

Fig. 5. ITS-based dilemma zone protection system design

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Authors' Response to the Review Comments

Journal: ASCE Journal of Transportation Engineering

Manuscript #: TEENG-666

Title of Paper: AN EMPIRICAL STUDY OF DRIVER RESPONSES DURING THE YELLOW SIGNAL PHASE AT SIX MARYLAND INTERSECTIONS

Authors: Yue Liu, Gang-Len Chang, Jie Yu

Date Sent: July 15, 2010

We appreciate the time and efforts by the editor and referees in reviewing this manuscript. We have addressed all issues indicated in the review report, and believed that the revised version can meet the journal publication requirements.

Response to Comments from Reviewer 1

Comment :

The authors present an interesting yet significant research study dedicated to investigating driver behavioral patterns during the yellow phase. In my opinion, the authors enhance the result accuracy and reliability in comparison with previously similar studies with the following reasons:

** Much larger sample size was used in the study.*

** Rather than use the controlled field experiments or simulation results, all the information was collected from real intersections to represent the real drivers' responses to signal phase changes.*

**The influential factors to be investigated were vitally expanded by including also intersection geometric characteristics, vehicle types and signal control types, and so on.*

Considering the non-uniform distribution of the driver behavior at signalized intersections, it is sensible to utilize the ordered-probit model and multi-stage statistical tests. The binary logit model and the associated procedure as described by the authors also help generate a reasonable estimate for the perceived critical distance.

Each table and figure provide readers a better understanding of the methodology and results presented. Without these tables the paper's message is severely compromised. While the paper is a little on the long side, it is so dense and full of relevant information that I don't think it can be shortened at all. Also, as mentioned above, this particular manuscript delves deeper than the previous published works. By using a larger sample size and implementing different measuring methods this particular study sets itself apart. However, it should be noted that there is also some space of improvement for this paper. For example: (1) The authors should elaborate on how to determine the number of reference lines which significantly impact the speed evolution results. (2)The reasons to select the specific intersection related factors are missing.

Overall, it is recommended for publication with its insightful findings and unique investigation methods.

Response:

We greatly appreciate the reviewer's efforts to carefully review the paper and the valuable suggestions offered. With respect to the concerns raised by the reviewer, please note that:

1) The elaboration on the details of the video-based data collection system can be found in the following paper:

Liu, Y., Chang, G.L., Tao, R., E. Tabacek, and T. Hicks, Measuring the response of drivers to a yellow phase with a video based approach. Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering. pp. 578-583, Chicago, Illinois, USA, August 13-16, 2006.

In the above paper, we have discussed the criteria to determine the distance between speed reference lines and estimate the maximal measurement error under different scenarios.

We have added the above paper as the reference in the second to last bullet point on page 5 in the revised manuscript. Due to the page limit for ASCE manuscript, we prefer not to restate the detail of vedio-based procedure in this paper.

2) The key criterion used to select survey intersections is the high frequency of read-end collisions. We also considered the variation of signal control parameters among those intersections. Operational feasibility and convenience serve as the selection factors..

Response to Comments from Reviewer 2

Overall Comment:

This is a decent paper on an old topic but a topic still with some legs. The paper could use a thorough edit but the writing is not bad. The paper is well-organized.

The best thing about the paper is the data collection system. Others could use the system as well. Better data on driver decision making are always welcome.

The paper suffers from three major flaws. The decision on whether the paper should be published hangs on the answer to the authors' responses to those flaws, in my opinion. The paper can be published if the authors can respond well to those.

Response:

We appreciate the comments by reviewer-2 and have made the following revisions accordingly.

Comment 1:

First on page 6 and Figure 2, were the cameras, cones, and observers hidden from driver view? Need to convince readers that the measuring system itself had no effect, because we know that drivers react differently when they see cameras at intersections.

Response:

Thanks for the insightful comments. The orange cones were placed along the roadside when we first took a very short benchmark video to record the locations and draw the reference points. We then removed all the cones and started the formal data collection process. By doing so, the impact of orange cones on drivers' response can be avoided. During the data collection process, the observer and the camera were hidden in the car to ensure that they will not distract drivers.

Comment 2:

Second, the results presented on page 15 or so are banal and uninteresting. This is the best that you found? These results remind me of some late-night comedy show, on which the comic will point out that the government spent many hundreds of thousands of dollars to find something totally obvious.

Response:

Thanks for the insightful comment suggestion. We need to mention here that the research presented in this paper is part of our long-term multi-phase project that aims to investigate the interrelations between the driving behavioral patterns, signal control, vehicle characteristics, and intersection crash rates. Based on the field collected data from the proposed video-based system and a careful calibration of key model parameters, a preceding work done by us (see "Liu, Y., Chang, G.L., Tao, R., E. Tabacek, and T. Hicks. Empirical observations of dynamic dilemma zones at signalized intersections. Transportation Research Record, 2035, 122-133, 2007") has successfully demonstrated the existence of dynamically distributed intersection dilemma zones and their interrelations between various driving populations.

Along the line of our previous work, in this research, we focus on investigating the qualitative impacts of various affecting factors on drivers' behavior within the dilemma zone. We agree with the reviewer that some findings are pre-mature. However, with the significantly enriched field datasets, we did disclose some hidden behavioral patterns that are neglected by other researchers, e.g. the impacts of traffic environmental factors (page 11 -12).

The results presented on page 15 actually introduce some of our on-going work. Based on the significant factors identified in this paper, we are currently developing a series of quantitative models to predict the driver's decision (aggressive pass, normal pass, normal stop, or conservative stop) in response to the yellow phase as well as the number of aggressive drivers potentially trapped in the dilemma zone in each signal cycle. Such models can be incorporated into the traditional signal control framework to improve intersection safety.

Due to the limitation of manuscript length, we only report the results of our qualitative investigation on driving behavioral patterns associated with all contributing factors in this paper. Our on-going research focused on the quantitative part will disclose more precise and interesting findings.

Comment 3:

Third, on page 16 or so, do I understand correctly that the system will judge whether to extend all-red based partially on driver characteristics? If not, reword to explain correctly. If so, that is unethical and probably illegal, profiling in the worst sense. Imagine the outcry when it is revealed that women get less time than men. Remove this offensive section. Also, will an index of safety will be better than standard collision data and models in prioritizing projects? Highly doubtful. Authors need to do much more to back up this line of reasoning.

Response:

We appreciate the reviewer's insightful comments and helpful suggestions. We are sorry for not explaining this part very well. The system will judge whether to extend the all-red phase, based on whether or not the detected driver is in his/her dilemma zone, Individual driver characteristics (gender, age, and etc) are difficult to measure reliably in real time and have potential ethical or legal issues as pointed by the reviewer. We expect to develop a 3-class or 4-class model to predict individual driver's response when approaching the yellow phase. If the model predicts that a driver who is the dilemma zone and intends to take an aggressive maneuver (potential red-light running), then the system will extend the all-red phase to let him/her clear the intersection safely.

We have clarified this part in the second bullet on page 15.

We agree with the reviewer that it is highly doubtful to judge the benefit of the safety index right now. So we remove this section in the revised manuscript.

Minor Comments:

Some small points include:

Title) Change "accident" to "crash" or "collision" to keep up with modern practice and acknowledge that many of the events are not accidental.

Page 2, Line 4) I am sure a small portion were fatal. Reword this.

Page 6) Anything special about the sites? Near a high school? Bar? Military base?

Page 7) All observations in daytime and good weather?

Response:

We much appreciate the reviewer's careful review.

1) We have eliminated the phrase "of high accident rate" based on the comment from Reviewer 3, and replaced "accident" with "crash" in the manuscript.
2) As we don't have the exact portion of fatal within that 20 percent, we delete "fatal" at line 4.
3) and 4) No specials about the sites and all observations are made during the daytime and good weather conditions. We have supplemented this information on page 6.

Response to Comments from Reviewer 3

Overall Comment:

The authors spent a great amount of effort and time to collect field data and to analyze the data to show individual drivers' passing pattern at selected signalized intersections. The intention (goal) and the approach (method) of this study are acceptable. The literature review seems to me also appropriate; however the design and interpretation of the study need to be improved substantially in order this manuscript to be considered as a scientific journal paper. The following is the suggestions for the potential improvement.

Response:

We greatly appreciate the reviewer's efforts and have made our best efforts to respond to all concerns raised by the review to the extent possible.

Comment 1:

Although the text is fully understandable, the standard of English of this manuscript is unsatisfactory to be published as a journal paper. A full- proof reading service can be considered to improve the quality of presentation.

Response:

Thanks for the suggestion. We have carefully edited this revised version.

Comment 2:

Page 1, Title: the terminologies are inappropriate. Accident rate and accident frequency are totally different terminologies. According to the authors' description in the main body of manuscript, "accident frequency" will be the appropriate terminology in the title; however, indeed, this reviewer recommends the complete elimination of the following words from the title - "of high accident rate". Although this study have collected necessary dataset from a few selected intersections with "higher than normal accident FREQUENCY (not rate!), this study did not conduct (any) accident data analysis. Furthermore, the following words are too vague to summarize what this study has done - "driver behavioral patterns". Consider of using more specific words that can represent drivers' passing maneuvers or patterns at signalized intersections

Response:

Thanks for valuable comments, and. we have eliminated the words "of high accident rate" from the title as suggested, and reworded the "driver behavioral patterns" as "driving maneuvers".

Comment 3:

Page 2, Last sentence in the first paragraph: Change "et.al" to "et al." Under the second *paragraph: Change the author list to "Gazis et al." This is an example of editorial errors. This reviewer believes that this kind of errors can be easily removed by doing proofreading. In addition, please try to reduce the use of "his/her" in the manuscript. In many sentences, simply write "a driver or drivers" instead of writing "his/her".*

Response:

We have made all changes suggested by the reviewer and performed a careful editing work.

Comment 4:

Page 5, in the first bullet point: I believe the authors are mentioning "speed evolution" (not spatial evolution). In fact, this reviewer is uneasy to see the expression - "speed evolution", why not simply saying "speed change" instead? Otherwise, provide the full definition of "speed evolution".

Response:

Thanks for the suggestion. We have replaced "speed evolution" with "speed change" in the revised manuscript as suggested.

Comment 5:

Page 5-7, Introduce "Field data collection" first and then discuss "The video based data collection". (Much of the info under the "The video based data collection" is discussed later in the "Field data collection").

Response:

Thanks for the comments. We have reorganized that section as suggested by the reviewer.

Comment 6:

Under the "Field data collection": it is unclear when the data collection effort has been made. What time (e.g. morning peak hours)? How long (30-min)? Month? Weekday (Monday)? Weather and visibility condition? And so on. These are simply the basic info *that needs to be provided from any field data collection.*

Response:

Thanks for the comments. We have provided such information on page 6.

Comment 7:

Page 7, last line: Do you mean the following: Approach vehicles' average speed per cycle? Average flow rate per lane per cycle? The current description is unclear.

Response:

Thanks for the comments. We have reworded it as suggested by the reviewer.

Comment 8:

Page 8, Change the followings:

a.From "Conservative stop" to "Conservative drivers".

b.From "Normal" to "Normal drivers"

c.From "Aggressive pass" to "Aggressive drivers"

Response:

Thanks for the comments. We have changed those words in the revised manuscript.

Comment 9:

From page 8, use Group 1, 2, and 3 in the later sections; otherwise, what is the point of defining driver groups in this section of manuscript if the authors don't use the terminology in a later section?

Response:

Thanks for the comments. We have eliminated the terminology of Group 1, 2, and 3 on page 8 so that the reviewers don't need to go back to page 8 to find the definition for each group in the later sections.

Comment 10:

Page 9, the definition of dependent variable in the last paragraph should be stated earlier (from the right beginning of the section); readers should not be in a position to hunt for the meaning of dependent variable.

Response:

Thanks for the comments. We have provided the definition of the dependent variable at the beginning of the section as suggested by the reviewer.

Comment 11:

Page 9, This is a scientific journal paper. The notations should be clearly defined. For instance, what is the "cnorm" and what is the difference between <beta> and <beta>'?

Response:

Thanks for the comments. We have defined all notations. <beta>' is the transpose of <beta>, which is vector of estimated coefficients.

Comment 12:

From Page 10, This reviewer agrees on the view that the proposed model is a multi-stage model. The authors first estimated the magnitude of a variable (described under appendix) using binary logit model and then used the estimated variable as the dependent variable in the next stage model (i.e. ordered probit model) to show the association between dependent and independent variables. However, this reviewer could not agree on the current definition (usage?) about the multi-stage model in the manuscript. Reviewer thinks that a model outcome (or output) from one stage should be used as an input for the next stage in order a model to be considered as a multi-stage model. The current usage (or definition) of stage simply represents the different functional form of a regression model. Say, the first stage model used one set of independent variables and the second stage model used different set of independent variables, and so on. This does not make sense to me.

Response:

Thanks for the comments. Please note that, the set of significant variables from Stage-I served as the background variables in Stage-II, and all significant variables from Stage I and Stage II were included in Stage-III. So there exist "output-input" relations between all defined stages. To prevent the confusion, we have reworded "multi-stage" as "multi-step" statistical tests. We also changed Figure 4 correspondingly.

Comment 13:

*Page 11, Stage-III: This reviewer doesn't get this stage work at all. It seems to me that the authors looked into the interaction effect among the independent variables; however, this reviewer doesn't understand how the authors did that without considering any main effect in the model. For instance, in order to see the interaction effect between Male and Young, the model should contain the complete form of driver's gender and driver's age as its independent variables. If the authors only considered the multiplication of different variables and treated it as a new variable, then this is a completely wrong way of designing a regression model. If the authors considered properly the main effect in the model, the current format of presentation including Table 7 should be entirely revised. Furthermore, I also don't clearly understand what the each test # represents? Say, Test 7 means the model that includes "Male * Young" as a single independent variable, and so on? This is very confusing.*

Response:

Thanks for the comments. We are sorry for not explaining this step very well.

Firstly, we do not analyze the interaction effect between two independent variables. To do so, we definitely need to include the complete form of driver's gender and driver's age as independent variables (as stated by the reviewer), and then evaluate the correlation between those variables. What we have done in step-III was to evaluate the compound effect of two independent variables on the dependent variable (a totally different definition).

Secondly, we do not intend to test the single multiplication of two independent variables alone in each test in Step-III, instead we have considered the main effect of the model by including all significant traffic background variables, intersection related variables, and individual vehicle dynamics variables in each test of Step-III (Test 7 through Test 76).

Thirdly, the complete form of driver's age and gender variables has been tested in Tests 4 and 6, since some variables are not significant in those tests; we further took Step-III to test their compound impacts.

Last, please note that, on page 11, for Test 7 – Test 76, each test # means including one additional variable into the base test set that includes all previously identified significant variables. The reason for having such a design is due to the fact that if we place all possible multiplications of variables in one test, it will cause the multicollinarity problem.

We have provided additional explanation on page 10-11 to clarify this confusion. Also, we change the head of Table 7 (reword "variables" as "Compound Impact of Variables" so that the referees won't have an impression that we only test one multiplication variable in each test).

Comment 14:

Page 6 and 27, Table 5: After looking at the definition of age in the table, this reviewer realized that there will be no defensible way to determine the age of a driver from visual observation regardless of the effort (i.e. lab experiment) described in page 6. A mature looking driver whose age is 44 or 45 can be easily assigned into a senior driver on vice versa - no doubt. Furthermore, what about the drivers whose age are in between 26 and 45? There is no level to describe this age group in the table. As a result, this reviewer thinks that the age should not be used as a model input.

Response:

We agree with the reviewer that the driver age factor is difficult to reliably capture. Our intent was to separate senior and young drivers from the observed driving population. Fortunately, these two groups of drivers are relatively identifiable from the field and laboratory investigation. Based on pre-survey training, all field observers have achieved good consistency in characterizing the driver's age group. The good consistency was obtained by training observers to read hundreds of individual faces from popular "friend-making" websites and compare their judgment with the true age provided in those websites. The preliminary analysis result presented in this paper aims to disclose how the age factor plays a role in affecting driving maneuvers characterized in this study. As suggested by the reviewer, investigating the impact of age factor on driving maneuvers with enhanced data quality will definitely be our next-step research.

We have a variable (i.e. "MIDDLE") to capture the driver group between age 26 and 45, since it is a dummy variable in the test (defined as 1– YOUNG – SENIOR), we didn't include it in the test with "YOUNG" and "SENIOR" to prevent their correlation. In addition, a test with "MIDDLE" (without "YOUNG" and "SENIOR") shows that "MID" is not significant at the alpha = 0.10 level, so we drop it from Step-II analysis.

We have defined the variable "MIDDLE" in Table 5 and indicated its relation with other age-related factors in the revised manuscript.

Comment 15:

Page 7, 13 and 27: Reviewer cannot understand the reason why using vehicle's model (made in US and so on) as an independent variable. Furthermore, the first bullet on page 13 (i.e. drivers in Japan made cars shows aggressive decision?) may be considered as a poor interpretation due to the poor model design. Suppose this is a clear pattern, then what kind of engineering actions can be considered to reduce the aggressive decision by the "Toyota" drivers per se? Do the authors suggest the customized driver education for the Japanese car owners as described under the abstract and page 15?

Response:

Thanks for the comments. We agree with the reviewer that some findings regarding the impact of vehicle-make and model factors on the driving maneuvers are preliminary and pre-mature. However, it opens a window for researchers to investigate how the improved technological advances of various vehicle-makes and models can ultimately have an adverse effect on a driver's decision making process during the yellow phase despite so much attention on the yellow phase design, seat-belt enforcement, and operational improvements to roadway geometric features. Some clear patterns indicated in this preliminary study (e.g. Japan-made cars) will offer the basis for further investigating the impact of those vehicle's mechanical factors on driver's decision in the yellow phase. For instance, one may design an intelligent signal controller that can predict a driver's decision in a dilemma zone, based on some identifiable factors, and vehicle-make and model could be such factors. Integration of the research results with vehicle incident reports can also disclose the interrelation among the vehicle models, aggressive maneuvers, and signal related incidents. Such information will all be valuable in design of safety improvement program.

We have provided more explanation for the first bullet on page 15 in the revised manuscript.

Comment 16:

Page 15, Reviewer thinks that this study has very little contribution to the answers for the proposed four questions (i.e. four bullets) in "Potential Applications of the Research Result". For instance, "Enhance traditional signal timing models for possible reduction of aggressive driving related factors identified in this study without much loss of operational efficiency" This reviewer will be happy if I can see a paragraph (or even a sentence) to provide any clues relating to the four questions.

Response:

(Please also refer to response to comment 15).

Thanks for the comments. We have supplemented more information for those four questions on page 15 as suggested by the reviewer.

Those questions presented on page 15 actually introduce some of our on-going work based on this study. For example, the first bullet: Based on the significant factors identified in this paper, we are currently developing a series of quantitative models to predict the driver's decision (aggressive pass, normal pass, normal stop, or conservative stop) in response to the yellow phase as well as the number of aggressive drivers potentially trapped in the dilemma zone in each signal cycle. Such models can be incorporated into the traditional signal control framework to improve intersection safety.

Comment 17:

Appendix, consider of using "a" and "r" instead of using "i" and "j" in equations.

Response:

Thanks for the comments. We have replaced "i" and "j" with "a" and "r".

Comment 18:

Table 4: What does the shade mean? Consider of using "conservative" and "aggressive" instead of using "C-Stop" and "A-Pass".

Response:

Thanks for the comments. We have made the changes as suggested by the reviewer. The shaded cells mean the percentage above or below the normal traffic flow speed. We have removed the shade to avoid confusion.

Comment 19:

Table 6-7: What does the shade mean?

Response:

We are sorry for the confusion. The shade means significant variables at the 0.10 level. We have provided explanation below both tables.

Comment 20:

Fig.1: What does the asterisk and triangle mean? Insert legend

Response:

Thanks for the comments. We have improved the presentation of Fig. 1.

Comment 21:

Fig.3: Insert x- and y-axis title.

Response:

Thanks for the comments. The titles for x- and y- in Fig 3 are y* and Prob(y*), respectively.

Comment 22:

Fig. 4: As I said in "13" above, I don't agree on the interpretation of multi-stage model in this manuscript. Imagine the 4-stage traffic demand modeling (Trip generation, distribution, model split, and assignment), the outcome from previous stage is used as an input for the next stage model.

Response:

Thanks for the comments. Please refer to response to comment 12.

Comment 23:

Fig.5 A word is not clear. "Extended?".

Response:

Thanks for the comments. We have reworded it as "Extend all-red time"