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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

INTERRELATIONS BETWEEN CRASH RATES, SIGNAL YELLOW TIMES, AND VEHICLE PERFORMANCE CHARACTERISTICS: PHASE II

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FINAL REPORT

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16. Abstract

The Phase II project has conducted extensive field observations of driver responses during a yellow phase at six intersections of high accident frequency with a specially-designed image processing system. The collected field data includes the speed evolution of drivers during the yellow phase, their decisions, traffic flow conditions, vehicle type, gender, signal controls, and geometric features of the target intersection. The analysis results from the sample size of **1123** drivers have confirmed the hypothesis that the dilemma zone at signalize intersections is not static, but dynamic in nature with its range and location varying with driving behaviors, the yellow phase duration, and the surrounding traffic conditions. Intersections having aggressive driving populations cannot effectively eliminate their dilemma zones with an extension of their yellow phase durations. The dilemma zone for aggressive and conservative driving populations are generally distributed at different locations from the intersection stopline. The standard practice of using the average driver data for computing the dilemma zone is likely to reach misleading conclusions.

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Interrelations between crash rates, signal yellow times, and vehicle performance characteristics: Phase II

(final report)

To

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Chapter 1- Introduction

1.1 RESEARCH BACKGROUND

Improving traffic safety is a primary responsibility of both federal and local transportation agencies across the nation. Over the past several decades, a tremendous amount of resources has been invested in projects and programs to improve the safety and efficiency of our transportation systems. However, despite the significant progress of these programs, traffic-signal-related crashes have not been significantly reduced over the past decade in most states.

As highway agencies attempt to address this issue, a crucial aspect that researchers have not yet sufficiently studied, is how such critical factors such as the design of the yellow-light phase and improved technological advances of automobiles can ultimately have an impact on a driver's decision-making process within dilemma zones. Systematically quantifying such relations, however, is quite difficult, requiring a sufficient understanding of the complex interactions between the behaviors of drivers at signalized intersections and their encountered environments, including roadway geometric features, congestion levels, and distribution of traffic flow speeds. Collectively, these factors can significantly affect the decisions of drivers responding to changes in signal phases.

To explore this critical issue, Phase I of this project conducted an empirical study of driver responses during the yellow phase. Based on field observations over 732 drivers at nine intersections across five counties in Maryland, it found that driver responses during the yellow signal phase can be classified into four distinct types: "aggressive pass," "conservative stop," "normal stop," and "normal pass." Since the response times, average speed, and acceleration/deceleration rates vary significantly among the classified driver groups, it is apparent that their likely encountered dilemma zones at the same intersection will not be identical, which are most likely to be a distribution. The response differences of drivers during the yellow phase are due not only to discrepancies in individual characteristics, but also to a variety of traffic environmental factors, distribution of traffic flow speeds, and vehicle performance characteristics.

The promising findings from the Phase I study revealed that with a sufficient number of field observations, one can develop an integrated intersection model for safety evaluation and performance improvement. Such a model will enable the classification of the driving population at a target intersection into several distinct groups and allow one to estimate the distribution of their dilemma zones, based on their estimated speeds and acceleration/deceleration rates. Responsible traffic professionals can further employ signal control or ITS-related strategies to eliminate those dilemma zones and improve overall intersection safety.

1.2 RESEARCH OBJECTIVES

Grounded in the research results of Phase I, the primary objectives of Phase II are to:

- Substantiate the Phase I research findings with additional field data to be collected at intersections selected by SHA;
- Develop a set of systematic procedures for analyzing the distribution of dynamic dilemma zones, based on both the driver behavioral and speed variance components calibrated from an enriched empirical data set; and
- Identify operational strategies for contending with the existence of dynamic dilemma zones, and investigate their potential for field demonstration.

1.3 REPORT ORGANIZATION

Based on the research objectives, this study has organized all primary results and key findings into six subsequent chapters. A brief description of the information contained in each chapter is presented below:

Chapter 2, after a review of dynamic dilemma zones as discussed in Phase I, illustrates the overall research framework and outlines critical project tasks along with major activities associated with each task. It also discusses the interrelations between the findings of each principal task and the primary research objectives of this study.

Chapter 3 presents mainly the operational guidelines adopted for field data collection, and the key components of a specially designed video-based system for quantifying the complex responses of drivers, including the evolution of their speeds as well as accelerations during a yellow signal phase. The description of data collection procedures includes the preliminary identification and final selection of candidate intersections for field observations, operational requirements for setting up all essential equipment for field data collection, and data filtering procedures to remove those observations contaminated by measurement noise.

Chapter 4 explains the statistical procedures used to perform preliminary data analysis and the underlying behavioral patterns uncovered during the yellow signal phase. The chapter also addresses the following critical issues: sample size of candidate intersections under the budget constraints and their location distribution; sample observations from each selected intersection; field observation constraints at each identified intersection; and potential measurement noise associated with each target variable to be collected. Empirical evidence of multiple dilemma zones observed at the six candidate intersections also constitutes a core part of this chapter.

Chapter 5 reports the potential impacts of various individual as well as environmental factors on the response of drivers during a yellow phase. Based on field-observed results, this study conducted comprehensive tests of hypotheses with respect to their potential impacts under various conditions, which the chapter discusses in detail.

Example hypotheses include: male drivers are more likely to make “aggressive-pass” decisions when approaching a yellow-light phase; young drivers are more likely than adult drivers to be classified in the “aggressive-pass” group; in peak hours, drivers appear to behave more aggressively with respect to signal phase changes; at intersections with major and minor streets, drivers on the minor streets (i.e., less through lanes and more crossing lanes) are more likely to react aggressively when encountering yellow-light phases; drivers at intersections with a longer yellow-light duration are less likely to take the “aggressive-pass” decision; and drivers of pick-up trucks tend to be classified in the “aggressive-pass” group when encountering a yellow-light phase.

Chapter 6 summarizes the primary research findings and their potential applications to improving intersection traffic safety. It discusses two potential systems to contend with the dynamic nature of dilemma zones. The proposed systems intend to integrate the research results from this study with advanced technologies in the Intelligent Transportation Systems (ITS), which will enable each signalized intersection to automatically monitor if any driver is to be trapped in a dynamic zone and activate necessary control decisions to prevent potential accidents.

Recommendations for field implementations and the needs for future research also constitute the core of the last section.

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Chapter 2 – Overall Research Framework

2.1 INTRODUCTION

To address the critical safety issues caused by intersection dilemma zones, Phase I of this study conducted an empirical study of driver responses during the yellow phase, based on field observations of over 732 drivers at nine intersections across five counties in Maryland. The study found that driver responses during the yellow signal phase can be classified into several distinct types, including: “aggressive pass,” “conservative stop,” and “normal stop.” Since response times, approaching speeds, and acceleration/deceleration rates vary significantly among these driver types, it is apparent that their likely encountered dilemma zones will not be identical and are most likely to be a distribution. The response differences of drivers during the yellow phase are due not only to discrepancies in individual characteristics, but also to a variety of traffic environmental factors, average traffic flow characteristics, and vehicle performances.

The informative findings from Phase I revealed that a sufficient number of field observations can allow one to develop an integrated intersection model for safety evaluation and performance improvement. Such a model will allow investigators to classify the driving population at a target intersection into several distinct groups, and to estimate the distribution of their dilemma zones based on their estimated speeds, acceleration/deceleration rates, and response times. Responsible traffic professionals can then employ signal control or ITS-related strategies to eliminate those dilemma zones and improve overall intersection safety.

Grounded in the previous research results, the research in this phase aimed to substantiate the Phase I study’s findings with an enriched dataset and to develop a set of statistical models for analyzing the distribution of dynamic dilemma zones, based on both driver behavioral and dynamic parameters calibrated from a specially designed data collection system. Based on the new dataset, Phase evaluated the impacts of existing traffic conditions, control features, yellow phase designs, individual driver and vehicle characteristics, and intersection geometry features on a driver’s decision-making process during the yellow phase. This study also investigated operational strategies for contending with the existence of dynamic dilemma zones as well as their potential for field demonstration. To fulfill the aforementioned tasks systematically, this chapter focuses on schematizing the overall research framework in this phase.

This chapter is organized as follows: the next section, 2 .2, describes the dynamic nature of intersection dilemma zones along with a numerical investigation of dilemma zone distribution for different driving populations and vehicle characteristics. Section 2.3 identifies potential Phase II research issues and presents the overall research flowchart. The last section concludes with summarizing comments about dynamic dilemma zones.

2.2 DYNAMIC NATURE OF INTERSECTION DILEMMA ZONES

As defined in the ITE handbook (ITE, 1985), a dilemma zone is a range within which a vehicle approaching an intersection during its yellow phase can neither safely clear the intersection, nor stop comfortably at the stop-line (see Figure 2-1). The existing practice (Xiang, H. et al., 2005) for computing the dilemma zone is based on the following kinematics equations:

$$x_{dz} = x_c - x_0 = v_0\delta_2 + \frac{v_0^2}{2a_2^*} - v_0\tau + (w+L) - \frac{1}{2}a_1^*(\tau - \delta_1)^2 \tag{2-1}$$

where:

$x_c =$ the critical distance for a smooth “stop” under the maximum deceleration rate;

$x_0 =$ the critical distance for a “pass” under the maximum acceleration rate;

$\tau =$ duration of the yellow phase (*sec*);

$\delta_1 =$ reaction time-lag of the driver-vehicle complex (*sec*);

$\delta_2 =$ decision-making time of a driver (*sec*);

$v_0 =$ approaching speed of vehicles (*ft/sec*);

$a_1 =$ average vehicle acceleration rate (ft/s^2);

$a_1^* =$ maximum acceleration rate of the approaching vehicles (ft/s^2);

$a_2 =$ average vehicle deceleration rate (ft/s^2);

$a_2^* =$ maximum deceleration rate of the approaching vehicles (ft/s^2);

$w =$ intersection width (*ft*); and

$L =$ average vehicle length (*ft*).

The impacts of a vehicle's approaching speed, driver responses, and vehicle characteristics on the resulting distribution of dilemma zones are illustrated in Figures 2-2, 2-3, and 2-4, respectively, through numerical analyses (Xiang, et al., 2005). Clearly, both the length and location of a dilemma zone may vary with the speed of the approaching vehicle, driver reaction times, and vehicle dynamics (field demonstration of the above phenomena will be presented in Chapter 4.)

Figure 2-1 A graphical illustration of the dilemma zone at signalized intersections

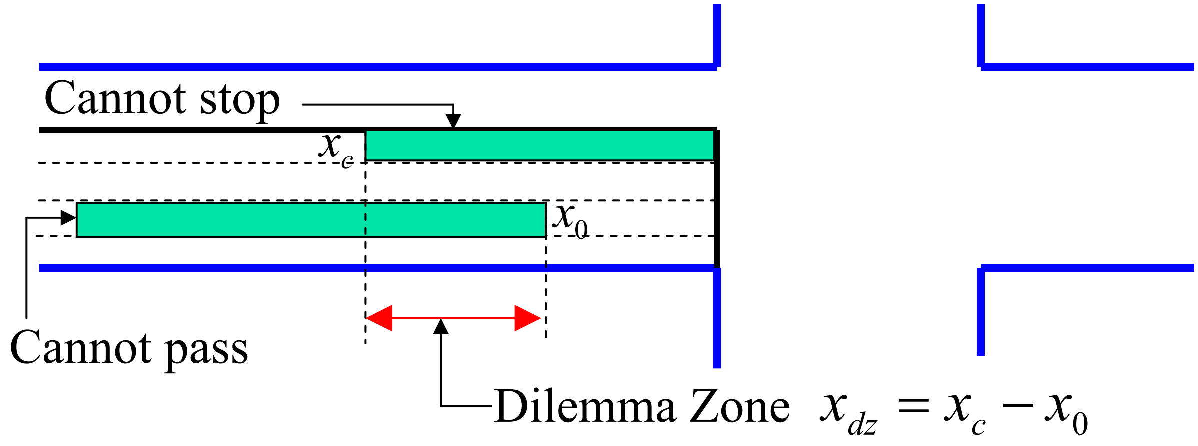
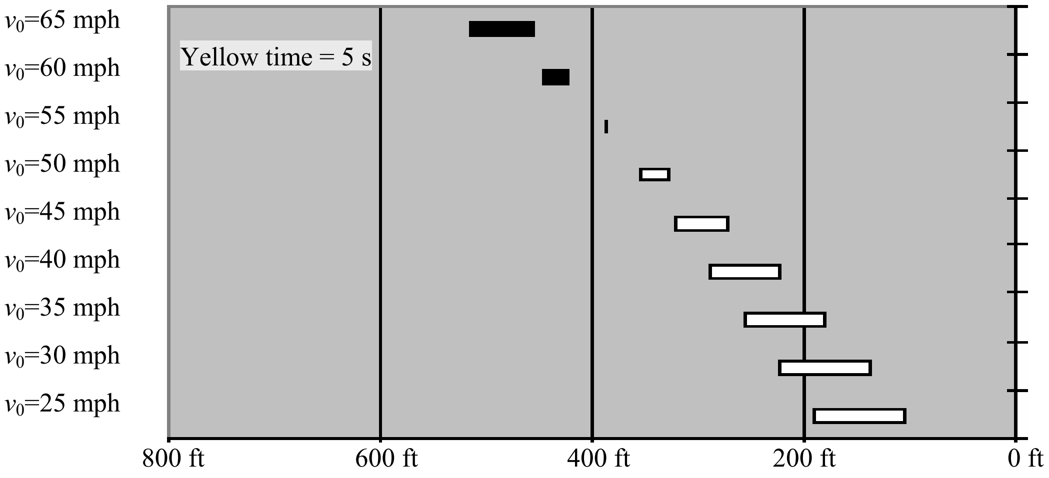


Figure 2-2 A graphical illustration of the dilemma zone distribution for different vehicle approaching speeds (yellow phase = 5 seconds)



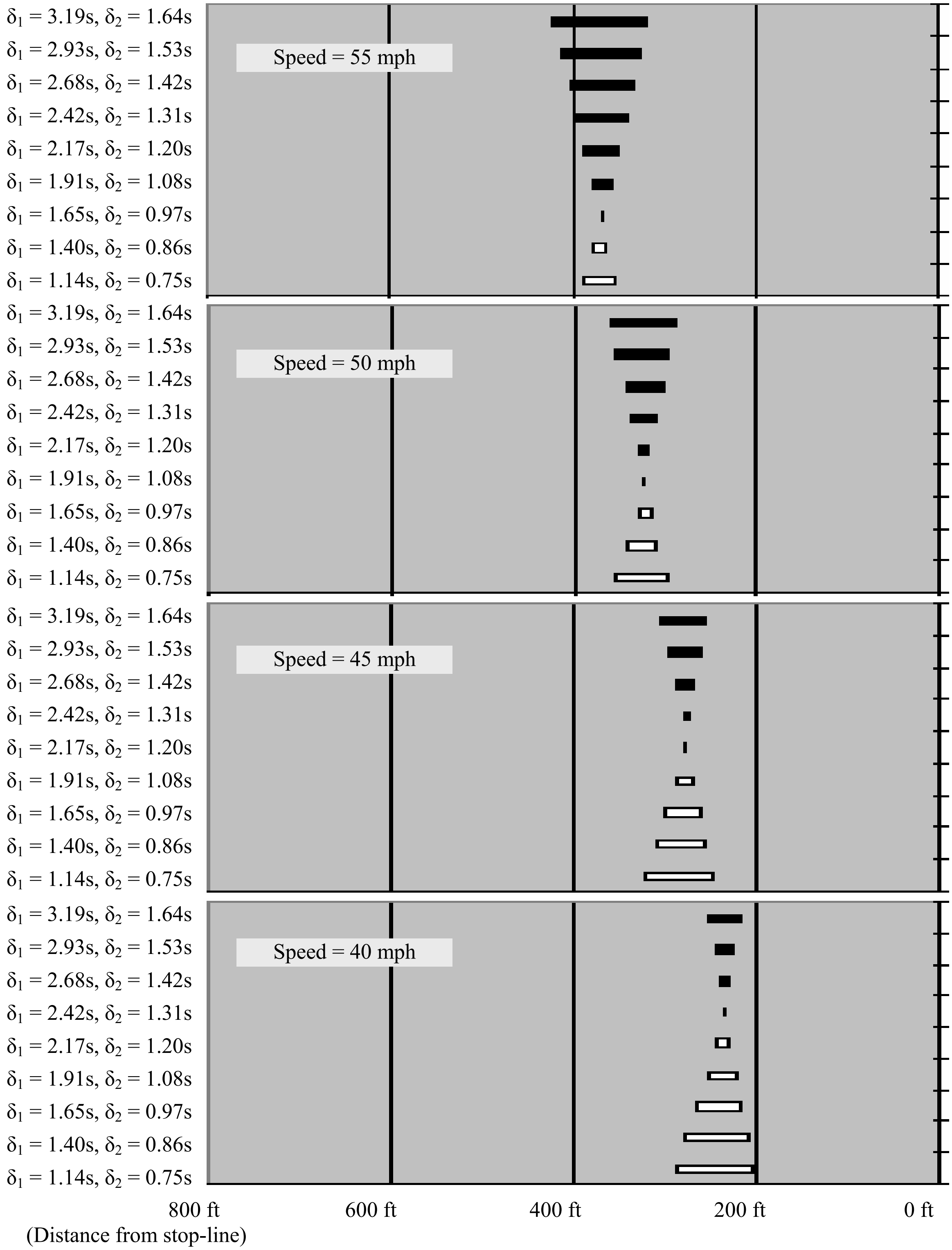
(Distance from stop-line)

■ : Dilemma zone (where a driver can neither stop safely nor pass completely during yellow)

□ : Option zone (where a driver can either stop safely or pass completely during yellow)

Note: this computation uses average perception-reaction time of drivers and performance characteristics of regular family sedans.

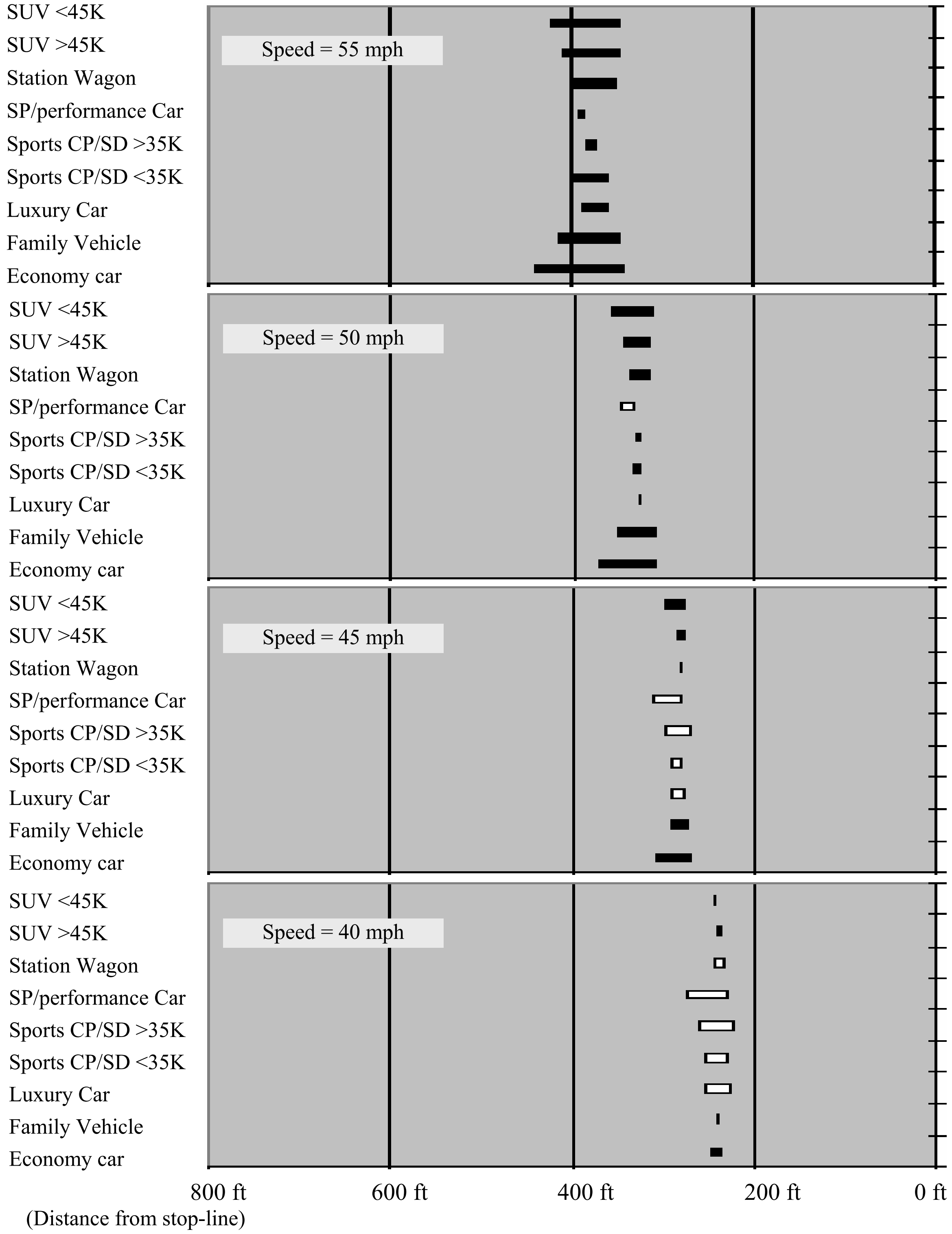
Figure 2-3 A graphical illustration of the dilemma zones for drivers with different perception reaction times at various approaching speeds



■ : Dilemma zone (where a driver can neither stop safely nor pass completely during yellow)
□ : Option zone (where a driver can either stop safely or pass completely during yellow)

Note: δ1 is the reaction time-lag of the driver-vehicle complex, and δ2 is the decision-making time of a driver.

Figure 2-4 A graphical illustration of the dilemma zones for different types of vehicles at various approaching speeds



■ : Dilemma zone (where a driver can neither stop safely nor pass completely during yellow)

▭ : Option zone (where a driver can either stop safely or pass completely during yellow)

Note: Acceleration and deceleration rates for nine vehicle classes are listed as follows (ft/s2):

(Reference: vehicle performance test summary of "Automobile Journalists Association" of Canada)

Vehicle Class	Acceleration	Deceleration
Sports Utility <45K ($CAD)	9.5	9.9
Sports Utility >45K ($CAD)	9.9	10.4
Station Wagon / MPV	10.0	10.7
Sports / Performance Car	15.1	10.9
Sports Coupe / Sedan >35K ($CAD)	12.9	11.2
Sports Coupe / Sedan <35K ($CAD)	11.9	10.8
Luxury Car	11.9	11.0
Family Vehicle	9.1	10.1
Economy Car	8.9	9.4

Under the same conditions, one can use a longer yellow phase to eliminate the dilemma zone if both the reaction time and vehicle acceleration/deceleration rates are identical among the driving populations. However, in reality, the parameters, δ_1 and δ_2, which represent the perception and reaction times, may vary significantly among driving populations. The maximum acceleration/deceleration rates (denoted as a_1^* and a_2^*), and the approaching speed (v_0) may also be distributed over a wide range among different driver and vehicle groups, as shown in the above figures. For example, young and aggressive drivers tend to exercise a higher speed and have a shorter perception-reaction time than old and/or conservative drivers when approaching the intersection. The acceleration/deceleration rates of sport cars are certainly different from those of family sedans. Hence, the actual dilemma zone at an intersection is more likely to be a distribution than a constant as computed in existing practices. Thus, increasing the yellow duration alone may not be sufficient for eliminating all such dilemma zones for different driving populations.

Transportation researchers in recent years have begun to realize that both the location and length of dilemma zones are dynamic in nature and may vary with the complex interactions between the response of drivers, yellow phase duration, vehicle mechanical performances, intersection geometric features, and average traffic flow characteristics. For instance, Moon and Coleman (2002) proposed a strategy to minimize the gate delay, by adjusting rail-gate closing actions based on the length and locations of dilemma zones at highway-rail intersections. McCoy and Pesti (2003) designed a set of detection/warning strategies for safety improvements at high-speed intersections in response to the dynamic distribution of dilemma zones.

For the signalized intersections in Phase I of this study, an extensive numerical investigation of the dilemma zone dynamics was performed for different driving populations and vehicle characteristics. However, due to the constraints of the sample size and the measurement method, their results, although informative, are not sufficient for computing the dilemma zone distribution for different driving populations.

2.3 RESEARCH ISSUES AND OVERALL FLOWCHART

Along the same lines of research as Phase I, this study continued to conduct the following critical tasks (Figure 2-5 shows the overall research flowchart):

- *Design a reliable data collection system and operational guidelines to capture the critical data needed for driver classification and analysis of dilemma zone dynamics;*
- *Develop a set of behavioral models to classify drivers based on their responses during the yellow phase;*
- *Extract key characteristics among driving groups to explore the interrelations between the average traffic characteristics and each group of drivers;*
- *Analyze different dilemma zones for different driver groups at target intersections;*
- *Test hypotheses presented in the Phase I study comprehensively, based on an enriched dataset;*
- *Identify potential ITS technologies for field demonstration of estimation models developed from this study.*

Note that one of the foremost critical tasks in the above listwas to design a video-based field data acquisition system. It was proposed in response to the lessons from the Phase I study, and intended to produce a cost-effective tool for researchers to reliably observe the complex interaction process between a driver’s response during the yellow phase and a variety of related factors that may affect his/her decision.

This is due to the fact that collection of all behavioral related data, such as speed and acceleration rates, for this study requires a very rigorous design to achieve a very high-level of data accuracy and precision. Failure to do so may render either misleading results or inconclusive observations even with a large sample of field data. Since the system or tool that can provide such required features and accuracy for the research needs within the acceptable cost is not available in the ITS and/or transportation industries, it was essential for this study to first develop such a specially-designed tool.

With respect to the computation of dynamic dilemma zones, it is actually one of the main objectives of this study, that is, to empirically demonstrate the existence of multiple dilemma zones at a given intersections having different driving populations. Although traffic safety professionals have increasingly recognized the dynamic nature of intersection dilemma zones, the traffic research community has not been able produce such empirical evidences due to the costs and difficulties involved in collecting related data.

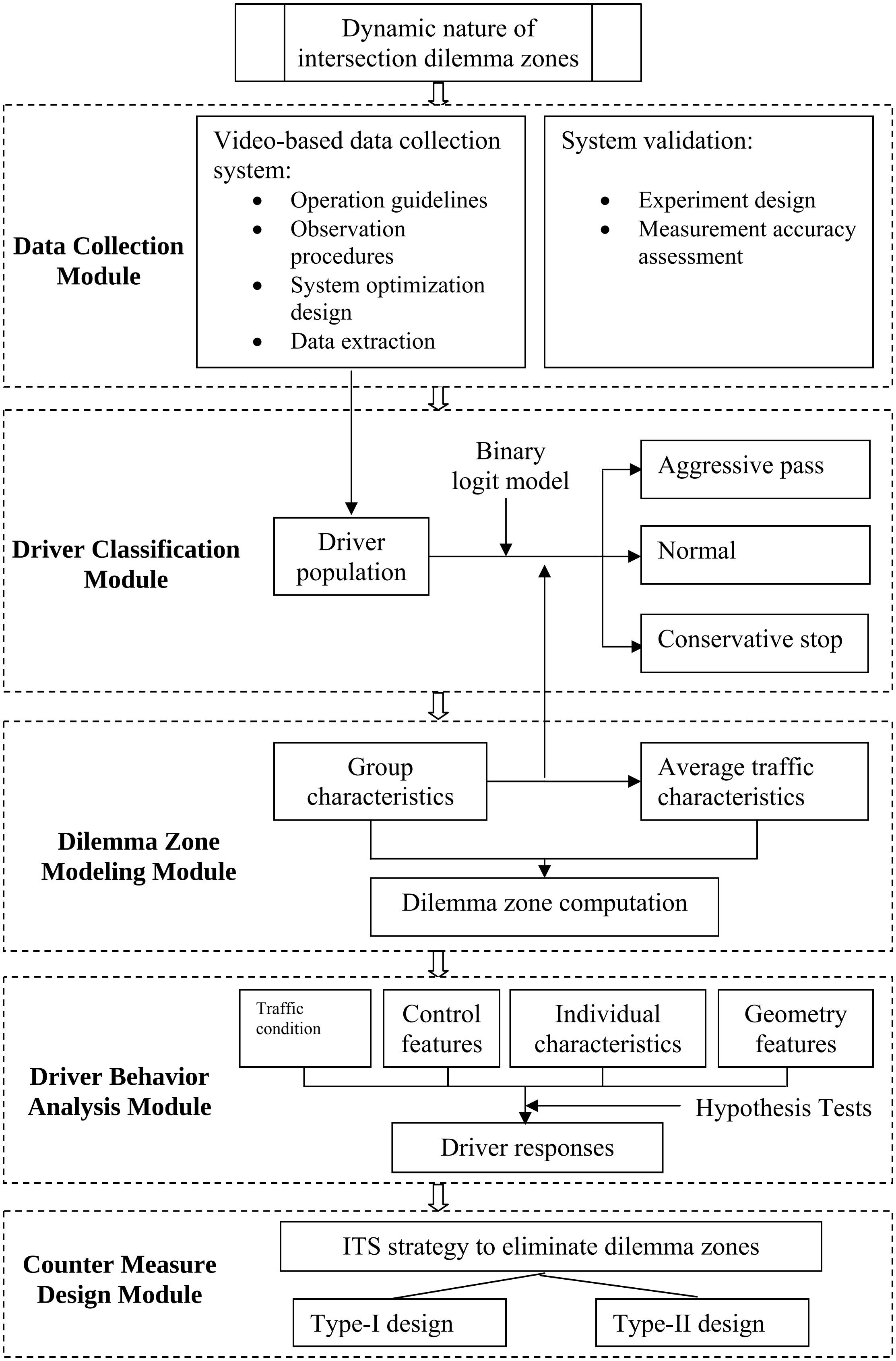
Based on more and higher quality samples from field observations, the last main task was to further investigate behavioral patterns revealed in the Phase I study. Hence, the study has employed similar procedures as used in Phase I for identifying all critical factors that may impact the response of a driver during the yellow phase under different traffic and environmental conditions. A better understanding of those vital factors and their collective influences on the behavior of driving populations will certainly offer informative data for design of safety improvement strategies.

Recognizing the difficulties in uncovering all complex interrelations between driver behavior and all related factors at signalized intersections, this study further explored potential ITS strategies that can best use research findings from our valuable field and analysis results. Both proposed ITS-safety systems are technically feasible for deployment at a reasonable cost.

2.4 CONCLUSIONS

The core of this chapter revealed the dynamic nature of intersection dilemma zones and outlined all Phase II key research tasks and issues. The following chapters will address, in detail, the limitations and implementations of all systems and models developed in this study, along with recommendations for their field implementation and potential applications.

Figure 2-5 Overall research flowchart



Chapter 3 – Data collection system and implementation procedures

3.1 INTRODUCTION

As is well recognized, the response of drivers during a yellow phase may vary with a variety of factors, including the speed evolution of approaching vehicles, intersection traffic conditions, signal control features, and driver characteristics. Collecting this data with a reliable and cost-effective system is thus essential for understanding the complex interactions between driver decisions and the conditions they encounter at signalized intersections.

For such needs, this study has developed a rigorous data collection system that includes a specially designed video-based module and statistical module. Figure 3-1 illustrates the flowchart of the proposed system for field data collection, validation, and analysis. This chapter will offer a detailed description of all principal modules and their interrelations in the remaining sections. The next section, 3 .2, presents the video-based data collection module, including the system components and implementation procedures for both field operations and data extraction. Section 3.3 discusses optimizing system design to minimize possible measurement errors with respect to the target applications. The results of the system validation, using an advanced test vehicle, are given in Section 3.4. The format of the field observation data and guidelines for the sample intersection selection will be presented in Section 3.5 and 3.6, respectively. Concluding comments and findings are summarized in the last section.

3.2 THE VIDEO-BASED DATA COLLECTION MODULE

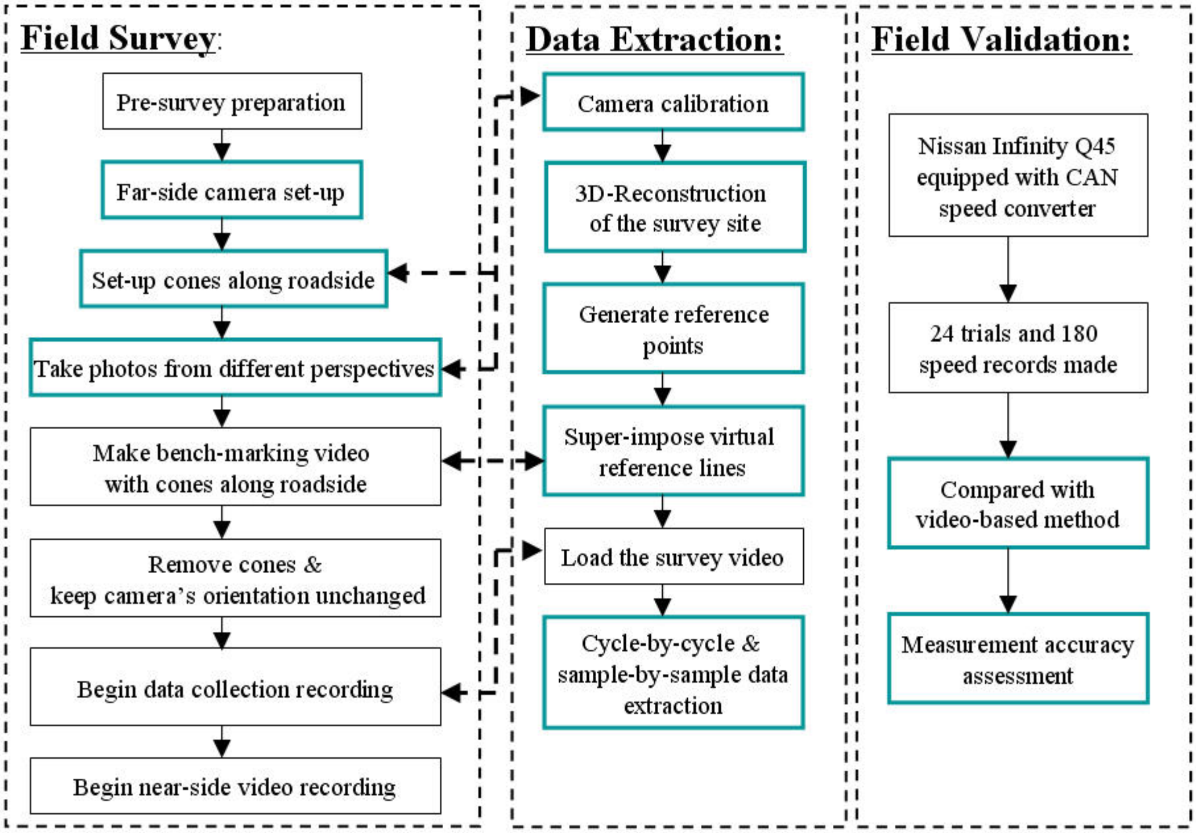
System Components

As shown in Figure 3-2, the entire system for data collection includes the following components:

- *Two DVD video cameras located at known distances from the intersection with 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 spatial evolution of each approaching vehicle trapped in a yellow phase, while the other was placed near the stop line and was used to collect 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;*
- *Several rewritable DVD video disks to facilitate computer operations and to save video tape conversion time;*
- *An adjustable tripod, to allow a flexible camera orientation setup;*

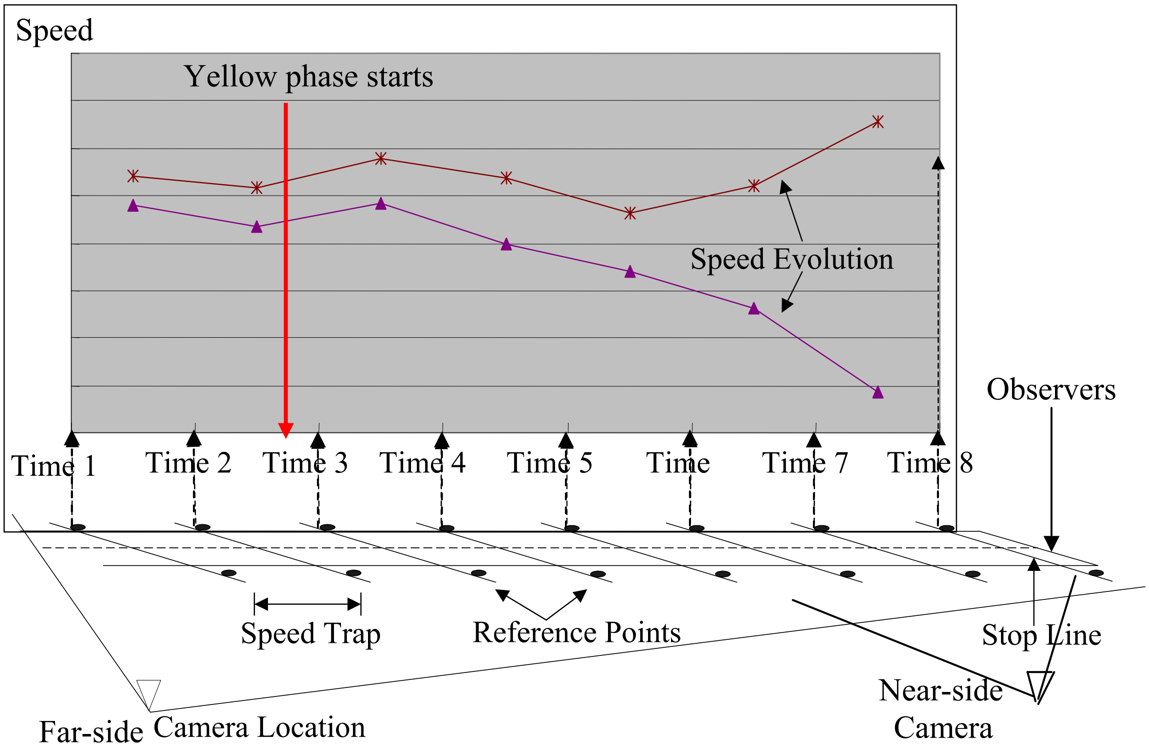
Figure 3-1 Flowchart of the data collection system



- *Orange cones, placed at identical intervals along the roadway as reference points for camera calibration and video benchmarking, to obtain the vehicle speed evolution profile;*
- *A frame-by frame video editing computer program, which must be able to:*
  - Read the video file directly from the video disk without any converting or capturing job;
  - Superimpose reference lines onto the video image;
  - Slice the video footage into a small set of segments (up to a frame) to facilitate future analysis;

    - Record the necessary timestamps;
    - Synchronize the far-side and near-side videos so as to match the speed evolution profile of each target vehicle with its corresponding traffic condition factors, intersection geometry factors, control features, vehicle performances, and individual driver-related characteristics.
- *An Infiniti Q45 instrumented with a CAN message converter to provide the true speeds for system validation.*

Figure 3-2 The video-based data collection module – design and components



Field Survey Procedures

To collect field video data at the target level of quality, this study has developed the following systematic procedures for field surveys:

- *Step 1: Make pre-survey preparations, including:*
    - Recharging the camera and formatting video disks;
    - Measuring the average speed of vehicles at the survey location for system placement and operations.

- *Step 2: Determine the far-side camera location and set it up according to the following criteria (see Figure 3-3):*
    - The entire survey segment can be captured for as long as necessary;
    - The signal phase changes can be captured;
    - The front wheel of vehicles can be identified as the detection point;
    - All orange cones can be observed clearly in the video image.

Figure 3-3 Far-side camera setup

Signal change identifiable

Front wheel identifiable

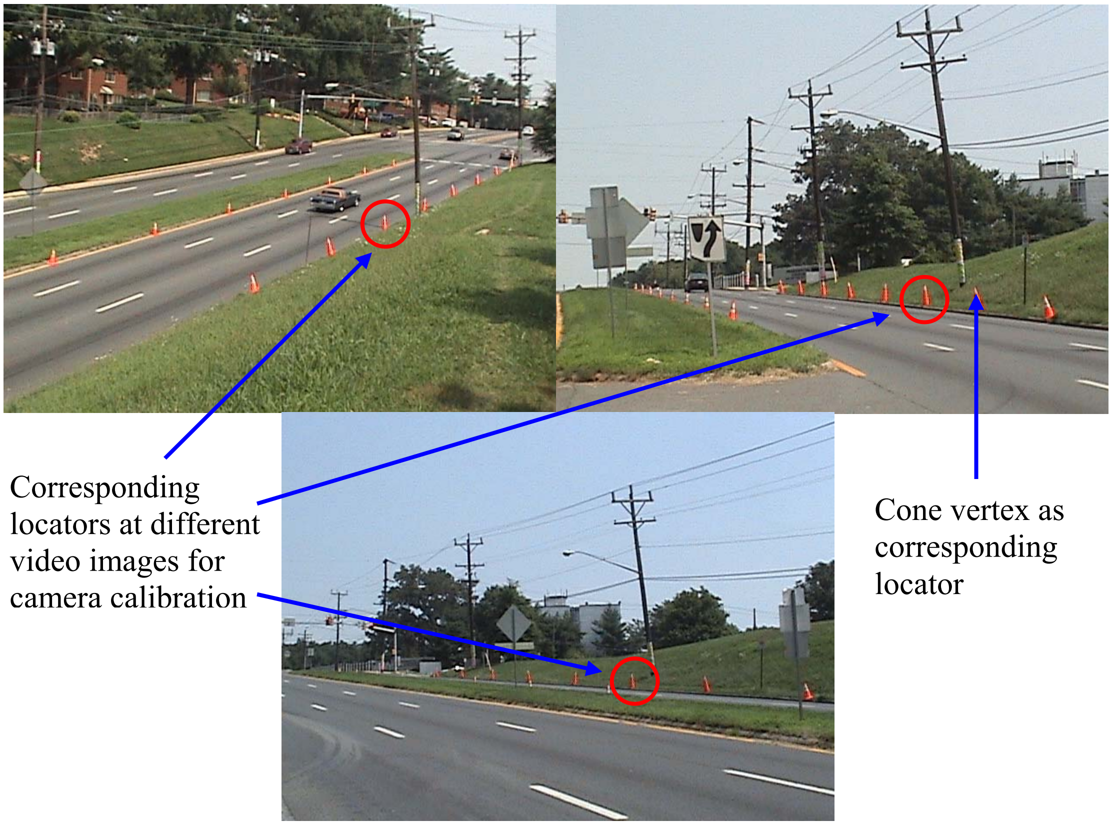
All cones observable in the target survey segment

- *Step 3: Set the video camera at* $K = 30$ *frames per second, and use high-quality mode to ensure that the time when a vehicle's front wheel breaks the reference lines can be clearly identified.*
- *Step 4: Set up the orange cones along both sides of the target survey segment at identical intervals (referring to the speed trap length discussed in Section 3.4); these cones' locations will then be used as reference points for camera calibration (see Figure 3-4).*
- *Step 5: Take three digital photos of the survey segment from different perspectives showing the placement of the cones for later camera calibration (see Figure 3-4).*

- *Step 6: Start the far-side video camera and record for 30 seconds with all orange cones remaining at the survey segment, to use as a benchmarking video (see Figure 3-5).*

Figure 3-4 Camera calibration and generation of virtual reference points

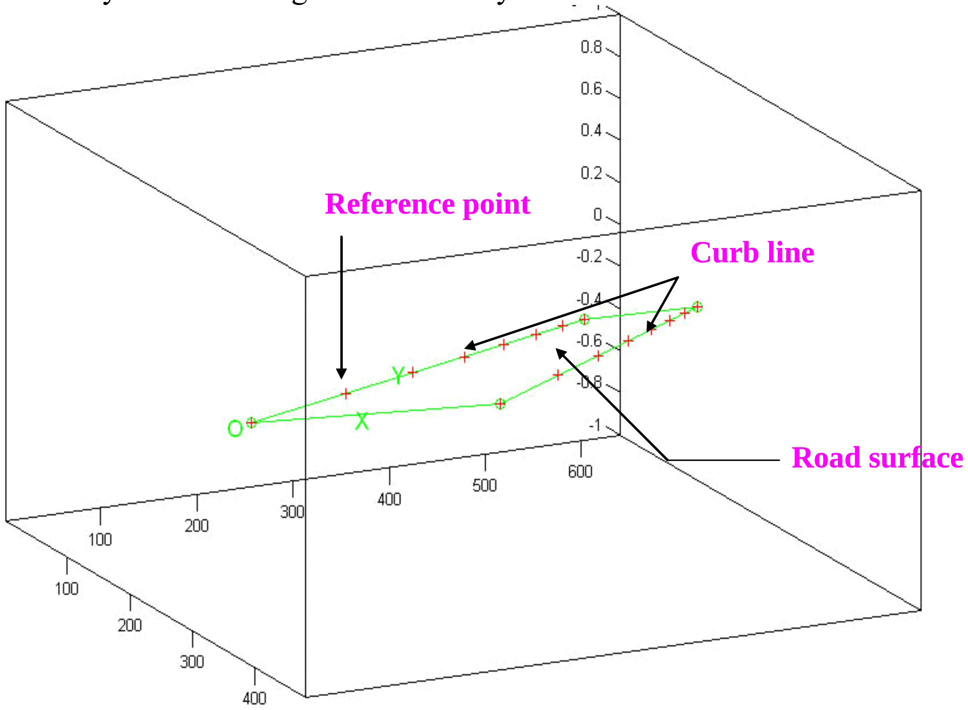
(a) Sampling images and camera calibration


Corresponding locators at different video images for camera calibration

Cone vertex as corresponding locator

(b) Generating virtual reference points

(c) Coordinate system modeling and 3-D survey site reconstruction



- *Step 7: Keeping the position and orientation of the camera unchanged to make sure that the data collection video can be used without any offsetting or shifting from the benchmarking video, remove all the orange cones to avoid influencing the behavior of drivers (see Figure 3-6).*
- *Step 8: Perform the data collection video recording using both far-side and near-side cameras, changing disks when necessary.*
- *Step 9: Finish recording, and save all information onto a DVD disk for future data extraction.*

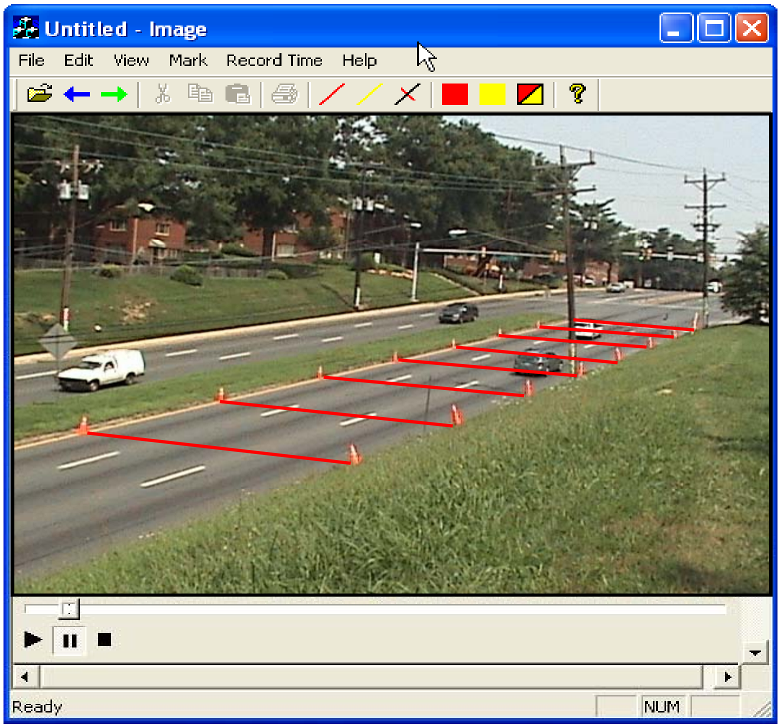
Data Extraction Procedures

Given the field-recorded videos, this study has developed the following procedures for extracting speed evolution data and other critical information:

- *Step 1: Perform camera calibration and image measuring using the three digital pictures taken prior to the field survey (Step 5, above), and generate virtual points where cones could not be used as reference points due to impedance. (Note that the difference between the virtual and real reference points is illustrated in Figure*

3-4, and it can be observed that the virtual reference points generated by camera calibration are very close to the real points marked by cones).

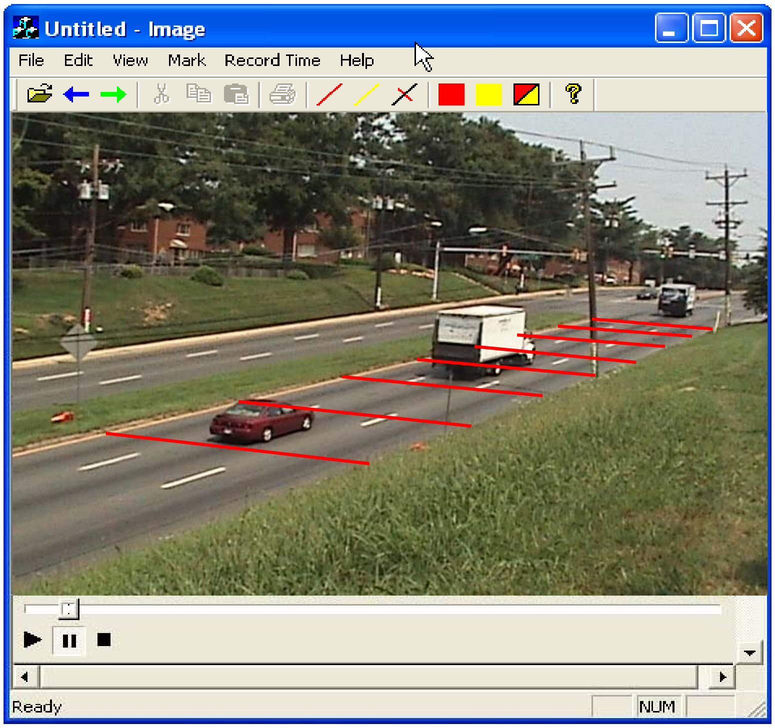
Figure 3-5 Benchmarking with cones or reference points



- *Step 2: Load the benchmarking video first into the video-editing computer program, and then superimpose the reference lines of each speed trap over the video image, based on the location of orange cones or virtual points.*
- *Step 3: Saving the location of reference lines and keeping them superimposed over the video image, unload the benchmarking video.*
- *Step 4: Load the survey video, keeping the reference lines at the same locations on the video image (see Figure 3-6).*
- *Step 5: For each cycle, record the yellow phase starting and ending times separately, and identify all the "pass" vehicles trapped in the yellow phase.*
- *Step 6: For each vehicle, record the time when it travels over each speed trap.*
- *Step 7: Calculate each vehicle's speed evolution from the elapsed time and the distance traveled.*

- *Step 8: Obtain the average traffic flow characteristics cycle-by-cycle using the specially designed tool shown in Figure 3-7;*
- *Step 9: Process the near-side video and survey forms, which are synchronized with the far-side video for sample identification purpose, and obtain each sample's corresponding intersection geometry, control, vehicle performance, and individual driver-related information (see Figure 3-8);*
- *Step 10: Match each vehicle's speed evolution profile with its corresponding traffic condition, intersection geometry, control, vehicle performance, and individual driver-related parameters to obtain one complete sample record.*

Figure 3-6 Data collection without cones to avoid influencing driver's behavior

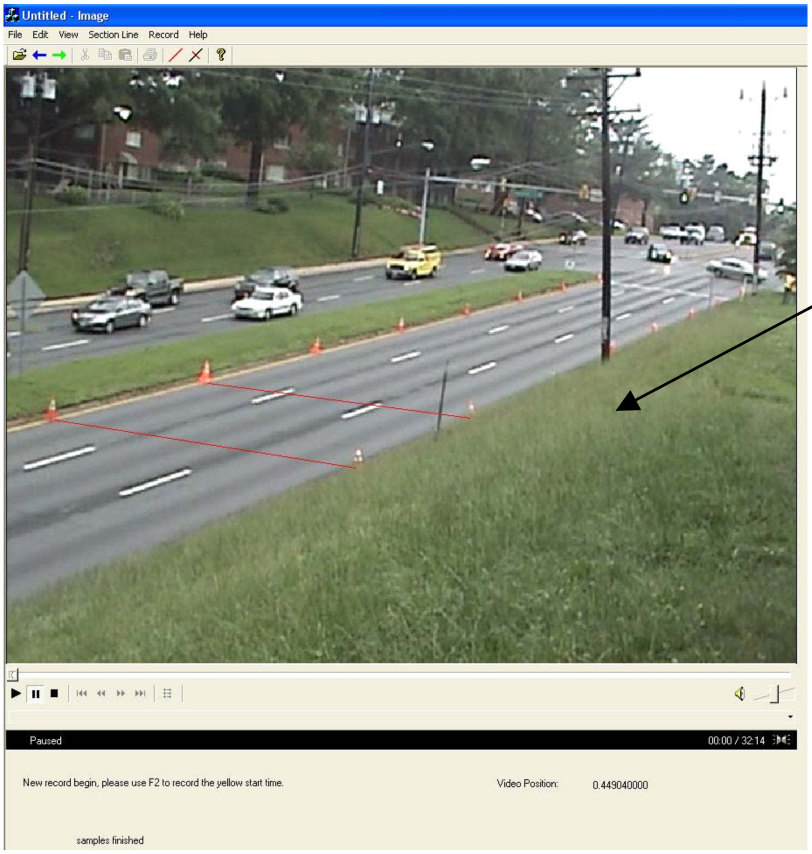


Camera Calibration and Virtual Reference Point Generation

The purpose of this task is to extract the spatial information of the target survey segment and to generate virtual points on the video image where cones could not be used as reference points. The study has developed the following procedures (see Figure 3-4):

- *Step 1: Sample images from different camera orientations during the field survey procedures.*
- *Step 2: Mark grid corners on each video image to construct the coordinate system.*
- *Step 3: Mark corresponding locators (same objects in different images – here, the cone's vertex is used as the corresponding locator) for calibration.*
- *Step 4: Calibrate camera parameters and model the coordinate system.*
- *Step 5: Use the calibrated information for virtual point extraction on the image.*
- *Step 6: Superimpose the extracted points over the video image to replace the cones as reference points for speed measurements.*

Figure 3-7 Traffic flow characteristics extraction



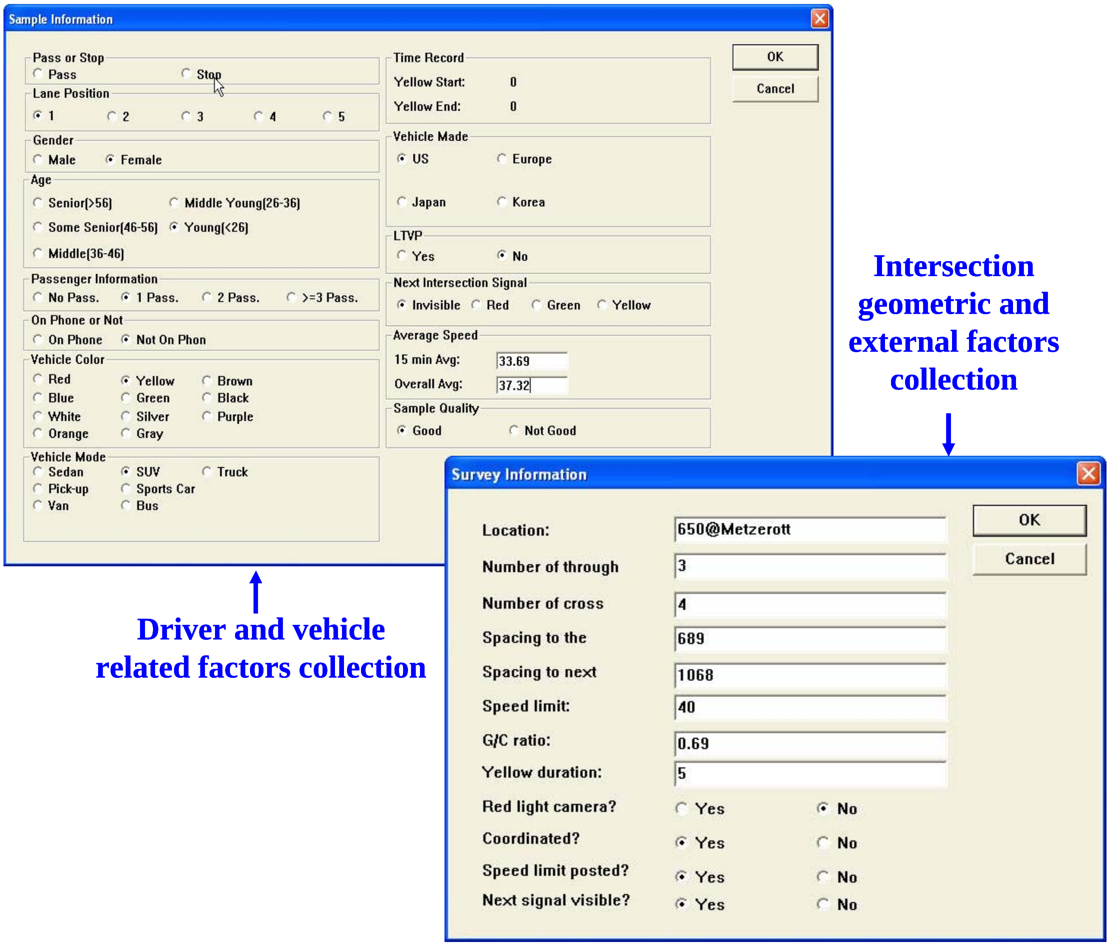
New record begin, please use F2 to record the yellow start time.

Video Position: 0.449040000

samples finished

Average speed & volume measure tool

Figure 3-8 Near-side video data extraction



Sample Information

Pass or Stop: ○ Pass ○ Stop

Lane Position: ● 1 ○ 2 ○ 3 ○ 4 ○ 5

Gender: ○ Male ● Female

Age: ○ Senior(>56) ○ Middle Young(26-36) ○ Some Senior(46-56) ● Young(<26) ○ Middle(36-46)

Passenger Information: ○ No Pass. ● 1 Pass. ○ 2 Pass. ○ >=3 Pass.

On Phone or Not: ○ On Phone ● Not On Phon

Vehicle Color: ○ Red ● Yellow ○ Brown ○ Blue ○ Green ○ Black ○ White ○ Silver ○ Purple ○ Orange ○ Gray

Vehicle Mode: ○ Sedan ● SUV ○ Truck ○ Pick-up ○ Sports Car ○ Van ○ Bus

Time Record

Yellow Start: 0

Yellow End: 0

Vehicle Made: ● US ○ Europe ○ Japan ○ Korea

LTVP: ○ Yes ● No

Next Intersection Signal: ● Invisible ○ Red ○ Green ○ Yellow

Average Speed

15 min Avg: 33.69

Overall Avg: 37.32

Sample Quality: ● Good ○ Not Good

Survey Information

Location: 650@Metzerott

Number of through: 3

Number of cross: 4

Spacing to the: 689

Spacing to next: 1068

Speed limit: 40

G/C ratio: 0.69

Yellow duration: 5

Red light camera? ○ Yes ● No

Coordinated? ● Yes ○ No

Speed limit posted? ● Yes ○ No

Next signal visible? ● Yes ○ No

Driver and vehicle related factors collection

Intersection geometric and external factors collection

Traffic Flow Characteristics Extraction

The purpose of this task is to extract the average traffic flow characteristics of the target survey segment on a cycle-by-cycle basis. This study has developed the following procedures (see Figure 3-7):

- *Step 1: Mark each cycle with the yellow start and end times;*
- *Step 2: Set the speed trap at the upstream segment of the target approach;*
- *Step 3: For each cycle, measure the speeds of all vehicles passing the speed trap after the queue is cleared and get their average;*
- *Step 4: Count the volume in each cycle and convert it into lane-based flow rate;*

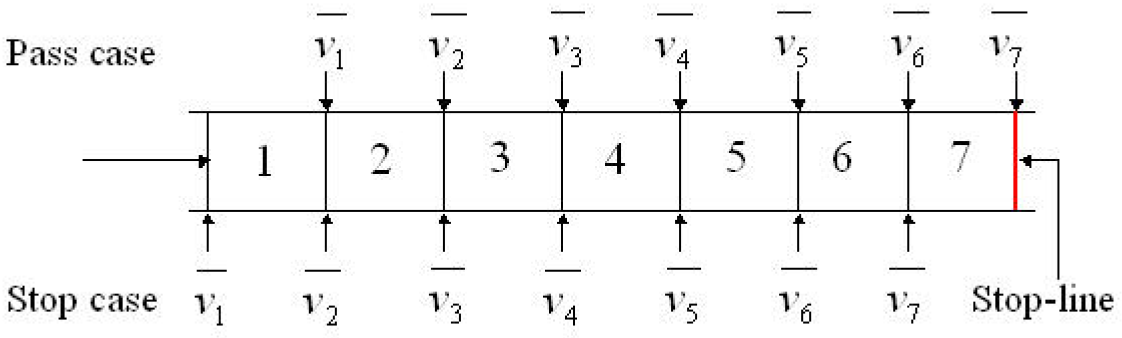
3.3. OPTIMIZING SYSTEM DESIGN

Note that since the proposed system offers an indirect measurement of vehicle speeds from a sequence of images, it is critical that all factors contributing to measurement errors be known and minimized in advance during the pre-survey preparation. This section will present the analysis of measurement errors with respect to the target applications.

Measurement Accuracy Analysis

First of all, to calculate acceleration/deceleration rates, the average speed data obtained from the video-based method need to be converted to spot speeds. Since the average speed over each trap length is approximated as the spot speed at the reference line, there inevitably exists some difference from the actual spot speed, and such differences vary significantly between "pass" and "stop" vehicles (see Figure 3-9). If the trap length is sufficiently small and the vehicle keeps constant speed within the trap, the average speed will be equal to its spot speed, and there will be no error associated with the above conversion. So the length of the speed trap should be set as short as possible to reduce the conversion errors. On the other hand, the length of the trap should be maximized to reduce the time-elapse errors caused by a video camera. Hence, there exists a trade-off between conversion errors and time-elapse errors in setting the speed trap length.

Figure 3-9 Difference between "pass" and "stop" cases in speed conversion



1…7 are the speed traps along the target survey segment, and $\overline{v_1} \ldots \overline{v_7}$ are the respective average speeds over those speed traps.

Note that vehicles traveling within the trap may execute different acceleration or deceleration rates. In this study, we use the worst scenario to assess the maximal possible measurement errors.

For the speed conversion errors, the worst scenario occurs when a vehicle keeps accelerating or decelerating within a trap using the maximum acceleration rate ($16.0 ft/\sec^2$) or deceleration rate ($-11.2 ft/\sec^2$) (Gazis, D. et al., 1960). For the time-elapse error, the worst scenario occurs if one frame of time is missing or overcounting from the calculation of travel time between two reference lines.

The maximal possible error estimation models are approximated with the following equations:

$$\varepsilon_{\max}^{c} = \frac{\left| v_{act} - \sqrt{v_{act}^{2} - \frac{2aD}{(1.47)^{2}}} \right|}{2} \tag{3-1}$$

$$\varepsilon_{\max}^{t} = \frac{v_{act}^{2}}{K(v_{act} - \sqrt{v_{act}^{2} - \frac{2aD}{(1.47)^{2}}}) + v_{act}} \tag{3-2}$$

where:

$\varepsilon_{\max}^{c}$ = maximal speed conversion error (mph);

$\varepsilon_{\max}^{t}$ = maximal time-elapse error (mph);

v_{act} = actual speed of a vehicle at the reference line (mph);

K = number of frames per second;

D = length of the speed trap (ft); and

a = maximal acceleration/deceleration rate within the speed trap ($ft/\sec^2$).

The above estimation model is somewhat conservative, as vehicles don't often use the maximal acceleration/deceleration rate within a speed trap, and the missing or overcounted time from the calculation of travel time is always a fraction of one frame. The error estimation equations show that $\varepsilon_{\max}^{c}$ increases with the length of a speed trap, and

$\varepsilon^{t}_{\max}$ decreases with an increase in the speed trap length. Table 3-1 indicates how the maximal speed conversion error and maximal time-elapse error vary with vehicle speeds and the length of a speed trap.

Selection of the Speed Trap Length

Although it is difficult to compute a theoretically optimized value, this study has taken into account both types of errors and their trade-off in setting the speed trap length. It can be easily seen that an effective speed trap length will lie at the point where $\varepsilon^{c}_{\max} = \varepsilon^{t}_{\max}$, so as to minimize and balance both types of errors. Table 3-2 summarizes the speed trap lengths computed by the above equation and the measurement errors at different speed levels. For each survey location, the average speed of the survey segment is used to decide which speed trap length should be used, and the selected speed trap length will then be applied in the benchmarking and speed data collection.

Table 3-1 Maximal Absolute Speed Measurement Errors

(a) Speed conversion errors

Speed[1]	Length of the Speed Trap (ft)												
(mph)	10	15	20	25	30	35	40	45	50	55	60	65	70
10	2.89	3.99	4.97	5.86	6.69	7.46	8.18	8.87	9.52	10.15	10.75	11.33	11.89
15	2.17	3.08	3.93	4.72	5.45	6.15	6.82	7.45	8.06	8.65	9.21	9.76	10.29
20	1.71	2.48	3.21	3.89	4.55	5.17	5.77	6.35	6.91	7.45	7.98	8.49	8.98
25	1.41	2.06	2.69	3.29	3.87	4.42	4.96	5.49	6.00	6.49	6.98	7.45	7.91
30	1.19	1.76	2.30	2.83	3.65	3.85	4.33	4.81	5.27	5.95	6.71	7.53	8.46
35	1.03	1.53	2.01	2.48	2.94	3.39	3.83	4.26	4.69	5.10	5.51	5.91	6.36
40	0.91	1.35	1.78	2.20	2.62	3.03	3.43	3.82	4.21	4.59	4.96	5.33	5.70
45	0.81	1.21	1.60	1.98	2.36	2.73	3.09	3.45	3.81	4.16	4.51	4.85	5.19
50	0.73	1.09	1.45	1.80	2.14	2.48	2.82	3.15	3.48	3.80	4.12	4.44	4.75
55	0.67	1.00	1.32	1.64	1.96	2.27	2.58	2.89	3.20	3.50	3.80	4.09	4.38
60	0.61	0.92	1.22	1.51	1.81	2.10	2.38	2.67	2.95	3.23	3.51	3.79	4.06

(b) Time-elapse errors

Speed[1]	Length of the Speed Trap (ft)												
(mph)	10	15	20	25	30	35	40	45	50	55	60	65	70
10	0.76	0.61	0.53	0.48	0.44	0.42	0.40	0.38	0.37	0.35	0.35	0.34	0.33
15	1.33	1.01	0.84	0.73	0.66	0.61	0.57	0.53	0.51	0.49	0.47	0.45	0.44
20	2.08	1.53	1.25	1.07	0.94	0.85	0.79	0.73	0.69	0.65	0.62	0.60	0.58
25	3.02	2.19	1.75	1.48	1.30	1.16	1.06	0.98	0.91	0.86	0.81	0.77	0.74
30	4.13	2.98	2.36	1.98	1.72	1.53	1.38	1.27	1.18	1.10	1.04	0.98	0.93
35	5.40	3.89	3.07	2.56	2.21	1.95	1.76	1.61	1.48	1.38	1.29	1.22	1.16
40	6.82	4.91	3.87	3.22	2.77	2.44	2.19	1.99	1.83	1.70	1.59	1.49	1.41
45	8.38	6.05	4.76	3.95	3.39	2.98	2.67	2.42	2.22	2.06	1.92	1.80	1.70
50	10.08	7.29	5.75	4.76	4.08	3.58	3.20	2.90	2.66	2.46	2.29	2.14	2.02
55	11.91	8.64	6.82	5.65	4.84	4.24	3.79	3.43	3.13	2.89	2.69	2.51	2.36
60	13.86	10.09	7.97	6.60	5.66	4.96	4.42	3.99	3.65	3.37	3.13	2.92	2.74

[1] The speed in the table is the v_{act} in Equation (3-1) and (3-2).

Table 3-2 Selected speed trap lengths and measurement errors

Speed[1] (mph)	Selected Speed Trap Length (ft)	Maximal Speed Conversion Error (mph)	Maximal Time-elapse Error (mph)
10	10[2]	2.89	0.76
15	10[2]	2.17	1.33
20	12	1.95	1.95
25	15	2.19	2.19
30	20	2.36	2.36
35	25	2.56	2.56
40	30	2.77	2.77
45	35	2.85	2.85
50	43	2.90	2.90
55	49	3.13	3.13
60	55	3.37	3.37

[1] The speed in the table is the average speed at the target survey segment.

[2] 10 ft was set as the minimum speed trap length for operational convenience.

3.4 SYSTEM VALIDATION

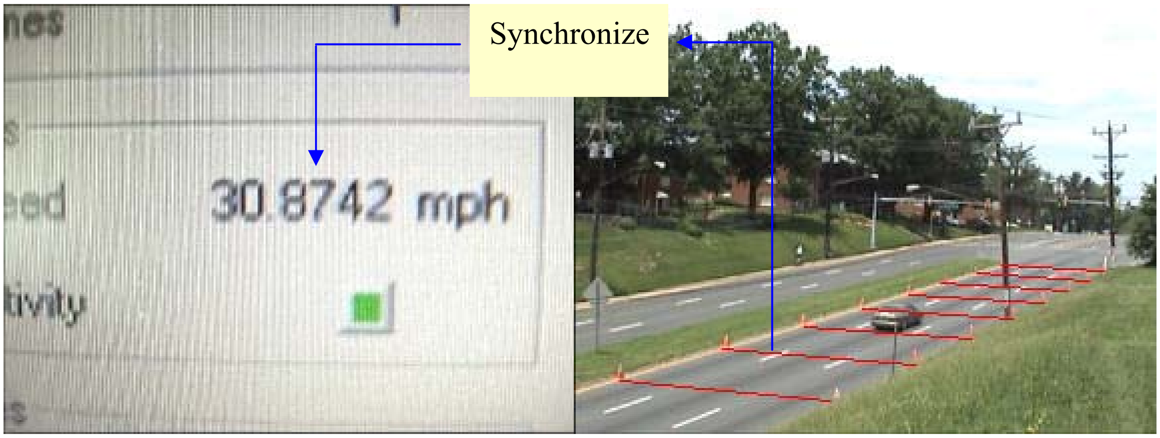
Experimental Design

To evaluate the accuracy of the proposed system for speed measurements, this study conducted a field test at the intersection of MD 650 and Metzerott Road.

An Infiniti Q45 equipped with a CAN message converter was employed in the test to provide the true speeds for comparison. The CAN message converter is a measuring device which can convert the actual speed messages of the vehicle to decimal values. The CAN message converter was calibrated to a precision of ±0.0001 mph and connected to a laptop computer via serial cable to display the speed of the experimental vehicle every 0.01 second (see Figure 3-10).

The experimental site was a three-legged T-intersection with a cycle length of 150 seconds and a yellow phase of 5 seconds. The northbound approach of MD 650 selected as the surveyed segment has three-through lanes, and the outside-most lane allows RTOR. The average speed of the targeted approach was about 40 mph.

Figure 3-10 System validation (video versus the CAN message converter)



In-vehicle speed display from CAN speed converter

Far-side video recording

Based on the analysis of Section 3.4, the speed trap was set at 30 ft to minimize possibly maximal conversion and/or time-elapse errors. The target survey segment of 210 ft was equally divided into seven speed traps by eight traffic cones, as shown in Figure 3-3.

The field validation consisted of 24 trials through the test site with entry speeds at six different mph levels (20-25, 25-30, 30-35, 35-40, 40-45, 45-50) and four trials (two for pass, two for stop) at each speed level. There were a total of 180 speed records (eight records for each “pass” trial and seven records for each “stop” trial) for system validation.

Measurement Accuracy

The speed data from the CAN message converter were deemed “true” for each trial, and the differences between field measured speeds and those from CAN were considered as errors. Speed evolution measurement results under different entry speeds with video recording and the CAN message converter were compared, and coefficients for the linear relationship between video recording and the CAN message converter under “pass” and “stop” trials were also estimated with a least-squares approach (Taylor, M. A. P. et al., 1989).

Data Collection and Extraction

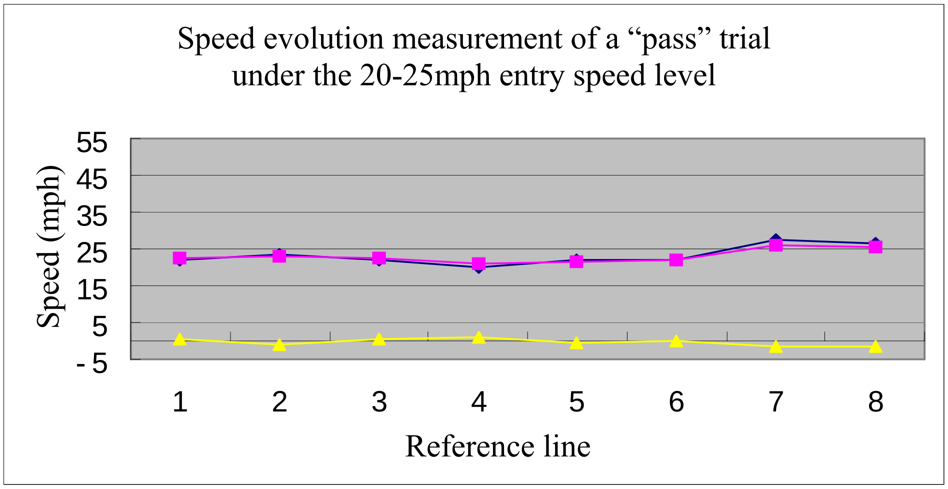
Two video cameras were used for data collection. One was set at the far side to record the movements of the experimental vehicle in the surveyed segment, and the other was installed in the vehicle to record its actual speed, displayed on the screen of the laptop. The synchronization of these two video cameras has yielded consistent results between the accurate speed by CAN and the measured speed illustrated in Figure 3-10.

In performing the experiments, the driver was instructed to begin at the upstream segment of the target intersection, and then adjust the car’s speed to the desired entry speed before entering the target survey segment. Each drive made two “pass” trials and two “stop” trials at each speed level. Each trial was made when there was no queue in the approach lane, so that the entire process of the test vehicle’s speed evolution could be captured. Upon completion of all trials, the videos recorded by the two cameras were processed in a laboratory using the methodology developed in the study, and the speeds for each individual trial were matched between the two cameras using the timestamp information.

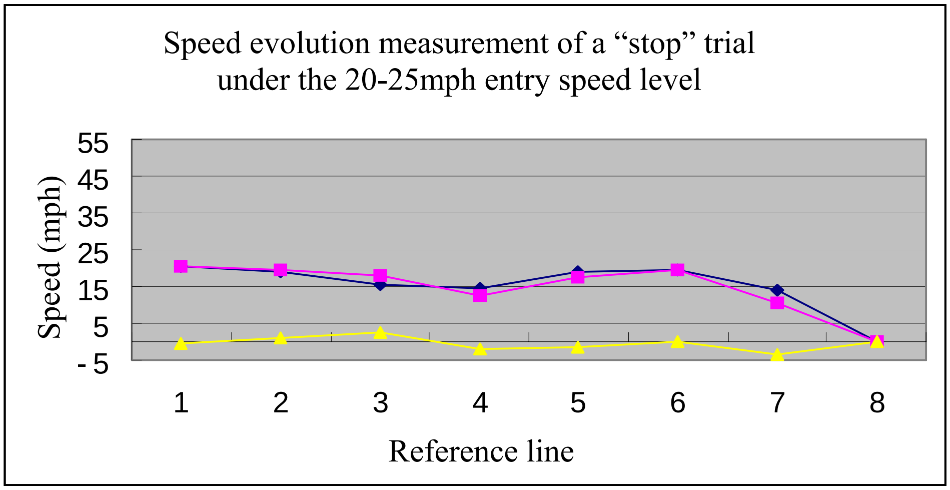
Figure 3-11 displays the speed evolutions from 12 trials, where the speed measurements (shown in purple) were matched to their corresponding accurate speed (shown in black) by using timestamp information.

Figure 3-11 Test results under different entry speeds

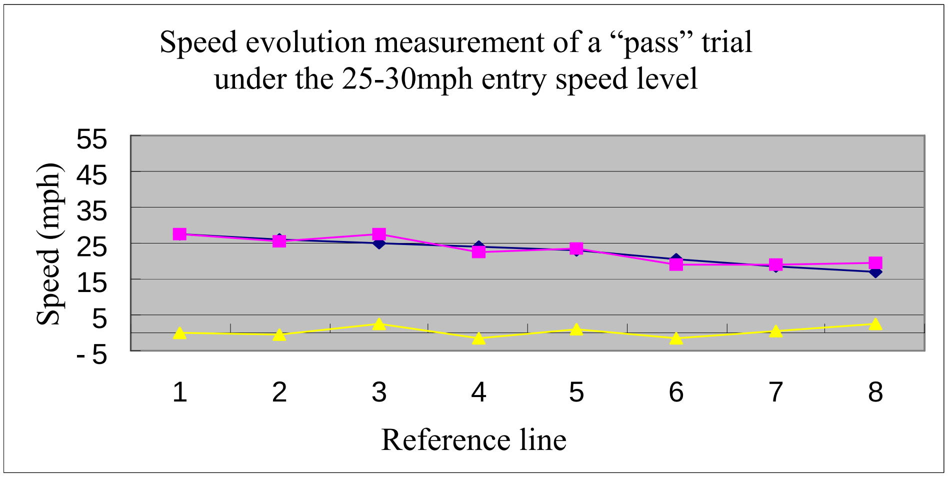
(a) 20-25 mph entry speed level – pass trial



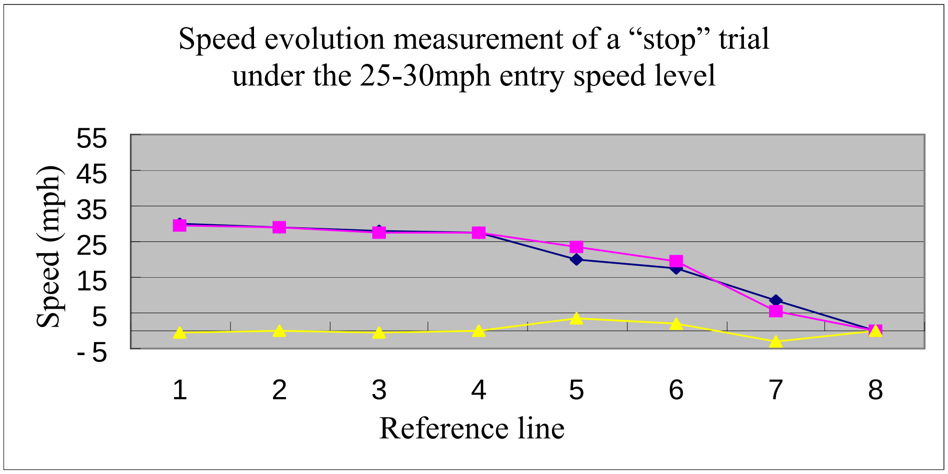
(b) 20-25 mph entry speed level – stop trial



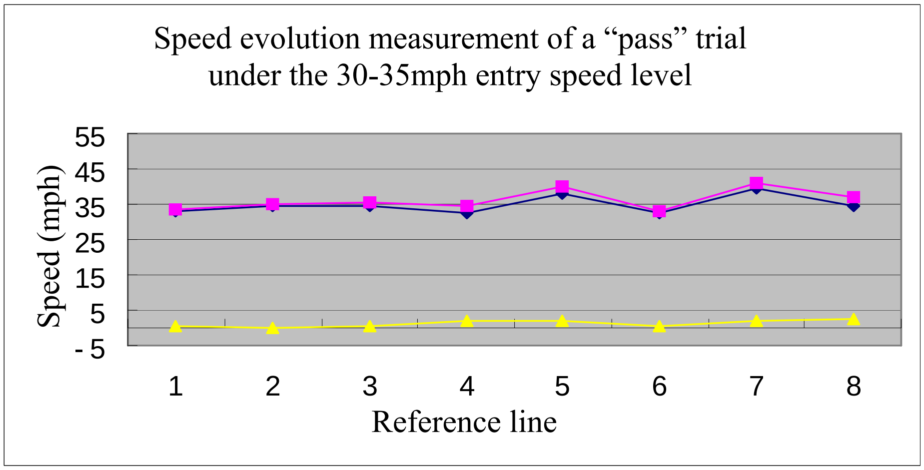
(c) 25-30 mph entry speed level – pass trial



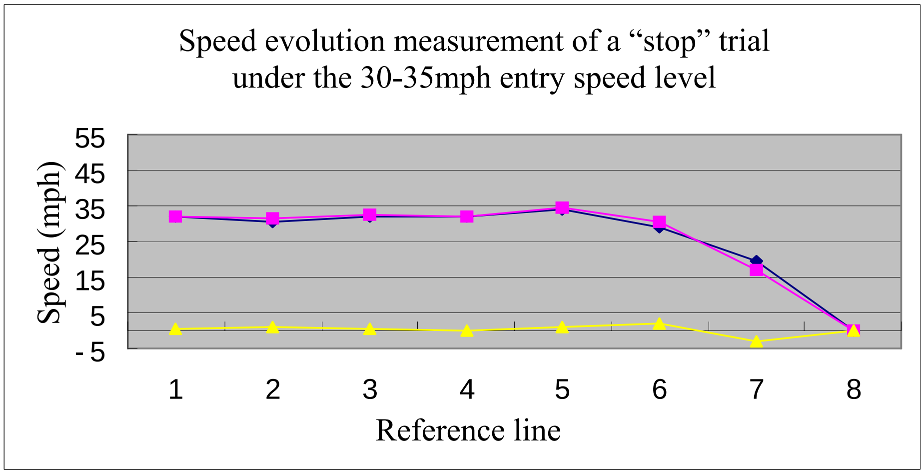
(d) 25-30 mph entry speed level – stop trial



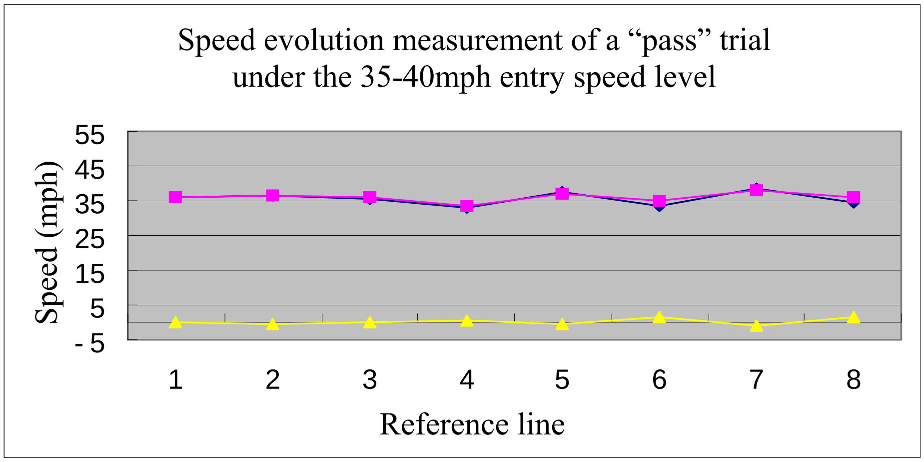
(e) 30-35 mph entry speed level – pass trial



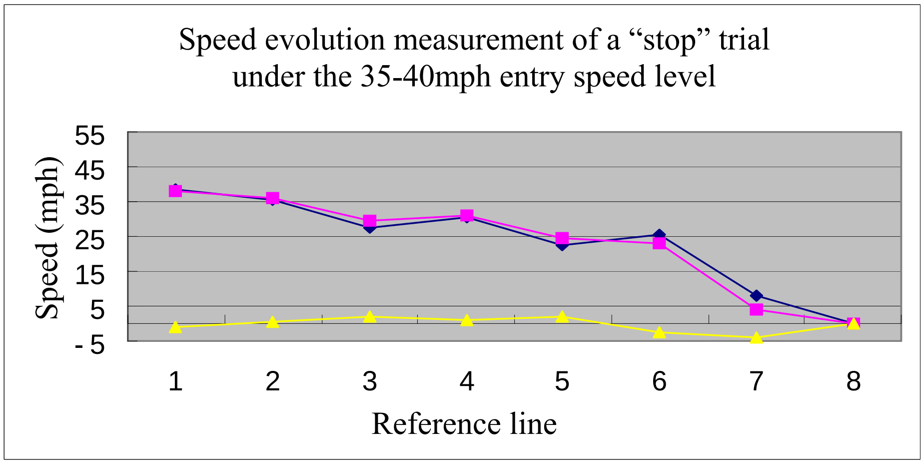
(f) 30-35 mph entry speed level – stop trial



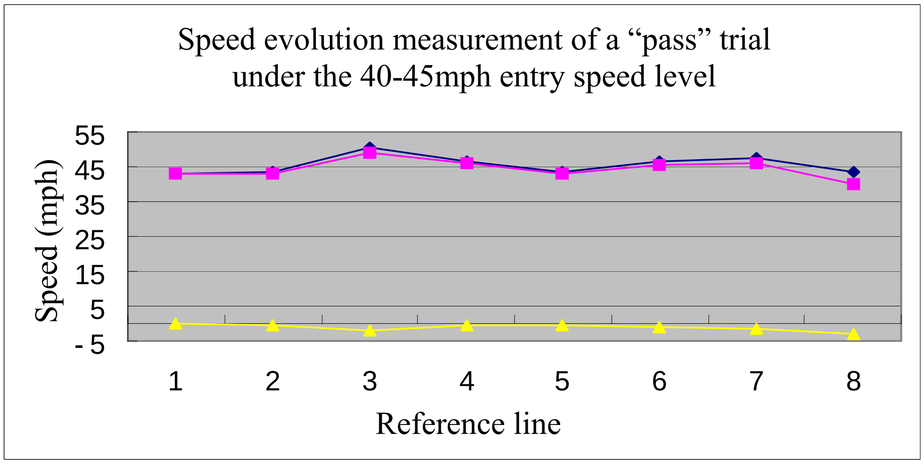
(g) 35-40 mph entry speed level – pass trial

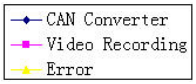


(h) 35-40 mph entry speed level – stop trial

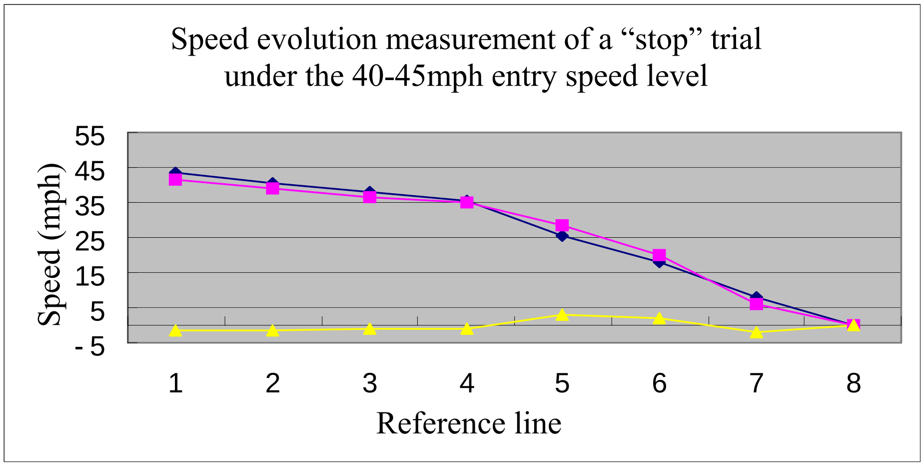


(i) 40-45 mph entry speed level – pass trial

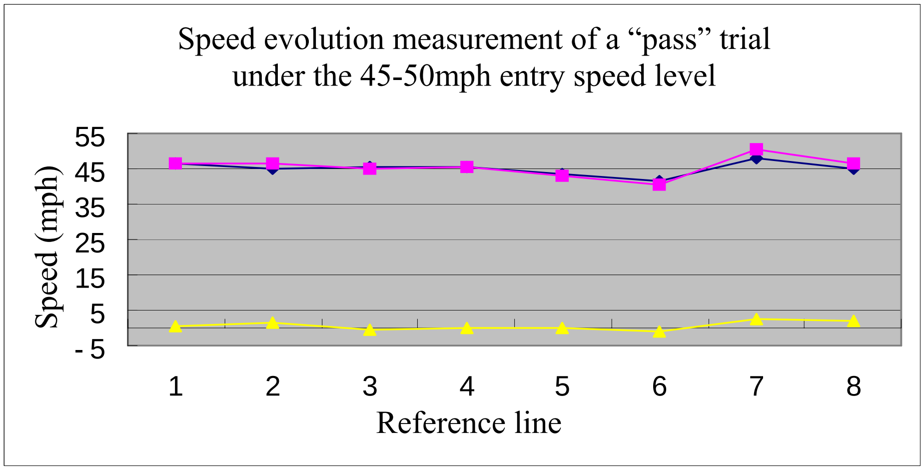




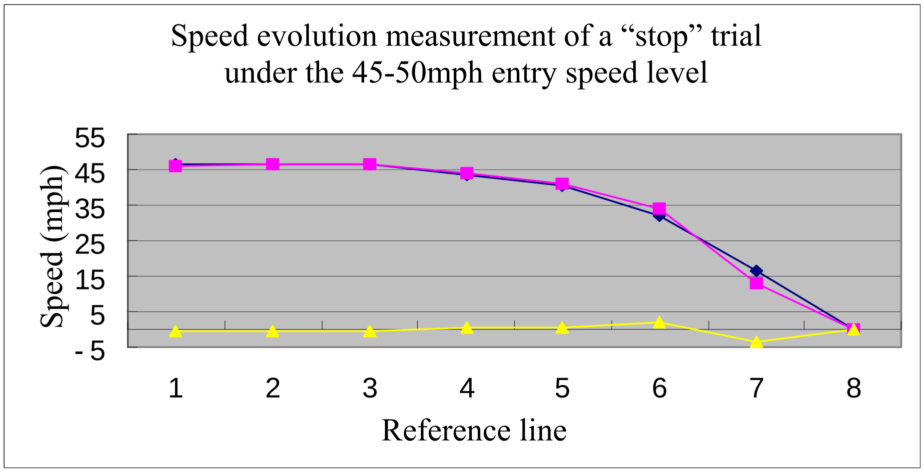
(j) 40-45 mph entry speed level – stop trial



(k) 45-50 mph entry speed level – pass trial



(l) 45-50 mph entry speed level – stop trial



Results

The speed measurement errors were calculated for each experiment and are displayed in Table 3-3. The maximum and minimum absolute values of the errors for the experiments and the maximum theoretical errors given by Equations (3-1) and (3-2) are also listed. It is obvious that the speed measurement errors were less than the maximum theoretical errors, which suggests that the methodology developed in the study is sufficiently reliable for estimating speed evolution.

Table 3-3 Errors of the video-based method under different entry speeds

Entry speed level[1] (mph)		Sample Size[2]	Speed Evolution Range (mph)	Mean Error[3] (mph)	(Min, Max) Error[3] (mph)	Maximal Theoretical Error[4] (mph)
20-25	pass	16	(20-32)	0.99	(0.01,3.59)	4.55 (>3.59)
	stop	14	(0-26)	1.33	(0.04,3.68)	6.69 (>3.68)
25-30	pass	16	(17-30)	1.22	(0.04,2.58)	5.45 (>2.58)
	stop	14	(0-30)	1.57	(0.04,3.99)	6.69 (>3.99)
30-35	pass	16	(32-39)	1.61	(0.17,3.56)	3.65 (>3.56)
	stop	14	(0-34)	1.79	(0.00,3.77)	6.69 (>3.77)
35-40	pass	16	(33-47)	0.75	(0.01,1.95)	4.08 (>1.95)
	stop	14	(0-39)	1.87	(0.27,4.14)	6.69 (>4.14)
40-45	pass	16	(41-50)	0.71	(0.01,3.18)	4.08 (>3.18)
	stop	14	(0-43)	1.62	(0.11,3.86)	6.69 (>3.86)
45-50	pass	16	(42-50)	1.26	(0.09,3.05)	4.08 (>3.05)
	stop	14	(0-48)	1.61	(0.32,3.54)	6.69 (>3.54)
Summary	pass	96	/	1.09	(0.01,3.59)	5.45 (>3.59)
	stop	84	/	1.53	(0.00,4.14)	6.69 (>4.14)

[1] The entry speed is the spot speed when the test vehicle enters the survey segment.

[2] The sample size of the "stop" trials is smaller than "pass" trials because the vehicle speed at the last reference point was 0 mph, which was not included in the calculation.

[3] All errors in the table are absolute errors.

[4] The maximal theoretical errors were the errors in Table 3-1 with the speed trap length of 30 ft.

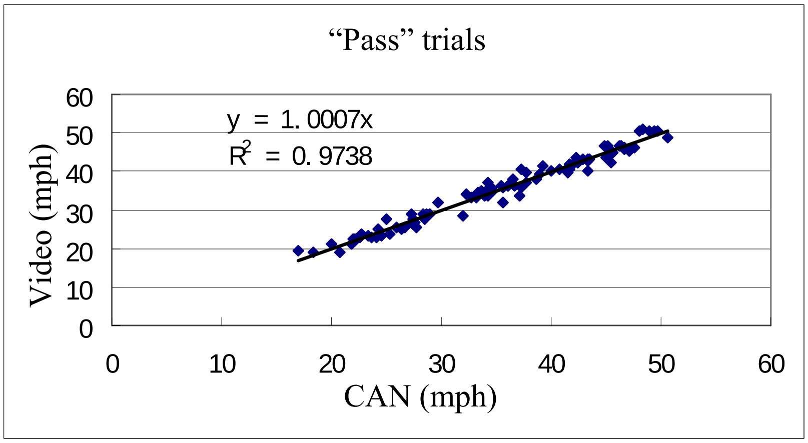
In addition, a high correlation exists between the measured speeds and the actual speeds (by CAN), as shown in Figure 3-12, which indicates that measuring these speeds with the developed video-based method was highly accurate.

In Table 3-3, it is noticeable that across all six levels of entry speed, the experiments with “stop” maneuvers produced larger measurement errors than those with “pass” operations, which suggests that the accuracy level of speed measurements are sensitive to the acceleration/deceleration rate. This is because we set the length of the speed trap to 30 ft on the basis of the 40-45 mph speed level to minimize the potential measurement errors. However, when the vehicle’s speed diverged from that speed level, the measurement errors may increase, and the preset speed trap length may not be the most effective selection. The way to improve accuracy of speed measurements for “stop” maneuvers is to use a best-fit-in-length for speed traps based on speed changes. However, it remains a challenge in practice.

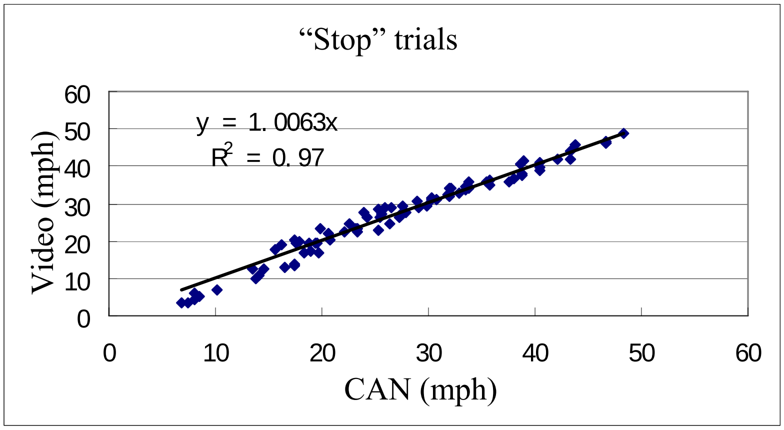
Another noticeable fact can be observed in Figure 3-11: stable speeds produced relatively small conversion errors, which again demonstrated that the accuracy level of speed measurements is sensitive to a vehicle’s speed and acceleration/deceleration rate.

Figure 3-12 Speed measurements by video versus the CAN converter

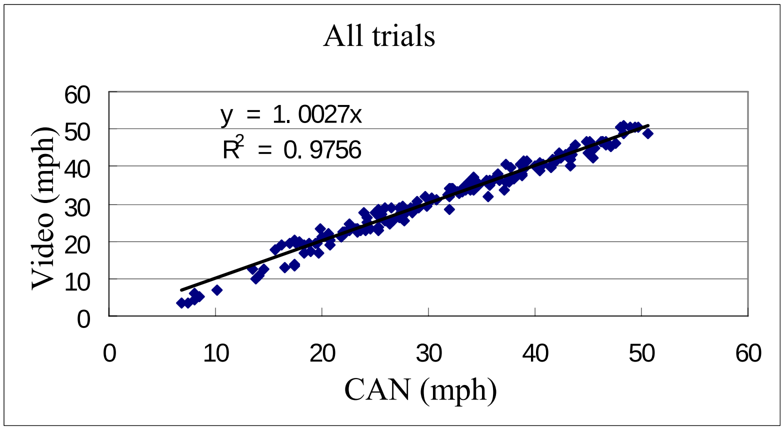
(a) Pass trials



(b) Stop trials



(c) All trials



3.5 FIELD OBSERVATION DATA

The field-observed information from video processing and survey forms can be organized into the following groups:

Intersection related factors:

- *Yellow phase duration*
- *Cycle length*
- *Number of cross/through lanes*
- *Green split of the target approach*
- *Speed limit*
- *Red light camera enforcement*
- *Signal coordination with the next intersection*

- *Visibility of the next intersection's signal*

Traffic characteristics:

- *Cycle-based average speed*
- *Cycle-based lane flow rate*

Driver characteristics:

- *Pass or stop decision*
- *Lane position he/she chooses*
- *Driver's gender*
- *Driver's age: young or middle young (<36), some senior or senior (>46), and middle (>36 and <46) (judging by appearance)*
- *Passenger in vehicle or not*
- *Driver on cell phone or not*

Vehicle characteristics:

- *Vehicle's type (sedan, SUV, pick-up, sports car, van, truck, or bus)*
- *Vehicle's model (US, Japan, Europe, or Korea)*

Vehicle dynamics:

- *Distance-to-stop-line when the yellow phase starts*
- *The approaching speed of the vehicle when the yellow phase starts (initial speed)*
- *Expected-to-stop-line when the yellow phase starts*
- *Speed evolution before and after the yellow phase*
- *Average acceleration/deceleration rates during the yellow phase*
- *Average perception-reaction time of the driving population*

3.6 GUIDELINES FOR SAMPLE INTERSECTION SELECTION

This study has proposed the following guidelines for target intersection selection:

- *Intersections ranked with high accident rate in Maryland;*
- *Intersections convenient for placing field survey equipment;*
- *Intersections with different yellow phase durations, ranging from three to six seconds;*
- *Coordinated intersections and uncoordinated intersections;*
- *Intersections with/without red light camera enforcement;*

- *Intersections with a target approach length of no less than 300 ft and no more than 1000 ft;*
- *Intersections with a cycle length ranging from 90 to 240 seconds;*
- *Intersections with the next adjacent signal visible or invisible;*
- *Intersections with speed limit ranges from 35 mph to 50 mph;*
- *The target approach with the number of cross lanes ranging from two to ten, and the number of through-lanes ranging from one to four;*
- *The target approach with green split ranging from 0.3 to 0.8;*
- *Intersections with recurrent peak-hour congestion, which can provide high probability for capturing more samples in the yellow phase;*
- *Intersections close to a senior citizen community or college to provide high probability for capturing young and senior samples;*
- *Intersections where accident reports show a high concentration of young or senior drivers;*
- *Intersections where accident reports show a high concentration of pick-up, SUV, van or other certain vehicle types;*
- *Intersections providing at least 280 ft for the observation segment length to measure speed evolution.*

With assistance from the Office of Traffic and Safety, six intersections were selected for field data collection under the guidelines and research budget constraints, and a total of 1123 individual driver response observations were made:

- *MD193 at MD201*
- *MD650 at Metzerott Rd.*
- *Randolph Rd. at Glenallan Rd.*
- *MD410 at Belcrest Rd.*
- *MD410 at Adelphi Rd.*
- *MD193 at Mission Dr.*

A summary of information associated with each intersection is shown in Tables 3-4 to 3-9 along with graphic illustrations in Figures 3-13 to 3-18.

Table 3-4 MD193 at MD201

Cycle length	150 seconds
Yellow phase duration	4.5 seconds
Green split	Ranging from 0.387 to 0.491
Speed limit	40 mph
Number of through lanes	4
Number of cross lanes	3
Red light camera enforcement	Yes
Coordination	Yes
Next signal visibility	Yes
Number of observations	292

Figure 3-13 MD193 at MD201

Table 3-5 MD650 at Metzerott Rd.

Cycle length	150 seconds
Yellow phase duration	5 seconds
Green split	0.603
Speed limit	40 mph
Number of through lanes	3
Number of cross lanes	3
Red light camera enforcement	No
Coordination	No
Next signal visibility	No
Number of observations	360

Figure 3-14 MD650 at Metzerott Rd.

Table 3-6 Randolph Rd. at Glenallan Rd.

Cycle length	120 seconds
Yellow phase duration	4 seconds
Green split	Ranging from 0.450 to 0.718
Speed limit	35 mph
Number of through lanes	3
Number of cross lanes	2
Red light camera enforcement	No
Coordination	Yes
Next signal visibility	Yes
Number of observations	77

Figure 3-15 Randolph Rd. at Glenallan Rd.

Table 3-7 MD410 at Belcrest Rd.

Cycle length	150 seconds
Yellow phase duration	4.5 seconds
Green split	0.316
Speed limit	35 mph
Number of through lanes	2
Number of cross lanes	5
Red light camera enforcement	Yes
Coordination	Yes
Next signal visibility	Yes
Number of observations	128

Figure 3-16 MD410 at Belcrest Rd.

Table 3-8 MD410 at Adelphi Rd.

Cycle length	150 seconds
Yellow phase duration	5 seconds
Green split	0.248
Speed limit	35 mph
Number of through lanes	2
Number of cross lanes	5
Red light camera enforcement	Yes
Coordination	No
Next signal visibility	No
Number of observations	150

Figure 3-17 MD410 at Adelphi Rd.

Table 3-9 MD193 at Mission Dr.

Cycle length	150 seconds
Yellow phase duration	5.5 seconds
Green split	0.785
Speed limit	45 mph
Number of through lanes	3
Number of cross lanes	4
Red light camera enforcement	No
Coordination	No
Next signal visibility	No
Number of observations	116

Figure 3-18 MD193 at Mission Dr.

3.7 CONCLUSIONS

Using the specially designed video-based system and field implementation procedures, this study conducted extensive field observations of 1123 drivers' responses to yellow phases at six intersections across the region, including all critical data such as speed evolution during yellow phases, acceleration/deceleration rates, approximate reaction times to encountered yellow phases, driver characteristics and activities, roadway traffic conditions, vehicle characteristics, and intersection geometry features. Measurement accuracy levels produced by the system were evaluated with field data. This chapter has yielded the following conclusions:

- *The system developed in the study is effective in measuring speed evolution profiles and other critical information at a signalized intersection.*
- *Accuracy levels of speed measurements produced by this video-based system are acceptable.*
- *The system introduced in this chapter is a cost-effective tool for analyzing driver behavior at a signalized intersection.*
- *Speed measurements accuracy levels are a function of several factors, such as length of speed trap, acceleration/deceleration rates, vehicle speed within the speed trap, time-elapse rate used and camera setup.*
- *The proposed system can be used in computing the speed, acceleration/ deceleration rates, and response times of different driving populations, which provide all essential information for understanding the spatial distribution of dilemma zone;*
- *The measuring system, implementation procedures, and the guidelines proposed for selecting intersections in this chapter could be further applied in similar intersection safety-related research.*

Chapter 4 – Empirical observation of dynamic dilemma zone distributions

4.1 INTRODUCTION

Along the line of previous research, this chapter will analyze the data obtained from field observations of 1123 drivers at six intersections, and will focus on the following critical subjects:

- *Classify drivers based on their responses to the yellow phase;*
- *Extract key characteristics for different driving groups;*
- *Estimate different dilemma zones for different driver groups at a target intersection;*
- *Demonstrate the discrepancies between theoretical and actual dilemma zone distributions at the six observed intersections;*
- *Show the problem with extending the yellow phase to eliminate dilemma zones at the six observed intersections;*

Driver classification criteria and classification results are discussed in Section 4.2. Section 4.3 extracts key characteristics associated with dilemma zone computation at each target intersection. Empirical results of the dynamic dilemma zone for different driver groups and yellow phase durations are presented in Section 4.4. Concluding comments and future research needs are summarized in the last section.

4.2 CLASSIFYING DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

In classifying driver behavior patterns, the Phase I study developed a mostly qualitative criterion (Xiang, H. et al., 2005), based on the relationship between the cumulative statistics of “pass” and “stop” groups under different time durations to the stop line. That study showed that a duration of four seconds seems to mark a critical point for classifying drivers responses during a yellow phase. Although informative, the method used neglected the variation of critical values among different intersections, and the empirical estimation of the critical value may have also caused misclassification of drivers.

In this study, the distance-to-stop-line when the yellow phase starts was designated as the criterion for driver classification and, similar to the Phase I, all drivers observed at each intersection were classified into the following three groups:

- *Group 1: "Conservative stop" – Drivers who took the stop action even though they could have proceeded through the intersection during the yellow phase (i.e., stopped even though the driver's distance-to-stop-line, x_d, is less than the critical distance, d_c);*
- *Group 2: "Normal" – Drivers who took the stop action when $x_d > d_c$ or the pass action when $x_d < d_c$;*
- *Group 3: "Aggressive pass" – Drivers who aggressively passed the intersection during the yellow phase even though they were quite far away ($x_d > d_c$).*

The critical value, d_c, for driver classification can be estimated through a binary logit procedure (shown below) for each intersection based on observations of each driver's distance-to-stop-line when the yellow starts and his/her corresponding response.

Core Concepts of the Logit Model

The logit model for the binary case can be formulated as follows:

Each driver approaching the yellow phase with a given distance-to-stop-line must judge between the two alternatives: i = accept the distance for the clearing the intersection; and j = 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_{id}, as an additive combination of a deterministic term, V_{id}, and a random term ε_{id}:

$$U_{id} = V_{id} + \varepsilon_{id} \tag{4-1}$$

$$U_{jd} = V_{jd} + \varepsilon_{jd} \tag{4-2}$$

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

$$V_{id} = \alpha + \beta_1 x_{id1} + \beta_2 x_{id2} + \ldots + \beta_K x_{idK} \tag{4-3}$$

$$V_{jd} = \alpha + \beta_1 x_{jd1} + \beta_2 x_{jd2} + \ldots + \beta_K x_{jdK} \tag{4-4}$$

where:

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

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

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

K = number of attributes.

The random component ε_{id} 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 $p_i(t)$ of acceptance of a distance-to-stop-line by a driver to clear the intersection is:

$$p_i(t) = p(U_{id} > U_{jd}) = p(\varepsilon_{jd} - \varepsilon_{id} \le V_{id} - V_{jd}) \qquad (4\text{-}5)$$

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

$$F_{\varepsilon_d}(x) = \frac{1}{1 + e^{-\mu x}} \qquad (4\text{-}6)$$

where μ is a parameter of the distribution. Therefore, Eqs. (4-5) and (4-6) can be written as:

$$p_i(t) = F_{\varepsilon_d}(V_{id} - V_{jd}) = \frac{1}{1 + e^{-\mu(V_{id} - V_{jd})}} \qquad (4\text{-}7)$$

As 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. (4-7) becomes:

$$p_i(t) = \frac{1}{1 + e^{\alpha + \beta x_d}} \qquad (4\text{-}8)$$

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 understand $p_i(t)$ (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:

$$\int_0^{d_c} p_i(t)dt = 0.5 \qquad (4\text{-}9)$$

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

$$L(\alpha,\beta)=\sum_{d=1}^{n}\left[\ln(\frac{1}{1+e^{\alpha+\beta x_d}})+\alpha+\alpha y_d+\beta x_d-\beta y_d x_d\right] \tag{4-10}$$

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 maximum of $L(\alpha,\beta)$ can be determined by forming the derivatives and setting both as zero:

$$\frac{\partial L}{\partial\alpha}=\sum_{d=1}^{n}\left[\ln(\frac{e^{\alpha+\beta x_d}}{1+e^{\alpha+\beta x_d}})+1-y_d\right]=0 \tag{4-11}$$

$$\frac{\partial L}{\partial\beta}=\sum_{d=1}^{n}\left[\ln(\frac{e^{\alpha+\beta x_d}}{1+e^{\alpha+\beta x_d}})+x_d-x_d y_d\right]=0 \tag{4-12}$$

The maximization of $L(\alpha,\beta)$ reveals values for α and β in Eq. (4-8). Since this is the distribution function of a logistic distribution, Eq. (4-9) can be solved for d_c as the mean of this distribution, which is:

$$d_c=\frac{\alpha}{\beta} \tag{4-13}$$

Classification Results

Using Eq. (4-13), the classification results for all six surveyed intersections, as well as the critical distances, are summarized in Table 4-1. It is noticeable that for all surveyed intersections, the driving population is not uniform and can be classified into different groups. The above classifications will be further used as the basis for estimating the dilemma zone for each driving group.

4.3 KEY CHARACTERISTICS OF DRIVING GROUPS

Based on the classification results, this study compared the following key characteristics among driving groups:

- *Approaching speed – the speed of a vehicle when the yellow phase starts;*
- *Average acceleration/deceleration rates after the yellow phase;*
- *Perception-reaction time to the yellow phase.*

As shown in Table 4-2, at all observed intersections, the aggressive-pass group usually executed an approaching speed about 10-20% higher than the average traffic flow speed, while the conservative-stop group averagely exhibited an approaching speed about 10-15% lower than the average traffic flow speed. The speed difference between different groups has been verified with the pair-t test.

We summarize the mean values as well as the standard deviations of the acceleration/deceleration rates during the yellow phase for each driving group in Table 4-3. These empirically observed values, rather than the maximum theoretical values, can reflect the actual acceleration/deceleration maneuvers of vehicles among different driving groups after the yellow phase, and offer the basis for computing the actual dilemma zone distribution

Table 4-1 Driver classification results

(a) Critical distance-to-stop-line

Surveyed Intersections	Yellow Duration (sec)	Cycle Length (sec)	Critical distance d_c (ft)
193 at 201	4.5	150	234.09ft
650 at Metzerott	5	150	205.43ft
Randolph at Glennian	4	120	269.45ft
410 at Belcrest	4.5	150	199.79ft
410 at Adelphi	5	150	176.98ft
193 at Mission	5.5	150	277.50ft

(b) Classification results

Surveyed Intersections	Total Samples	Aggressive Pass	Normal	Conservative Stop
193 at 201	292	13	260	19
650 at Metzerott	360	28	292	40
Randolph at Glennian	77	3	71	3
410 at Belcrest	128	6	115	7
410 at Adelphi	150	10	125	15
193 at Mission	116	9	97	10
Summary	1123	69	960	94

Table 4-2 Speed difference analyses among driving groups

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

* "A-Pass" means aggressive pass group, and "C-Stop" means conservative stop group.

A driver’s perception-reaction time in response to YELLOW is also a critical factor that affects the dilemma zone distribution at signalized intersections. Unfortunately, the perception-reaction time of most drivers is quite short and difficult to observe. The proposed measuring system offers a convenient way to approximate a driver’s response time with his/her speed profile (approximately equal to a theoretical perception-reaction time). Figure 4-1 shows a speed evolution of a stop-maneuvered case in the field validation. A yellow phase started at the timestamp of 1164.01584 seconds. After that, a significant speed reduction (10.43 mph) occurred between the timestamps of 1164.70886 and 1165.21386, as shown in Figure 4-1.

Despite the average speed measurement error of ±1.53 mph for “stop” cases (see Table 3-3), the speed change in this case was still significant in such a short time period. Therefore, this speed reduction was identified as the driver’s response to YELLOW, and the driver’s response time was then estimated to lie between 0.69 and 1.20 seconds. One may use the average to represent the approximate response time of a driving population. The perception-reaction time analysis was made based on the entire sample size, and the mean values as well as the standard deviations are summarized in Table 4-3.

Table 4-3 Field-measured acceleration/deceleration rates and drivers' response times

(a) Field-measured acceleration/deceleration rates

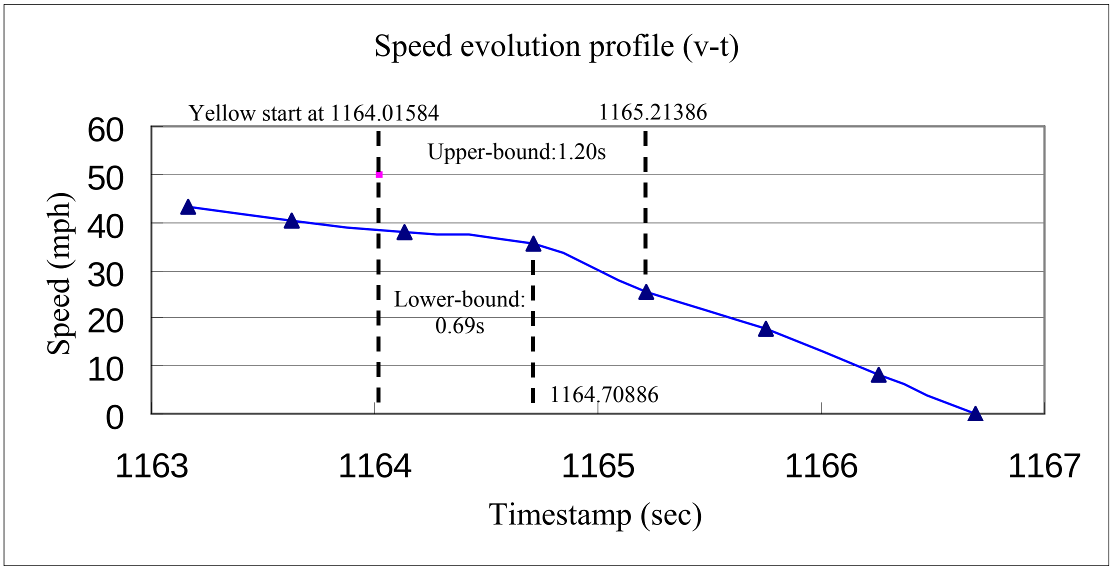
Surveyed Intersections	a/c rates after yellow	A-Pass ($ft/\sec^2$)	Normal ($ft/\sec^2$)	C-Stop ($ft/\sec^2$)
193 at 201	acceleration Mean/Std	0.39/1.63	0.20/1.51	0.20/1.51*
	deceleration Mean/Std	-4.93/1.29*	-4.93/1.29	-6.46/1.67
650 at Metzerott	acceleration Mean/Std	0.80/1.79	1.10/2.23	1.10/2.23*
	deceleration Mean/Std	-5.10/1.20*	-5.10/1.20	-5.20/1.42
Randolph at Glennian	acceleration Mean/Std	0.92/2.05	-0.82/3.25	-0.82/3.25*
	deceleration Mean/Std	-6.94/1.59*	-6.94/1.59	-7.61/1.55
410 at Belcrest	acceleration Mean/Std	2.66/0.99	1.10/2.04	1.10/2.04*
	deceleration Mean/Std	-4.17/1.31*	-4.17/1.31	-4.22/1.94
410 at Adelphi	acceleration Mean/Std	0.69/0.83	-0.28/1.46	-0.28/1.46*
	deceleration Mean/Std	-4.30/1.24*	-4.30/1.24	-5.40/1.43
193 at Mission	acceleration Mean/Std	1.33/2.77	1.00/2.46	1.00/2.46*
	deceleration Mean/Std	-5.87/1.48*	-5.87/1.48	-8.24/1.78

* Uses the same values as the "Normal" group.

(b) Field-measured drivers' response to YELLOW

Driving Group	Applicable Sample Size	Reaction time	
Aggressive Pass	64	Mean	1.86s
		Std.	1.26s
Normal	538	Mean	1.86s
		Std.	0.72s
Conservative Stop	78	Mean	2.32s
		Std.	1.15s

Figure 4-1 Measuring the response of drivers to a yellow phase



4.4 ESTIMATION OF DYNAMIC DILEMMA ZONES

Note that with the above analyses one can effectively obtain the approaching speed, acceleration/deceleration rates, and response time of drivers at a target intersection. These critical data are essential behavioral information for estimating the dilemma zone of each target driving group.

In this study, the dilemma zone distributions for different driving groups are estimated with Eq. (2-1) at each of the six intersections under the following three scenarios:

- *Estimation using the set of parameters with theoretical values (see Table 4-4a) recommended by the ITE handbook (ITE, 1985) and with the actual yellow duration from field observation;*
- *Estimation using the set of parameters measured from field studies (see Table 4-4b) with the proposed video-based system and the actual yellow duration;*
- *Estimation using the set of parameters measured from field studies (see Table 4-4b) with the proposed video-based system and an extended yellow duration.*

In Table 4-4, we summarize those parameter values used for estimating the dilemma zones at all observed intersections, and the results of the dilemma zone distributions are shown in Figure 4-2. Note that, in Figure 4-2(a), no dilemma zones (denoted as the dark bar in the figure) exist at any of the six observed intersections if the existing practice and the theoretical values for all key parameters (e.g., theoretical acceleration/deceleration rates and reaction times of normal drivers) are used in the computation.

In contrast, as Figure 4-2(b) shows, dilemma zones exist at all observed intersections if field-measured parameter values are applied in the computation. For instance, at the intersection of MD193 at MD201, the dilemma zone for the conservative driver group is distributed from 160.63 ft to 229.28 ft to the stop-line with a range of 68.65 ft, while the dilemma zone for the aggressive driver group has a wider and upstream range from 219.42 ft to 423.62 ft to the stop-line with a length of 204.2 ft. Even for the normal group, there exists the dilemma zone actually of 140.66 ft (321.51 ft-180.85 ft). Similarly, at all other five intersections, the dilemma zone actually exists and varies with different driving populations. In general, aggressive drivers tend to encounter a wider dilemma zone with a location near the upstream of the approach than other driver groups, while conservative drivers are more easily trapped in the dilemma zone located at the downstream part of the approach.

This study also evaluated the impact of extended yellow duration on reducing or eliminating dilemma zones at signalized intersections. In this case, we extended the yellow phases at all intersection to six seconds to see the effect on the distribution of dilemma zones. As shown in Figure 4-2(c), although this significantly reduced or eliminated dilemma zones for all driving groups, some driving groups still encountered a dilemma zone even with six-second yellow duration. For example, at the intersection of MD193 at MD201, after extending the yellow phase from the current 4.5 seconds to six seconds, the dilemma zone for the conservative driver group disappears. However, the dilemma zones for the normal and aggressive driver groups still exist, although significantly reduced from 140.66 ft and 204.2 ft to 61.51 ft and 111.37 ft, respectively. The same impact exists at the intersections of Randolph Rd. at Glenallan Rd. and MD193 at Mission Dr. after extending their current yellow durations to six seconds. For the intersections of MD650 at Metzerott Rd., MD410 at Belcrest Rd., and MD410 at Adelphi Rd., extension of the yellow phase did not eliminate dilemma zone distributions for any driver group.

The above analysis of dilemma zones, shown in Figure 4-2, could reflect the following findings:

- *For all six observed intersections, the length and the location of their dilemma zones vary with the speed of the approaching vehicles, driver reaction times, and vehicle acceleration/deceleration rates of different driving populations;*
- *Significant differences exist between theoretically estimated and actual distributed dilemma zones;*
- *Extension of the yellow phase alone may not eliminate all dilemma zones.*

Table 4-4 Parameter values applied in the computation of dilemma zones

(a) Theoretical parameter values by the ITE manual

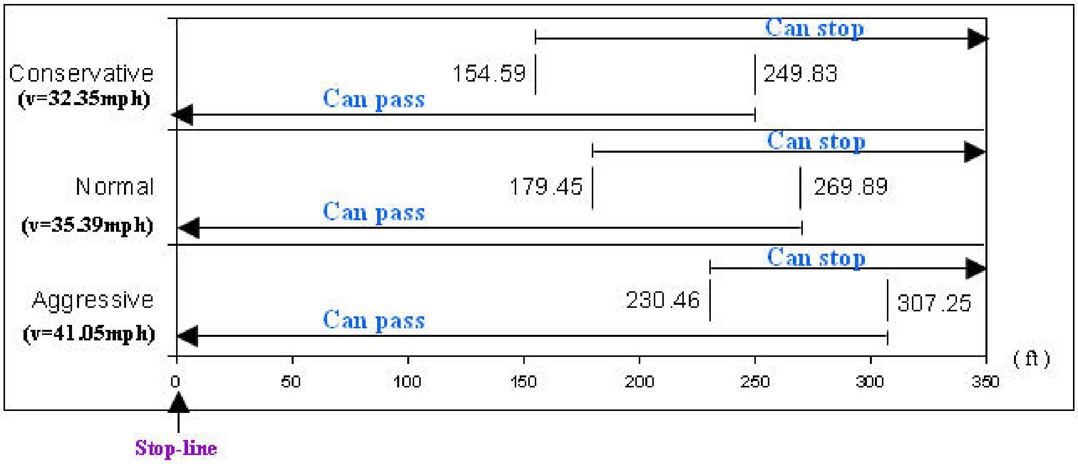
Surveyed Intersections	Group	a_1 (ft/sec^2)	a_2 (ft/sec^2)	v_0 (mph)	τ (sec)	w (ft)	L (ft)	δ_1 (sec)	δ_2 (sec)
193 at 201	A-Pass	16.0	-11.2	41.05	4.5	42	12	1.14	1.14
	Normal	16.0	-11.2	35.39			12	1.14	1.14
	C-Stop	16.0	-11.2	32.35			12	1.14	1.14
650 at Metzerott	A-Pass	16.0	-11.2	38.74	5	40	12	1.14	1.14
	Normal	16.0	-11.2	34.13			12	1.14	1.14
	C-Stop	16.0	-11.2	30.00			12	1.14	1.14
Randolph at Glennian	A-Pass	16.0	-11.2	52.25	4	30	12	1.14	1.14
	Normal	16.0	-11.2	45.91			12	1.14	1.14
	C-Stop	16.0	-11.2	40.81			12	1.14	1.14
410 at Belcrest	A-Pass	16.0	-11.2	38.09	4.5	84	12	1.14	1.14
	Normal	16.0	-11.2	31.19			12	1.14	1.14
	C-Stop	16.0	-11.2	29.55			12	1.14	1.14
410 at Adelphi	A-Pass	16.0	-11.2	38.70	5	87	12	1.14	1.14
	Normal	16.0	-11.2	30.49			12	1.14	1.14
	C-Stop	16.0	-11.2	27.21			12	1.14	1.14
193 at Mission	A-Pass	16.0	-11.2	54.40	5.5	56	12	1.14	1.14
	Normal	16.0	-11.2	44.15			12	1.14	1.14
	C-Stop	16.0	-11.2	41.00			12	1.14	1.14

(b) Field-measured values

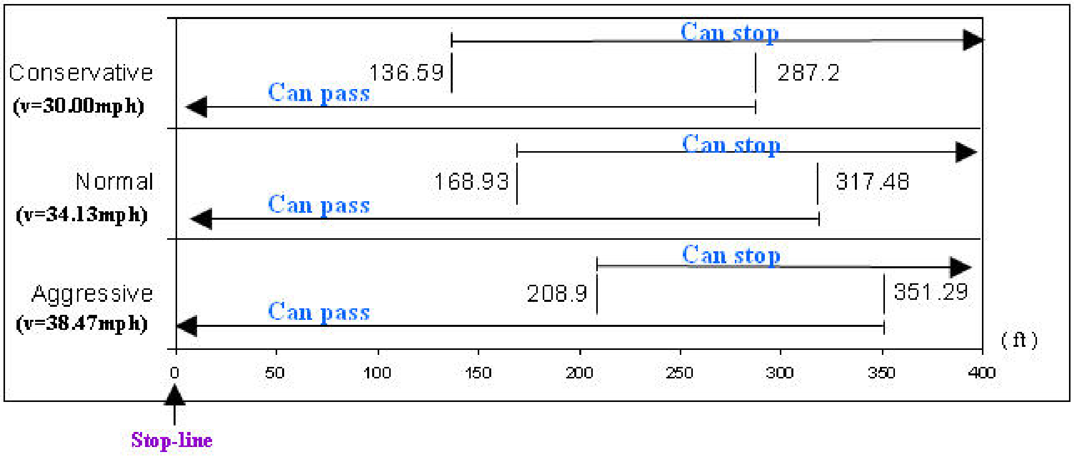
Surveyed Intersections	Group	a_1 (ft/sec^2)	a_2 (ft/sec^2)	v_0 (mph)	τ (sec)	w (ft)	L (ft)	δ_1 (sec)	δ_2 (sec)
193 at 201	A-Pass	0.39	-4.93	41.05	4.5	42	12	0.93	0.93
	Normal	0.20	-4.93	35.39			12	0.93	0.93
	C-Stop	0.20	-6.46	32.35			12	1.16	1.16
650 at Metzerott	A-Pass	0.80	-5.10	38.74	5	40	12	0.93	0.93
	Normal	1.10	-5.10	34.13			12	0.93	0.93
	C-Stop	1.10	-5.20	30.00			12	1.16	1.16
Randolph at Glennian	A-Pass	0.92	-6.94	52.25	4	30	12	0.93	0.93
	Normal	-0.82	-6.94	45.91			12	0.93	0.93
	C-Stop	-0.82	-7.61	40.81			12	1.16	1.16
410 at Belcrest	A-Pass	2.66	-4.17	38.09	4.5	84	12	0.93	0.93
	Normal	1.10	-4.17	31.19			12	0.93	0.93
	C-Stop	1.10	-4.22	29.55			12	1.16	1.16
410 at Adelphi	A-Pass	0.69	-4.30	38.70	5	87	12	0.93	0.93
	Normal	-0.28	-4.30	30.49			12	0.93	0.93
	C-Stop	-0.28	-5.40	27.21			12	1.16	1.16
193 at Mission	A-Pass	1.33	-5.87	54.40	5.5	56	12	0.93	0.93
	Normal	1.00	-5.87	44.15			12	0.93	0.93
	C-Stop	1.00	-8.24	41.00			12	1.16	1.16

Figure 4-2 Estimation of the dilemma zone distributions

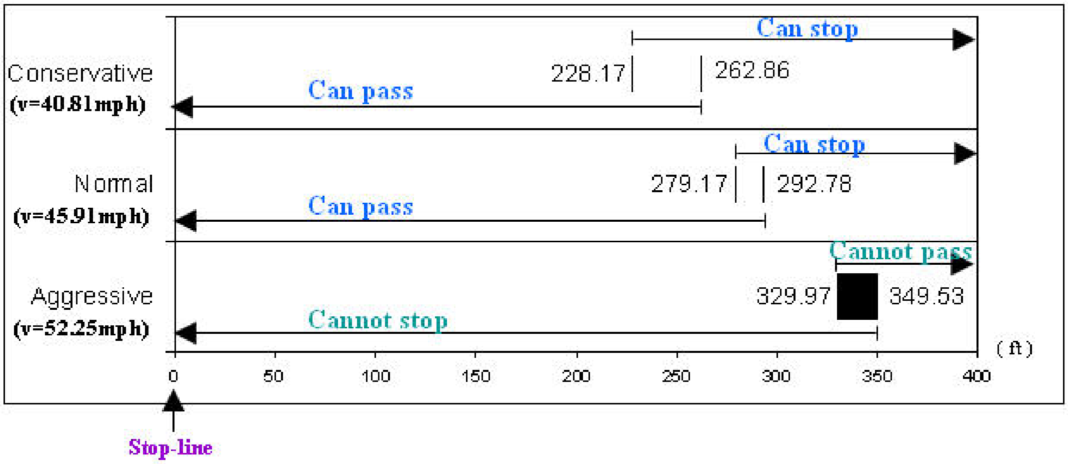
(a) Dilemma zone estimation using theoretical parameter values



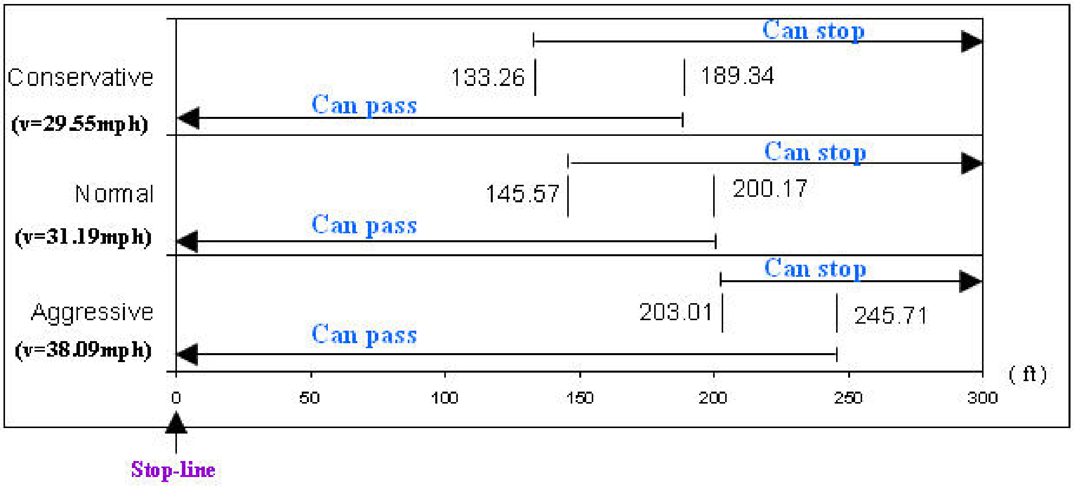
MD 193 at MD 201



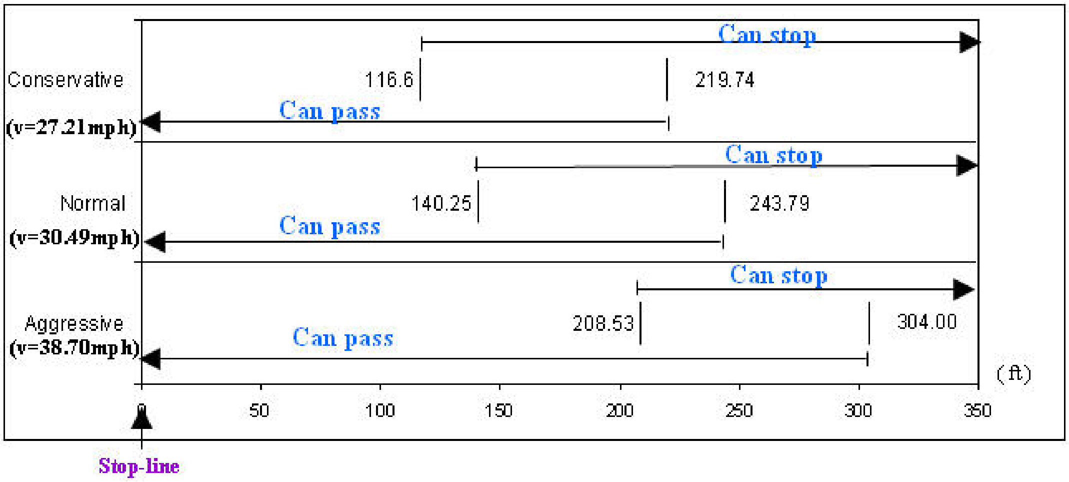
MD 650 at Metzerott Rd.



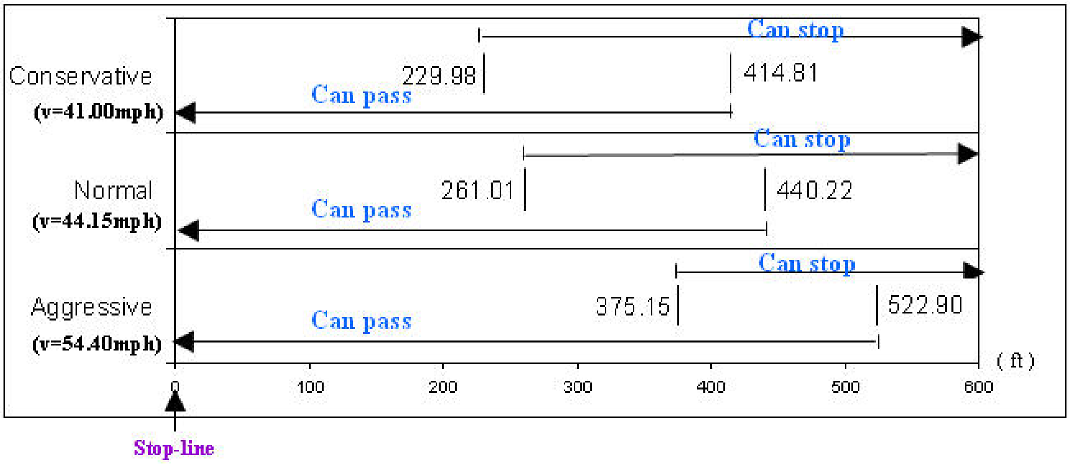
Randolph Rd. at Glenallan Rd.



MD 410 at Belcrest Rd.

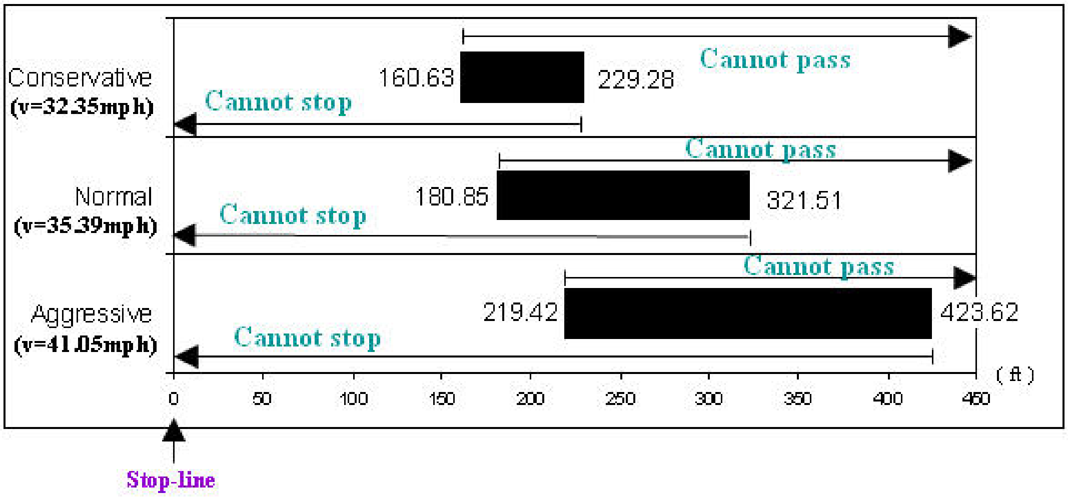


MD 410 at Adelphi Rd.



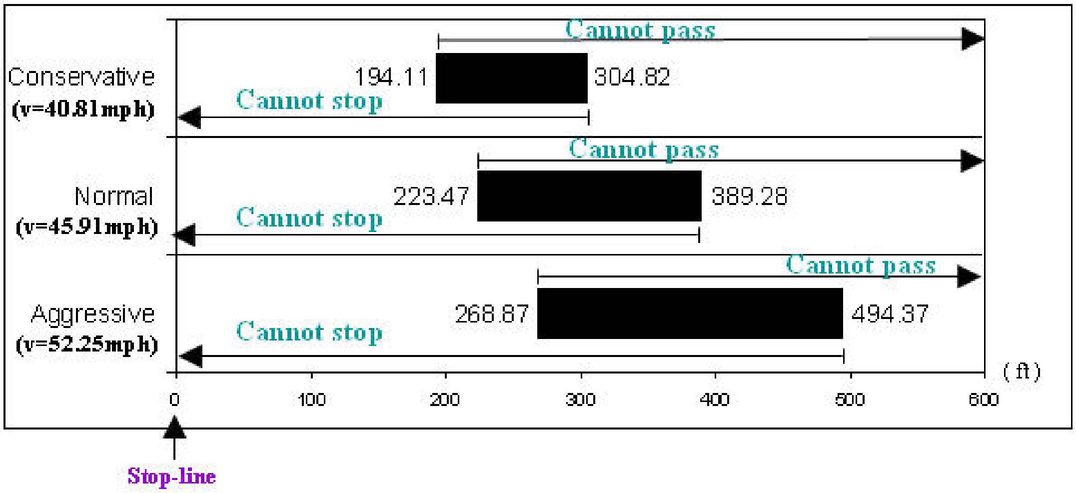
MD 193 at Mission Dr.

(b) Dilemma zone estimation using field-measured parameters



MD 193 at MD 201

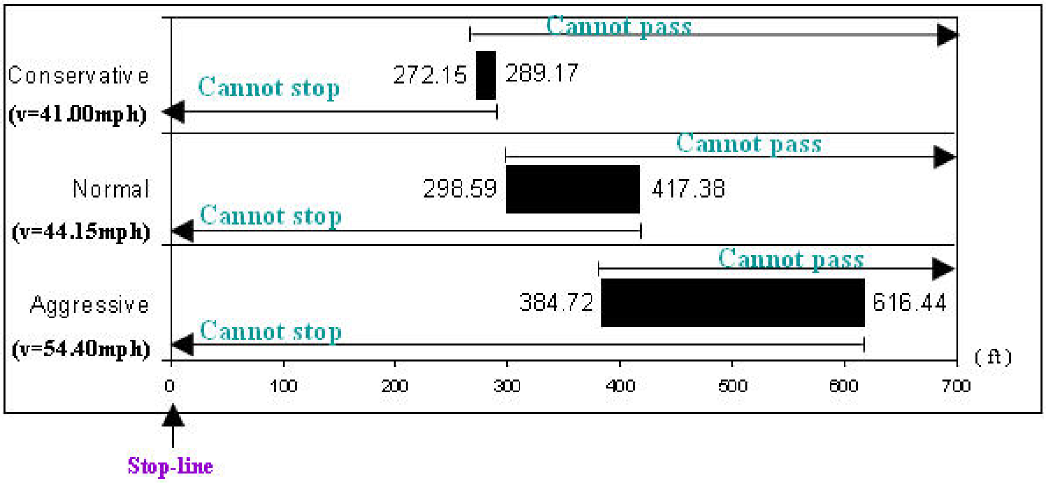
MD 650 at Metzerott Rd.



Randolph Rd. at Glenallan Rd.

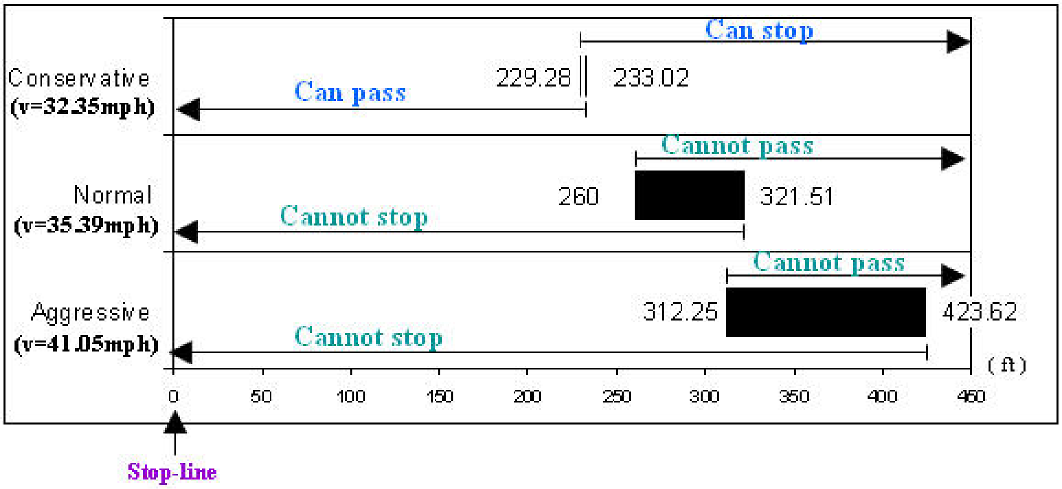
MD 410 at Belcrest Rd.

MD 410 at Adelphi Rd.

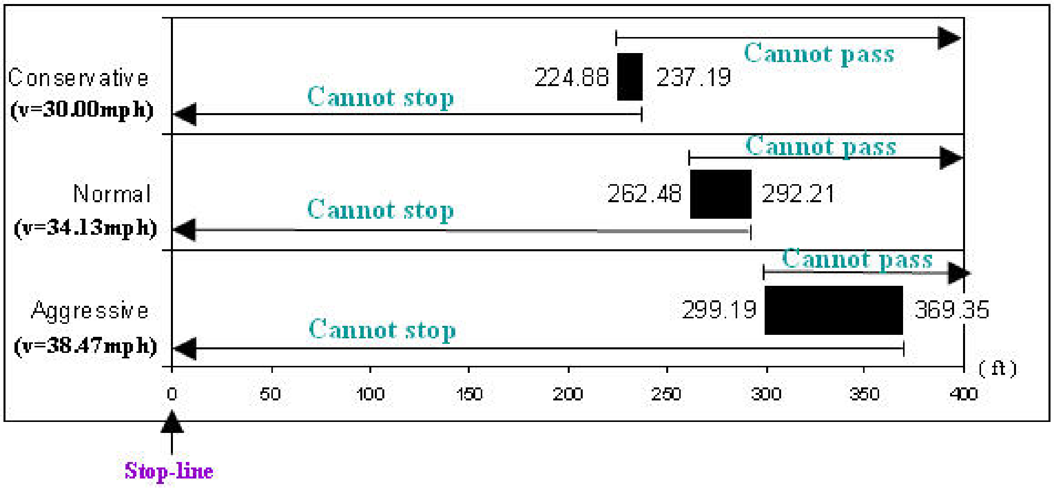


MD 193 at Mission Dr.

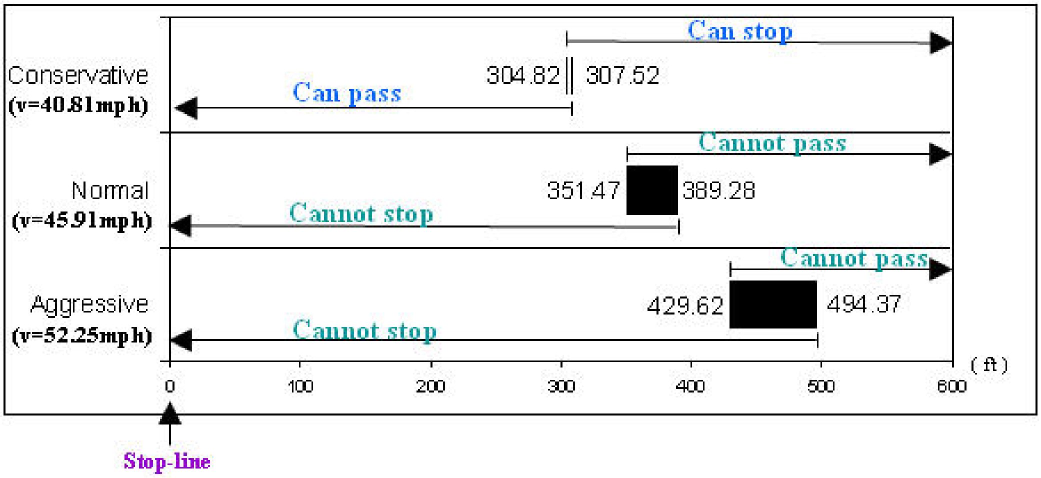
(c) Dilemma zone distribution under the impact of extended yellow phase



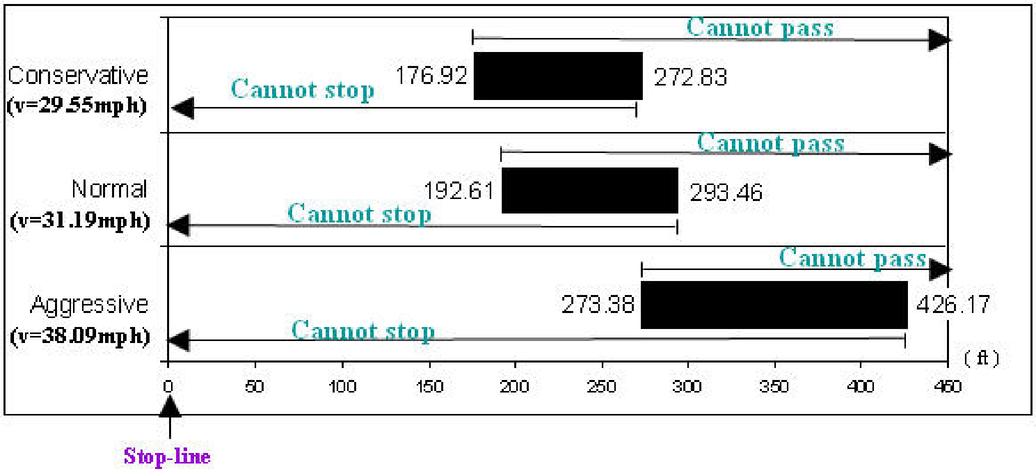
MD 193 at MD 201



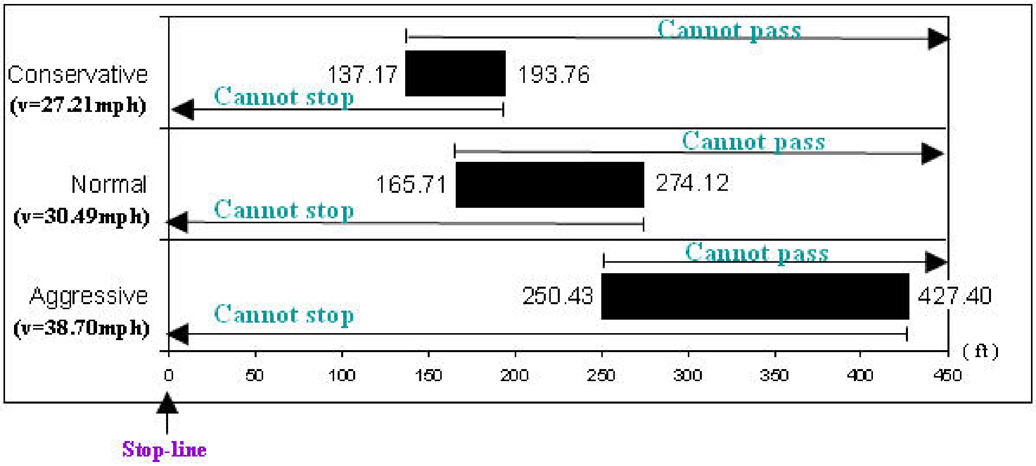
MD 650 at Metzerott Rd.



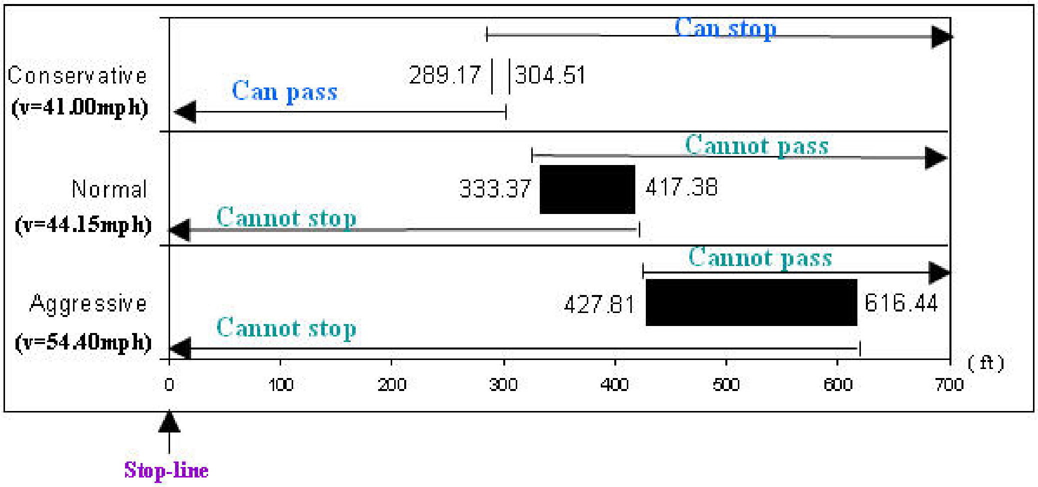
Randolph Rd. at Glenallan Rd.



MD 410 at Belcrest Rd.



MD 410 at Adelphi Rd.



MD 193 at Mission Dr.

4.5 CONCLUSIONS

The chapter presented the results of the empirical study of dilemma zones distribution for different groups of drivers at signalized intersections. Using a specially designed video-based system, this study conducted extensive field observations of 1123 drivers' responses to yellow phases at six intersections of high accident frequency, including all critical data such as speed evolution during the yellow phase, acceleration/deceleration rates, and approximate reaction times to an encountered yellow phase. The empirical results clearly indicate the existence of multiple dilemma zones at all six intersections, and the location and range of those dilemma zones vary with the behavior of the driving population. The aggressive driver group is more likely to encounter a wide range of dilemma zones. The numerical analyses have further evidenced the substantial differences between theoretical dilemma zones based on existing practice and the actual distribution of such zones. In brief, this chapter has demonstrated that:

- *The length and location of dilemma zones vary with the speed of the approaching vehicles, driver reaction times, vehicle acceleration/deceleration rates, and the yellow phase duration;*
- *Significant discrepancies exist between the theoretically computed distribution and the actual distribution of dilemma zones at signalized intersections;*
- *Extension of the yellow phase alone may not eliminate all dilemma zones at intersections having high-speed approaching flows.*

Chapter 5 – Analysis of drivers' response to the yellow phase

5.1 INTRODUCTION

Phase I of this study presented preliminary results of 665 observed drivers under the impact of surrounding traffic conditions, control strategies, geometry features, and individual characteristics during a yellow phase. The driving population was divided into three groups: "conservative stop", "normal", and "aggressive pass", based on the nature of their responses (i.e., stop or pass) and their distances from the stop line when the signal turns yellow. It is fully recognized that due to a large number of factors potentially influencing a driver's response during the yellow phase, their complex interrelations, and the limited number of samples, the results from the Phase I study are preliminary in nature. Nevertheless, the findings from the Phase I study offer a solid basis for further reevaluation of the following critical hypotheses with an enriched data set:

- *Male drivers are more likely to take "aggressive-pass" decisions when approaching a yellow-light phase;*
- *Young drivers are more likely to take the "aggressive-pass" as opposed to adult drivers;*
- *Senior drivers are more likely to be classified in the "normal-stop" and "normal-pass" groups when approaching a yellow-light phases;*
- *Drivers, talking on cellular phones, generally respond to the yellow-light phase in a relatively conservative manner;*
- *Drivers at high speeds are more likely to take an "aggressive-pass" action when approaching a yellow-light phase;*
- *Drivers driving below the average flow speed are more likely to be conservative drivers;*
- *Drivers driving under high-volume traffic conditions are more likely to take an "aggressive-pass" decision, but the congestion associated with high traffic volumes may place some constraints on their response and force them to take "normal" smooth stops or "pass" actions at a constant speed;*
- *Drivers driving during the peak hours appear to behave more aggressively with respect to signal phase changes;*

- *At intersections with major and minor streets, drivers on the minor streets (i.e., less through lanes and more crossing lanes) are more likely to react aggressively when encountering yellow-light phases;*
- *Drivers at intersections with a longer yellow-light duration seem less likely to take the "aggressive-pass" decision; and*
- *Drivers of pick-up vehicles tend to take an "aggressive-pass" action when encountering a yellow-light phase.*

This chapter is focused on further exploring the complex interrelations between a driver's response to an intersection yellow phase, his/her individual and vehicle's performance characteristics, traffic environments, and key intersection geometric features. With the nearly doubled field observations and improved measurement accuracy in Phase II, this chapter will first identify the potential factors affecting a driver's response and then test their individual as well as collective impacts on a driver's behavior during a yellow phase.

5.2 POTENTIAL FACTORS AFFECTING A DRIVER'S RESPONSE

All factors potentially influencing the response of a driver when approaching a yellow phase can be classified into the following groups:

Group 1: Traffic environmental factors

- *Cycle-based average traffic flow speed (AVGSPEED)*
- *Cycle-based traffic volume (VOLUME)*
- *Vehicle in platoon or not (PLATOON)*
- *Green split (SPLIT)*
- *Lane position of the vehicle (MIDL)*

Group 2: Intersection related factors

- *Yellow phase duration (YD)*
- *Cycle length (CYCLE)*
- *Number of through lanes (THRUL)*
- *Number of cross lanes (CROSSL)*
- *Speed limit sign posted or not (POST)*
- *Speed limit value (SPL)*
- *Red light camera enforced or not (REDLIGHT)*

- *Signal coordinated or not (COOR)*

Group 3: Individual vehicle dynamics

- *Approaching speed when the yellow phase starts (I_SPEED)*
- *Percentage of vehicles above the average traffic flow speed (PER_ABOVE)*

Group 4: Individual driver characteristics

- *Driver's gender (MALE, FEMALE)*
- *Driver's age: young to middle young (<36 years)), some senior or senior (>46 year), and middle (>36 year and <46 year) (Judging by appearance) (YOUNG, SENIOR, MIDDLE)*
- *Passenger in vehicle or not (PASSENGER)*
- *Driver on cell phone or not (PHONE)*

Group 5: Individual vehicle characteristics

- *Vehicle's type (SEDAN, SUV, PU, SPORTCAR, VAN, TRUCK, and BUS)*
- *Vehicle's model (US, JAP, EUR, and KOR)*

Based on the above classification, this study has employed the following statistical tests to explore the interrelations between the response of drivers approaching the yellow phase and all aforementioned factors.

5.3 ESTIMATION RESULTS FROM THE STATISTICAL TESTS

Since the dependent variables in the ensuing statistical analysis represent the response of drivers and are discrete in nature, the order-probit model was employed to evaluate the driver's response to the yellow phase under the impacts of different factors described previously.

5.3.1 Concepts of the order-probit model

An order-probit model for a generalized case of three classes can be presented with the following latent regression expression:

$$y^{*} = \beta ' x + \varepsilon \qquad (5\text{-}1)$$

Where, y^* is unobservable, and those observed outcomes are:

$y = 1$ if $y^* \leq 0$

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

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

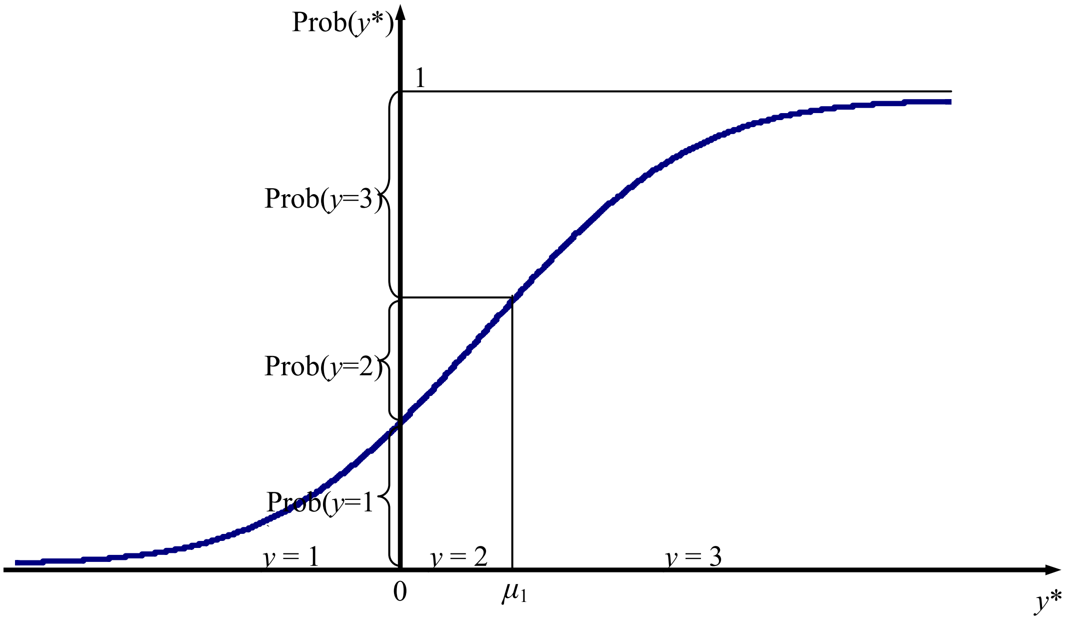
The unknown parameter μ_1, representing the boundary between ordered responses will be estimated with β (parameters for explanatory variables).

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

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

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

Figure 5-1 A graphical illustration of the probability distribution in an ordered-probit model.

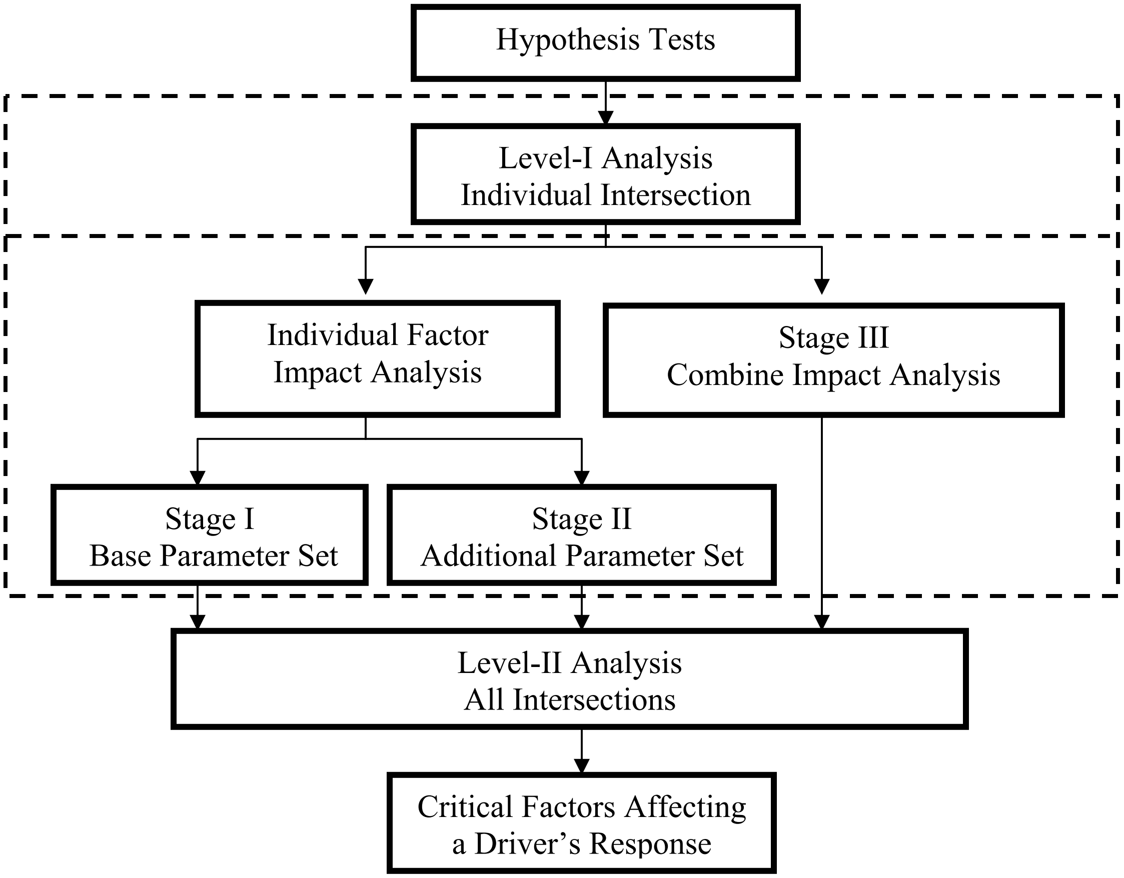


A graphic depiction of the relationship between the probability and the observed outcomes is shown in Figure 5-1.

The unobservable latent variable y^*, in the above model is the difference between the estimated distance-to-stop-line and the threshold value d_c for a driver, the discrete dependent variable is the nature of responses: conservative stop, normal, and aggressive pass. The independent variables are the class of factors identified previously.

5.3.2 Hypothesis test procedures

Figure 5-2 Parameter significant test procedure



Parameter-significant tests are performed using the procedure shown in Figure 5-2, which consists of two levels: the single intersection level and the entire sample level. The first level is composed of three stages. At Stage I, all factors in the environmental and intersection characteristics group are included in the model as the base parameter set. For Stage II and Stag-III, the analysis has used as the same base parameter set along with additional grouped factors to test their compounded impact on a driver's response pattern during the yellow phase. The statistic test for Level II has employed the sample observations for all six intersections and used those factors showing statistically significant parameters during the Level I analysis.

5.3.3 Level I - Hypothesis tests at the individual intersection level

Stage 1 Test:

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

Stage 2 Test:

- *Test 2 – base parameter set + a vehicle's approaching speed when the yellow starts (I_SPEED)*
- *Test 3 – base parameter set + the percentage of a vehicle's individual speed above the average traffic flow speed (PER_ABOVE)*
- *Test 4 – base parameter set + male factor (MALE)*
- *Test 5 – base parameter set + female factor (FEMALE)*
- *Test 6 – base parameter set + young driver factor (YOUNG)*
- *Test 7 – base parameter set + senior driver factor (SENIOR)*
- *Test 8 – base parameter set + middle driver factor (MIDDLE)*
- *Test 9 – base parameter set + passenger factor (PASSENGER)*
- *Test 10 – base parameter set + talking-on-phone factor (PHONE)*
- *Test 11-17 – base parameter set + each of the vehicle type factors: (SEDAN, VAN, SUV, PU, SPORTCAR, TRUCK, BUS)*
- *Test 18-21 – base parameter set + each of the vehicle made factor: (JAP, US, EUR, KOR)*
- .

The estimation results indicate that *average traffic flow speed* and *traffic volume* are definitely significant factors, even estimated at the level of individual intersection with small samples. The remaining factors, however, need to be further tested at the aggregated level using the samples from all intersections. A detailed presentation of the estimation results for State-I analysis is available in Appendix- I.

Summary of the Stage 2 Test:

The impacts of factors influencing a driver’s response at all the above intersections are summarized in Table 5-1. Although there exists no perfect consistency for all the affecting factors over all the observed intersections due to the sample size variation, one can still identify the following factors that could possibly affect a driver’s behavior significantly during the yellow phase: Average traffic flow speed, cycle-based volume, the approaching speed of the vehicle when the yellow phase starts, the percentage of vehicles having approaching speeds above average traffic flow speed, gender factor, age factor, passenger or not, talking on phone or not, vehicle type factors (van, pick-up, sports car, truck), vehicle made factors (Japan, Europe, Korea).

Note that since the factors of “In platoon” and “lane position” are insignificant for all the intersections, they will be dropped in the Level II analysis.

As for other insignificant driver-related or vehicle-related factors such as “middle age”, “sedan”, “SUV”, etc., they will be further analyzed in the collective test to see whether these factors exhibit any correlation.

Table 5-1 Summary of the Stage 2 test results over all observed intersections

Parameters	IS 1	IS 2	IS 3	IS 4	IS 5	IS 6
AVGSPEED	-	-	N/A	-	-	-
VOLUME	-	-	N/A	-	-	-
SPLIT	+	N/A	N/A	N/A	N/A	N/A
PLATOON	+	-	N/A	-	-	N/A
MIDLANE	+	-	N/A	+	+	-
INI_SPEED	+	+	N/A	+	+	+
PER_ABOVE	+	+	N/A	+	+	+
MALE	+	+	N/A	+	+	+
FEMALE	-	-	N/A	-	-	-
YOUNG	+	+	N/A	+	+	+
SENIOR	-	-	N/A	-	-	-
MIDDLE	-	-	N/A	-	-	-
PASSENGER	-	-	N/A	-	-	-
PHONE	-	-	N/A	-	-	-
SEDAN	-	+	N/A	+	+	+
VAN	-	-	N/A	-	-	-
SUV	-	-	N/A	+	-	-
PU	+	+	N/A	+	+	+
SPORTCAR	+	+	N/A	+	+	+
TRUCK	-	-	N/A	-	-	+
BUS	-	+	N/A	+	N/A	N/A
JAP	+	+	N/A	+	+	+
US	-	-	N/A	-	-	-
EUR	-	-	N/A	-	-	-
KOR	-	-	N/A	+	-	+

* IS 1 – the intersection of 193@201;

IS 2 – the intersection of 650@Metzrott;

IS 3 – the intersection of Randolph@Glenallan;

IS 4 – the intersection of 410@Belcrest;

IS 5 – the intersection of 410@Adelphi;

IS 6 – the intersection of 193@Mission;

"+" denotes a positive impact on aggressiveness, "-"denotes a negative impact on aggressiveness;

The highlighted cell denotes the statistical significant level of less than 10%.

Stage III Test:

Stage-III test is to explore the correlations among individual driver and vehicle related factors, as well as their collective impacts on a driver's response during the yellow phase. Table 5-2 shows the example estimation results of the collective analysis at the intersection between MD193 and MD201. Each cell in Table 5-2 denotes the collective impact of those two factors in the corresponding rows and columns. "+" denotes a positive impact on aggressiveness, "-" denotes a negative impact on aggressiveness, and the value in the cell is the significant level. For example, as shown in Table 5-2, the collective impact of young and male factors on driver's response tends to be on the aggressive side with the p-value of 0.004. The estimation results for all other intersections are reported in Appendix- II

Table 5-2 Collective analysis results of MD193@MD201

Individual driver and vehicle related factors	MALE	FEMALE	YOUNG	SENIOR	MIDDLE
MALE	N/A	N/A	N/A	N/A	N/A
FEMALE	N/A	N/A	N/A	N/A	N/A
YOUNG	+ [.004]	+ [.291]	N/A	N/A	N/A
SENIOR	- [.923]	- [.000]	N/A	N/A	N/A
MIDDLE	+ [.944]	- [.001]	N/A	N/A	N/A
PASSENGER	+ [.406]	- [.005]	- [.746]	- [.073]	- [.648]
PHONE	- [.354]	- [.000]	- [.678]	- [.002]	- [.002]
SEDAN	+ [.889]	- [.475]	+ [.593]	- [.328]	- [.482]
VAN	- [.522]	- [.005]	+ [.111]	- [.018]	- [.001]
SUV	+ [.088]	- [.000]	+ [.816]	- [.026]	- [.868]
PU	+ [.005]	*	+ [.076]	+ [.425]	+ [.066]
SPORTCAR	+ [.076]	+ [.008]	+ [.001]	+ [.944]	- [.965]
TRUCK	- [.770]	*	+ [.878]	- [.750]	- [.921]
BUS	- [.648]	- [.974]	+ [.993]	- [.745]	- [.848]
JAP	+ [.000]	+ [.144]	+ [.000]	+ [.829]	+ [.378]
US	- [.588]	- [.000]	+ [.650]	- [.017]	- [.005]
EUR	+ [.344]	- [.147]	- [.718]	- [.094]	+ [.422]
KOR	- [.659]	- [.058]	- [.412]	- [.240]	- [.249]

Summary of the Stage 3 Test:

The impacts of multiple factors on a driver's response at all the above intersections are summarized in Table 5-3. Due to the sample size limitation at each intersection, the following observations are preliminary in nature.

- *For the "passenger" factor, the impact of having passengers in the vehicle exhibits a negative sign with a significant level less than 10% for most intersections. This implies that drivers with passengers tend to make conservative actions when approaching a yellow phase. However, it is interesting to note that male drivers behave quite differently from female drivers when carrying* *passengers. Some men tend to be aggressive even with passengers in their vehicles. While female drivers always behave conservatively if they have passengers in vehicles. Similar discrepancies also exist for drivers of different age groups with passengers;*

- *The impact of talking on phone exhibits a negative sign with a significant level less than 10% for all intersections, which definitely implies that drivers talking on phone tend to take conservative actions when approaching a yellow phase. However, discrepancies exist for male and female drivers, and also for drivers of different ages. Young or male drivers tend to take aggressive actions even when talking on the phone, while female or senior drivers tend to be conservative if they are on the phone;*
- *The impact of driving a van exhibits a negative sign with a significant level less than 10% for most intersections, implying that van drivers tend to make conservative actions when approaching a yellow phase. However, discrepancies exist for male and female drivers, and also for drivers of different ages. Female or senior drivers tend to be conservative, while male or young drivers do not show clear patterns when driving vans.*
- *The effect of driving a SUV exhibits a negative sign with a significant level greater than 10% for most intersections, meaning that there are no significant behavior patterns for drivers in SUVs when approaching a yellow phase. However, it is clear to note in Table 5-8 that, male drivers show a positive sign and have a significant level less than 10% if they are driving SUVs, while female drivers exhibit a definitely negative sign with a significant level less than 10% when driving SUVs;*
- *It is evident from the effects of driving a sports car that drivers of sports cars tend to be aggressive when approaching a yellow phase. However, female drivers of sports cars tend to make aggressive actions when approaching a yellow phase, although the female factor itself shows a negative sign;*
- *The impact of driving a Japanese- made car exhibit a positive sign with a significant level less than 10% for some intersections, which implies that drivers driving made-in-Japan cars tend to make aggressive actions when approaching a*

yellow phase. However, significant discrepancies exist for male and female drivers, and also for drivers of different ages when they are driving made-in-Japan vehicles. Male or young drivers tend to be aggressive, while female or senior drivers do not show clear patterns when driving Japanese- made vehicles.

- *There are no significant behavior patterns for drivers of American- made vehicles when approaching a yellow phase. However, female drivers show a negative sign with a significant level less than 10% for most intersections. Young drivers show a positive sign and significant level less than 10% for most intersections, while senior and middle drivers show the negative signs with a significant level less than 10% for most intersections.*
- *There are no significant behavior patterns for drivers in European- made vehicles when approaching a yellow phase. However, female drivers show a negative sign with a significant level less than 10% for most intersections. And, senior drivers also show a negative sign with significant level less than 10% for most intersections.*

In summary, it is noticeable from the Stage 3 analysis that some factors may not be significant in the individual test. However, when combined with other factors they will have a significant collective impact on a driver's response during the yellow phase.

Table 5-3 Summary of the Stage III test results over all observed intersections

Parameters	IS 1	IS 2	IS 3	IS 4	IS 5	IS 6
MALE*YOUNG	+ [.004]	+ [.000]	N/A	+ [.012]	+ [.012]	+ [.026]
MALE*SENIOR	- [.923]	- [.006]	N/A	- [.911]	- [.029]	- [.951]
MALE*MIDDLE	+ [.944]	+ [.059]	N/A	- [.477]	+ [.347]	+ [.644]
MALE*PASSENGER	+ [.406]	- [.020]	N/A	- [.485]	- [.263]	- [.660]
MALE*PHONE	- [.354]	- [.035]	N/A	+ [.560]	- [.232]	- [.716]
MALE*SEDAN	+ [.889]	+ [.161]	N/A	- [.771]	- [.987]	+ [.921]
MALE*VAN	- [.522]	- [.213]	N/A	+ [.587]	- [.405]	- [.052]
MALE*SUV	+ [.088]	+ [.001]	N/A	+ [.093]	+ [.035]	+ [.352]
MALE*PU	+ [.005]	+ [.192]	N/A	+ [.232]	+ [.489]	+ [.522]
MALE*SPORTCAR	+ [.076]	+ [.037]	N/A	+ [.125]	+ [.216]	+ [.129]
MALE*TRUCK	- [.770]	- [.346]	N/A	- [.034]	- [.852]	+ [.366]
MALE*BUS	- [.648]	+ [.967]	N/A	+ [.786]	N/A	N/A
MALE*JAP	+ [.000]	+ [.000]	N/A	+ [.064]	+ [.017]	+ [.520]
MALE*US	- [.588]	+ [.331]	N/A	+ [.492]	+ [.680]	+ [.143]
MALE*EUR	+ [.344]	+ [.898]	N/A	- [.193]	- [.193]	- [.595]
MALE*KOR	- [.659]	- [.352]	N/A	N/A	N/A	N/A
FEMALE*YOUNG	+ [.291]	+ [.020]	N/A	+ [.453]	+ [.156]	+ [.091]
FEMALE*SENIOR	- [.000]	- [.000]	N/A	- [.002]	- [.113]	- [.087]
FEMALE*MIDDLE	- [.001]	- [.001]	N/A	- [.178]	- [.003]	- [.034]
FEMALE*PASSENGER	- [.005]	- [.000]	N/A	- [.554]	- [.336]	- [.035]
FEMALE*PHONE	- [.000]	- [.001]	N/A	- [.006]	- [.002]	- [.037]
FEMALE*SEDAN	- [.475]	+ [.782]	N/A	+ [.674]	+ [.181]	- [.994]
FEMALE*VAN	- [.005]	- [.000]	N/A	- [.006]	- [.001]	- [.030]
FEMALE*SUV	- [.000]	- [.000]	N/A	- [.124]	- [.000]	- [.084]
FEMALE*PU	N/A	N/A	N/A	N/A	+ [.770]	N/A
FEMALE*SPORTCAR	+ [.008]	+ [.004]	N/A	+ [.332]	+ [.011]	+ [.033]
FEMALE*TRUCK	N/A	N/A	N/A	N/A	N/A	N/A
FEMALE*BUS	- [.974]	N/A	N/A	N/A	N/A	N/A
FEMALE*JAP	+ [.144]	- [.985]	N/A	+ [.386]	+ [.651]	+ [.565]
FEMALE*US	- [.000]	- [.000]	N/A	- [.155]	- [.495]	- [.018]
FEMALE*EUR	- [.147]	- [.007]	N/A	- [.001]	- [.006]	- [.294]
FEMALE*KOR	- [.058]	- [.644]	N/A	+ [.503]	- [.072]	+ [.032]
YOUNG*PASSENGER	- [.746]	- [.658]	N/A	+ [.975]	- [.704]	- [.309]
YOUNG*PHONE	- [.678]	- [.344]	N/A	- [.979]	- [.096]	- [.244]
YOUNG*SEDAN	+ [.593]	+ [.010]	N/A	+ [.726]	+ [.030]	- [.751]
YOUNG*VAN	+ [.111]	+ [.910]	N/A	+ [.707]	+ [.780]	- [.526]
YOUNG*SUV	+ [.816]	+ [.197]	N/A	+ [.320]	+ [.826]	+ [.925]
YOUNG*PU	+ [.076]	+ [.189]	N/A	+ [.062]	+ [.404]	+ [.205]
YOUNG*SPORTCAR	+ [.001]	+ [.000]	N/A	+ [.025]	+ [.017]	+ [.003]
YOUNG*TRUCK	+ [.878]	+ [.702]	N/A	N/A	N/A	+ [.366]
YOUNG*BUS	+ [.993]	N/A	N/A	N/A	N/A	N/A
YOUNG*JAP	+ [.000]	+ [.000]	N/A	+ [.085]	+ [.009]	+ [.147]
YOUNG*US	+ [.650]	+ [.042]	N/A	+ [.051]	+ [.063]	+ [.477]
YOUNG*EUR	- [.718]	+ [.673]	N/A	- [.786]	- [.914]	- [.518]
YOUNG*KOR	- [.412]	+ [.160]	N/A	N/A	N/A	N/A
SENIOR*PASSENGER	- [.073]	- [.000]	N/A	- [.260]	- [.035]	- [.609]

SENIOR*PHONE	- [.002]	- [.004]	N/A	- [.048]	- [.085]	N/A
SENIOR*SEDAN	- [.328]	- [.000]	N/A	+ [.518]	- [.097]	+ [.300]
SENIOR*VAN	- [.018]	- [.000]	N/A	- [.002]	N/A	- [.032]
SENIOR*SUV	- [.026]	- [.000]	N/A	- [.395]	- [.051]	- [.203]
SENIOR*PU	+ [.425]	+ [.198]	N/A	- [.316]	- [.966]	- [.688]
SENIOR*SPORTCAR	+ [.944]	- [.877]	N/A	- [.799]	+ [.985]	N/A
SENIOR*TRUCK	- [.750]	- [.221]	N/A	+ [.985]	N/A	N/A
SENIOR*BUS	- [.745]	N/A	N/A	+ [.786]	N/A	N/A
SENIOR*JAP	+ [.829]	- [.000]	N/A	- [.908]	+ [.404]	+ [.943]
SENIOR*US	- [.017]	- [.003]	N/A	- [.220]	- [.062]	- [.220]
SENIOR*EUR	- [.094]	- [.001]	N/A	- [.999]	- [.003]	- [.657]
SENIOR*KOR	- [.240]	- [.026]	N/A	N/A	N/A	- [.136]
MIDDLE*PASSENGER	- [.648]	- [.056]	N/A	- [.760]	- [.680]	- [.149]
MIDDLE*PHONE	- [.002]	- [.015]	N/A	- [.283]	- [.022]	- [.168]
MIDDLE*SEDAN	- [.482]	+ [.062]	N/A	- [.525]	+ [.911]	- [.801]
MIDDLE*VAN	- [.001]	- [.005]	N/A	- [.679]	- [.001]	- [.036]
MIDDLE*SUV	- [.868]	- [.907]	N/A	- [.768]	- [.447]	+ [.816]
MIDDLE*PU	+ [.066]	- [.432]	N/A	+ [.703]	+ [.672]	- [.696]
MIDDLE*SPORTCAR	- [.965]	- [.745]	N/A	- [.684]	+ [.144]	- [.989]
MIDDLE*TRUCK	- [.921]	- [.379]	N/A	- [.022]	- [.852]	N/A
MIDDLE*BUS	- [.848]	+ [.967]	N/A	N/A	N/A	N/A
MIDDLE*JAP	+ [.378]	+ [.044]	N/A	+ [.221]	- [.693]	- [.649]
MIDDLE*US	- [.005]	- [.066]	N/A	- [.083]	- [.300]	- [.728]
MIDDLE*EUR	+ [.422]	+ [.973]	N/A	- [.973]	- [.169]	- [.110]
MIDDLE*KOR	- [.249]	- [.356]	N/A	+ [.503]	+ [.659]	N/A

* IS 1 – the intersection of 193@201;

IS 2 – the intersection of 650@Metzrott;

IS 3 – the intersection of Randolph@Glenallan;

IS 4 – the intersection of 410@Belcrest;

IS 5 – the intersection of 410@Adelphi;

IS 6 – the intersection of 193@Mission;

"+" denotes a positive impact on aggressiveness, "-" denotes a negative impact on aggressiveness, and the value in the cell is the significant level of the test;

The highlighted cell denotes the statistical significant level of less than 10%.

Summary of the Level I Analysis

The Level I analysis explores the impacts of all the observed factors on a driver's response during the yellow phase at each individual intersection. Despite the sample size constraint and possible measurement errors, the following list of factors exhibit consistent and significant impacts on a driver's response during a yellow phase at all intersections through three sequential tests:

- *Average traffic flow speed*
- *Traffic volume per cycle*
- *Individual approaching speed of a vehicle when the yellow phase starts*
- *Gender factor*
- *Young or senior*
- *Talking on phone or not*
- *Van and Sports car*
- *Japanese-made vehicles*
- *Male + Young*
- *Male + SUV*
- *Male + Sports car*
- *Male + Japanese- made*
- *Female + Young*
- *Female + Senior*
- *Female + Middle*
- *Female + Passenger*
- *Female + Phone*
- *Female + Van*
- *Female + SUV*
- *Female + Sports car*
- *Female + American- made*
- *Female + European- made*
- *Female + Korean- made*
- *Young + Sports car*
- *Young + Japanese-made*
- *Young + US made*
- *Senior + Passenger*
- *Senior + Phone*
- *Senior + Van*
- *Senior + SUV*
- *Senior + American- made*

- *Senior + European-made*
- *Middle + Phone*
- *Middle + Van*
- *Middle + American- made*

5.3.4 Level II - Hypothesis Tests with the observations from all intersections

Grounded on the significant factors identified in the Level I analysis, Level-II has performed hypothetical tests on the entire sample to overcome the sample size variation for each intersection. In the Level II, both insignificant factors, “platoon” and “lane position” have been dropped from the base variable set. A new set of variables that reflect the different features among observed intersections is added to the base set of factors. Those include cycle length, yellow duration, green split, the number of through lanes, the number of cross lanes, red-light camera enforcement, speed limit posted or not, speed limit value, and coordination of signals. Level-II analysis consists of two stages: individual factors and their collective impacts tests. The estimation results of individual factors are shown in Table 5-4.

Individual factor analysis:

- *Dependent variable – one of the following responses: “conservative stop”, “normal”, and “aggressive pass”*
- *Test 1 on the base parameter set – AVGSPEED, VOLUME, and SPLIT*
- *Test 2 – base parameter set + yellow phase duration (YD)*
- *Test 3 – base parameter set + cycle length (CYCLE)*
- *Test 4 – base parameter set + number of through lanes (THRUL)*
- *Test 5 – base parameter set + number of cross lanes (CROSSL)*
- *Test 6 – base parameter set + speed limit sign post or not (POST)*
- *Test 7 – base parameter set + speed limit value (SPL)*
- *Test 8 – base parameter set + red light camera enforced or not (REDLIGHT)*
- *Test 9 – base parameter set + coordination with next intersection (COOR)*
- *Test 10 – base parameter set + a vehicle’s approaching speed when the yellow starts (I_SPEED)*

- *Test 11 – base parameter set + the percentage of a vehicle's individual speed above the average traffic flow speed (PER_ABOVE)*
- *Test 12 – base parameter set + male factor (MALE)*
- *Test 13 – base parameter set + female factor (FEMALE)*
- *Test 14 – base parameter set + young driver factor (YOUNG)*
- *Test 15 – base parameter set + senior driver factor (SENIOR)*
- *Test 16 – base parameter set + middle driver factor (MIDDLE)*
- *Test 17 – base parameter set + passenger factor (PASSENGER)*
- *Test 18 – base parameter set + talking-on-phone factor (PHONE)*
- *Test 19-25 – base parameter set + each of the vehicle type factors: (SEDAN, VAN, SUV, PU, SPORTCAR, TRUCK, BUS)*
- *Test 26-29 – base parameter set + each of the vehicle made factor: (JAP, US, EUR, KOR)*

Table 5-4(a) Estimation results of Level II analysis (Test 1 - 9)

Parameter Coefficient [P value]	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
C	3.42652 [.000]	3.77994 [.000]	4.24886 [.000]	4.88941 [.000]	4.19104 [.000]	3.43267 [.000]	4.38127 [.000]	4.86921 [.000]	3.47070 [.000]
AVGSPEED[-]	-.038295 [.000]	-.039288 [.000]	-.040128 [.000]	-.034658 [.000]	-.044066 [.000]	-.038563 [.000]	-.038895 [.000]	-.038446 [.000]	-.036557 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.307985E-02 [.000]	-.309550E-02 [.000]	-.325016E-02 [.000]	-.331817E-02 [.000]	-.307477E-02 [.000]	-.311155E-02 [.000]	-.341941E-02 [.000]	-.321077E-02 [.000]
SPLIT[+]	2.19921 [.000]	2.26178 [.000]	2.21713 [.000]	1.80451 [.000]	2.22624 [.000]	2.22724 [.000]	2.64324 [.000]	2.412062 [.000]	2.30906 [.000]
YD[+]		.072551 [.643]							
CYCLE[-]			-.508597E-02 [.422]						
THRUL[-]				-.187635 [.009]					
CROSSL[+]					.111961 [.003]				
POST[-]						-.017446 [.863]			
SPL[-]							-.028985 [.198]		
REDLIGHT[-]								-.724066 [.001]	
COOR[+]									.228643 [.019]
MU3	3.31429 [.000]	3.31544 [.000]	3.31657 [.000]	3.34210 [.000]	3.34836 [.000]	3.31459 [.000]	3.32213 [.000]	3.35891 [.000]	3.33739 [.000]

Table 5-4(b) Estimation results of Level II analysis (Test 10 - 11)

Parameter Coefficient [P value]	Test 1	Test 10	Test 11
C	3.42652 [.000]	2.63956 [.000]	2.72087 [.000]
AVGSPEED[-]	-.038295 [.000]	-.114318 [.000]	-.034820 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.302336E-02 [.000]	-.303726E-02 [.000]
SPLIT[+]	2.19921 [.000]	1.67266 [.000]	1.63908 [.000]
I_SPEED[+]		.113243 [.000]	
PER_ABOVE[+]			4.16042 [.000]
MU3	3.31429 [.000]	3.87316 [.000]	3.90764 [.000]

Table 5-4(c) Estimation results of Level II analysis (Test 12 - 13)

Parameter Coefficient [P value]	Test 1	Test 12	Test 13
C	3.42652 [.000]	3.20207 [.000]	3.85481 [.000]
AVGSPEED[-]	-.038295 [.000]	-.040155 [.000]	-.040155 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.321578E-02 [.000]	-.321578E-02 [.000]
SPLIT [+]	2.19921 [.000]	2.21011 [.000]	2.21011 [.000]
MALE[+]		.652736 [.063]	
FEMALE[-]			-.652736 [.063]
MU3	3.31429 [.000]	3.45174 [.000]	3.45174 [.000]

Table 5-4(d) Estimation results of Level II analysis (Test 14 - 15)

Parameter Coefficient [P value]	Test 1	Test 14	Test 15	Test 16
C	3.42652 [.000]	3.21776 [.000]	3.67614 [.000]	3.57946 [.000]
AVGSPEED[-]	-.038295 [.000]	-.042393 [.000]	-.039472 [.000]	-.039144 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.323588E-02 [.000]	-.310807E-02 [.000]	-.310744E-02 [.000]
SPLIT[+]	2.19921 [.000]	2.43595 [.000]	2.29973 [.000]	2.23731 [.000]
YOUNG[+]		.925133 [.004]		
SENIOR[-]			-.977655 [.083]	
MIDDLE[-]				-.326829 [.259]
MU3	3.31429 [.000]	3.64098 [.000]	3.49027 [.000]	3.35225 [.000]

Table 5-4(e) Estimation results of Level II analysis (Test 17 - 18)

Parameter Coefficient [P value]	Test 1	Test 17	Test 18
C	3.42652 [.000]	3.52930 [.000]	3.79529 [.000]
AVGSPEED[-]	-.038295 [.000]	-.037603 [.000]	-.041604 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.307641E-02 [.000]	-.328605E-02 [.000]
SPLIT [+]	2.19921 [.000]	2.23076 [.000]	2.32662 [.000]
PASSENGER[-]		-.609143 [.378]	
PHONE[-]			-1.08745 [.039]
MU3	3.31429 [.000]	3.39288 [.000]	3.48579 [.000]

Table 5-4(f) Estimation results of Level II analysis (Test 19 - 25)

Parameter Coefficient [P value]	Test 1	Test 19	Test 20	Test 21	Test 22	Test 23	Test 24	Test 25
C	3.42652 [.000]	3.41162 [.000]	3.58722 [.000]	3.47671 [.000]	3.39003 [.000]	3.32609 [.000]	3.43708 [.000]	3.42560 [.000]
AVGSPEED[-]	-.038295 [.000]	-.038363 [.000]	-.036814 [.000]	-.038473 [.000]	-.038662 [.000]	-.035720 [.000]	-.038476 [.000]	-.038305 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.308115E-02 [.000]	-.308584E-02 [.000]	-.308299E-02 [.000]	-.303887E-02 [.000]	-.297120E-02 [.000]	-.306941E-02 [.000]	-.307493E-02 [.000]
SPLIT[+]	2.19921 [.000]	2.20749 [.000]	2.14486 [.000]	2.22665 [.000]	2.19549 [.000]	2.02633 [.000]	2.19961 [.000]	2.20100 [.000]
SEDAN[+]		.037881 [.667]						
VAN[-]			-.851381 [.021]					
SUV[-]				-.222024 [.316]				
PU[+]					.609430 [.221]			
SPORTCAR[+]						1.26346 [.009]		
TRUCK[-]							-.246264 [.693]	
BUS								.112362 [.855]
MU3	3.31429 [.000]	3.31441 [.000]	3.43950 [.000]	3.32458 [.000]	3.35948 [.000]	3.47360 [.000]	3.31713 [.000]	3.31442 [.000]

Table 5-4(g) Estimation results of Level II analysis (Test 26 - 29)

Parameter Coefficient [P value]	Test 1	Test 26	Test 27	Test 28	Test 29
C	3.42652 [.000]	3.21497 [.000]	3.54855 [.000]	3.51203 [.000]	3.46079 [.000]
AVGSPEED[-]	-.038295 [.000]	-.038138 [.000]	-.037833 [.000]	-.038773 [.000]	-.038790 [.000]
VOLUME[-]	-.307467E-02 [.000]	-.303225E-02 [.000]	-.307013E-02 [.000]	-.304420E-02 [.000]	-.304504E-02 [.000]
SPLIT[+]	2.19921 [.000]	2.18386 [.000]	2.18246 [.000]	2.19352 [.000]	2.22366 [.000]
JAP[+]		.666026 [.021]			
US[-]			-.252868 [.541]		
EUR[-]				-.725748 [.354]	
KOR[-]					-.734910 [.187]
MU3	3.31429 [.000]	3.47823 [.000]	3.33715 [.000]	3.36677 [.000]	3.34384 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%.

Collective impact analysis:

The analyses are to explore the correlations between the individual related factors and their collective impacts on a driver's response during the yellow phase. The estimation results of the collective impact analysis are shown in Table 5-5.

Table 5-5 Estimation results of the collective impact tests with the entire sample

Parameters	P-Value
MALE*YOUNG	+ [.000]
MALE*SENIOR	- [.005]
MALE*MIDDLE	+ [.314]
MALE*PASSENGER	- [.170]
MALE*PHONE	+ [.154]
MALE*SEDAN	+ [.774]
MALE*VAN	- [.126]
MALE*SUV	+ [.000]
MALE*PU	+ [.035]
MALE*SPORTCAR	+ [.000]
MALE*TRUCK	- [.393]
MALE*BUS	- [.876]
MALE*JAP	+ [.000]
MALE*US	+ [.074]
MALE*EUR	- [.221]
MALE*KOR	- [.369]
FEMALE*YOUNG	+ [.022]
FEMALE*SENIOR	- [.000]
FEMALE*MIDDLE	- [.000]
FEMALE*PASSENGER	- [.000]
FEMALE*PHONE	- [.000]
FEMALE*SEDAN	- [.817]
FEMALE*VAN	- [.000]
FEMALE*SUV	- [.000]
FEMALE*PU	+[.957]
FEMALE*SPORTCAR	+ [.000]
FEMALE*TRUCK	*
FEMALE*BUS	- [.922]
FEMALE*JAP	+ [.182]
FEMALE*US	- [.000]
FEMALE*EUR	- [.047]
FEMALE*KOR	- [.004]
YOUNG*PASSENGER	- [.110]
YOUNG*PHONE	- [.237]
YOUNG*SEDAN	+ [.024]
YOUNG*VAN	+ [.508]
YOUNG*SUV	+ [.185]
YOUNG*PU	+ [.000]
YOUNG*SPORTCAR	+ [.000]
YOUNG*TRUCK	+ [.426]
YOUNG*BUS	+ [.913]
YOUNG*JAP	+ [.000]
YOUNG*US	+ [.001]
YOUNG*EUR	- [.820]
YOUNG*KOR	- [.904]
SENIOR*PASSENGER	- [.000]
SENIOR*PHONE	- [.000]
SENIOR*SEDAN	- [.018]
SENIOR*VAN	- [.000]
SENIOR*SUV	- [.000]
SENIOR*PU	+ [.658]
SENIOR*SPORTCAR	+ [.730]
SENIOR*TRUCK	- [.379]
SENIOR*BUS	- [.928]
SENIOR*JAP	- [.153]
SENIOR*US	- [.000]
SENIOR*EUR	- [.000]
SENIOR*KOR	- [.000]
MIDDLE*PASSENGER	- [.050]
MIDDLE*PHONE	- [.000]
MIDDLE*SEDAN	- [.594]
MIDDLE*VAN	- [.000]
MIDDLE*SUV	- [.993]
MIDDLE*PU	+ [.676]
MIDDLE*SPORTCAR	- [.744]
MIDDLE*TRUCK	- [.271]
MIDDLE*BUS	- [.795]
MIDDLE*JAP	+ [.203]
MIDDLE*US	- [.000]
MIDDLE*EUR	- [.011]
MIDDLE*KOR	- [.087]

"+" denotes positive impact on aggressiveness, "-" denotes negative impact on aggressiveness, and the value in the cell is the significant level of the test;

The highlighted cell denotes the statistical significant level of less than 10%.

Summary of the Level II test

Based on the estimation results from Table 5-4 and Table 5-5, one can reach the following list of conclusions with respect to a driver's behavioral patterns during the yellow phase:

- *Drivers are more likely to behave aggressively when encountering a yellow phase if the green split for them is short;*
- *Drivers are more likely to behave aggressively when encountering a long yellow, as they are more likely to take advantage of long yellow phase to clear the intersection;*
- *Drivers tend to behave conservatively at intersections with a long cycle length;*
- *Drivers on an approach with more through lanes seem more likely to be conservative, while drivers who need to cross more lanes seem more likely to be aggressive;*
- *Red-light camera enforcement tends to play an important role to depress a driver's aggressiveness;*
- *At coordinated intersections, drivers tend to behave aggressively with an expectation to pass the next intersection;*
- *Drivers are more likely to behave conservatively when encountering a yellow phase if the traffic condition allows vehicles to move smoothly;*
- *Drivers are more likely to behave conservatively when encountering a yellow phase during the high traffic volume condition;*
- *Drivers having their approaching speeds higher than the average flow speed are more likely to behave aggressively when encountering a yellow phase;*
- *Male drivers tend to take aggressive actions when approaching the yellow phase;*
- *Female drivers tend to take conservative actions when approaching the yellow phase;*
- *Young drivers tend to take aggressive actions when approaching the yellow phase, while senior and middle-age drivers tend to take relatively conservative actions when approaching the yellow phase;*

- *Drivers with passengers in his/her car tend to take conservative actions when approaching the yellow phase;*
- *Drivers talking on phone tend to take conservative actions when approaching the yellow phase;*
- *Drivers in vans tend to take conservative actions when approaching the yellow phase;*
- *Drivers in pick-ups and sports cars tend to take aggressive actions when approaching the yellow phase;*
- *Young male drivers tend to be more aggressive than senior or middle male drivers when approaching the yellow phase;*
- *Young female drivers tend to take aggressive actions when approaching the yellow phase, while senior and middle-age female drivers tend to take conservative actions when approaching the yellow phase;*
- *Female drivers with passengers tend to take conservative actions when approaching the yellow phase, which is quite different from male drivers;*
- *Senior drivers with passengers tend to take conservative actions when approaching the yellow phase ,which is quite different from young and middle-age drivers;*
- *Female drivers talking on phone tend to take conservative actions when approaching the yellow phase, which is quite different from male drivers;*
- *Senior and middle drivers talking on phone tend to take conservative actions when approaching the yellow phase ,which is quite different from young drivers;*
- *Female drivers in vans tend to take conservative actions when approaching the yellow phase, which is quite different from male drivers;*
- *Senior and middle-age drivers in vans tend to take conservative actions when approaching the yellow phase ,which is quite different from young drivers;*
- *Male drivers in SUVs tend to take aggressive actions when approaching the yellow phase, while female drivers in SUVs tend to take conservative actions when approaching the yellow phase;*
- *Female drivers in sports cars tend to take aggressive actions when approaching the yellow phase;*

- *Young drivers in sports cars tend to take aggressive actions when approaching the yellow phase ,which is quite different from senior and middle drivers;*
- *Male drivers in Japanese- made cars tend to take aggressive actions when approaching the yellow phase, which is quite different from female drivers;*
- *Young drivers in Japanese- made cars tend to take aggressive actions when approaching the yellow phase, which is quite different from senior and middle-age drivers;*
- *Female drivers in American-made cars tend to take conservative actions when approaching the yellow phase, which is quite different male drivers;*
- *Young drivers in US made cars tend to take aggressive actions when approaching the yellow phase, while senior and middle-age drivers in American-made cars tend to take conservative actions when approaching the yellow phase;*
- *Female drivers in European- made cars tend to take conservative actions when approaching the yellow phase, which is quite different male drivers;*
- *Senior drivers in European- made cars tend to take conservative actions when approaching the yellow phase, which is quite different young and middle drivers.*

5.4 Conclusions

This chapter has presented the statistical analysis results with respect to those hypotheses tested in the Phase I study. With an enriched and higher quality data set, the estimation results with respect to the factors that may have significant impacts on intersection driver behaviors are consistent with those concluded in Phase I. Thus, while recognizing that six sample sites represent only a small set of the large network intersections, the analysis results based on the field observations of more than 1000 local drivers shall provide a reasonable profile of possible local driver patterns. One can take advantage of the research results for design of strategies for traffic safety improvement. This study has proposed two deployable ITS-safety improvement systems using the research findings from the empirical observations. A brief presentation of their design concepts will be presented in Chapter 6.

Chapter 6-Conclusions and recommendations

6.1 SUMMARY OF RESEARCH FINDINGS

Based on the preliminary findings and lessons from the Phase-I project, this study has furthered 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 an image-based system that enables users to track the speed and acceleration rates of a target vehicle at an increment of approximately every 30 feet before reaching the intersection. The comprehensive field data obtained with such a reliable system offers the basis for this study to rigorously analyze the impacts of various behavioral and environmental factors on distribution of intersection dilemma zones.

Depending on the decision of an 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, and investigated the underlying factors that may have significant impacts on their behavior at signalized intersection. Using the average speed and acceleration rates computed with the image-based system, this study has also successfully identified the spatial distribution of dilemma zones associated with each group of driving populations at those six field sites.

To best use the research findings in improving intersection traffic safety, this study has proposed two systems for monitoring driver behaviors approaching dilemma zones with the ITS technologies. The core logic of those proposed systems is to identify the location of a dilemma zone associated the target driver based on an intelligent module developed with the findings from this study. The system will then track the target driver, and concurrently activate the warning message and extend the all-red phase to prevent any read-end collision or side-crash if the target driver is to be trapped in his/her dilemma zone.

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

. Dilemma zone at signalized intersections is indeed dynamic in nature, and its spatial distribution varies with both the speed and acceleration/deceleration rate of each individual driver.

. Every high-speed intersection has a unique type of dilemma zone distribution that varies with its geometric features, signal control design, congestion level, and the behavior of driving populations.

. The common practice of extending the yellow phase duration cannot eliminate all dilemma zones, as their locations and ranges vary with each individual driver's speed, acceleration rate, and surrounding traffic conditions at the intersections.

. 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.

. Drivers in different driving groups may encounter different dilemma zones at signalized intersections.

. The average speed of drivers in the aggressive group, observed from the field observations, exhibited about 10 percent higher than the average flow speed.

. The average speed of drivers in the conservative group, observed from the field studies, exhibited about 8-10 percent lower than the average flow speed.

. The average speed of drivers in the normal group is consistent with the average speed of vehicles approaching the intersections.

. A variety of factors may affect a driver's decision on taking an aggressive or conservative action during the yellow phase. Examples of factors include: yellow phase duration, cycle length, average traffic flow speed, 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 remains the best indicator for identifying if the driver belongs to the aggressive or conservative driving population group.

. 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 and the need to cross multiple lanes on the major street.

. A coordinated signal system with an excessively long cycle length may encourage drivers to take an aggressive passing decision during the yellow phase.

. Understanding the distribution of different driving populations and the approximate locations of their dilemma zones is essential for improving the intersection traffic safety.

6.2 Recommendations

Based on the research findings from this study and the increasing demand of improving traffic safety, it is imperative for SHA to take the following actions:

- conduct a comprehensive speed profile analysis with appropriate traffic sensors at all major intersections plagued by accidents so as to understand the distribution of driving populations;
- perform an in-depth driving population classification for intersections experiencing a high accident frequency with the image-based approach developed in this study;
- identify the spatial distribution of dilemma zones for each driving population group at each target intersection; and
- experiment ITS technologies for improving intersection traffic safety.

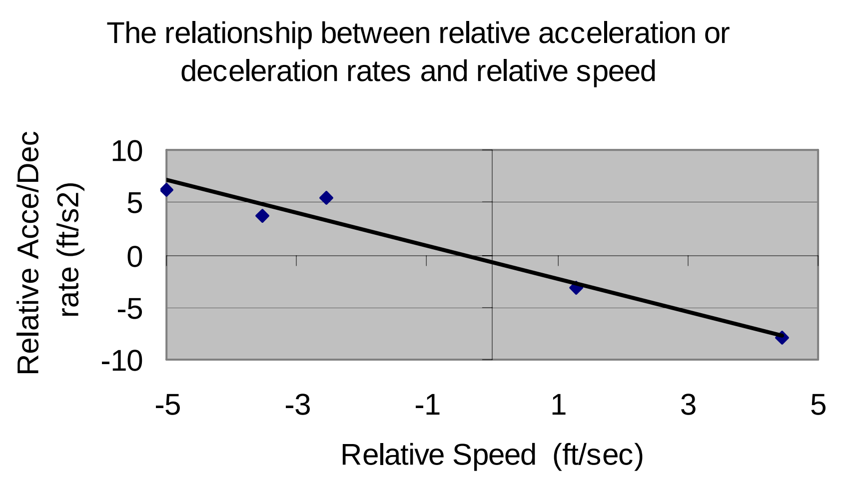
Three potential applications that integrate existing ITS & control technologies with the research findings from this study are summarized below:

Intersection driver behavior monitoring system

In addition to measuring speed evolution, the video-based system developed in this study allows traffic researchers to monitor the car-following patterns of drivers during the yellow phase.

Figure 6-1 shows the relation between relative acceleration/deceleration and relative speed of two consecutive vehicles that followed each other at the experimental intersection during a yellow phase. It appeared that the relative acceleration rates linearly decreased as the relative speed increased in this case. Although one can reach a conclusion only with a sufficient size of field data, it shows the potential of using the proposed video-based system for understanding the car-following relations between drivers during the yellow phase.

Figure 6-1 Capturing the car-following behavior during the yellow phase



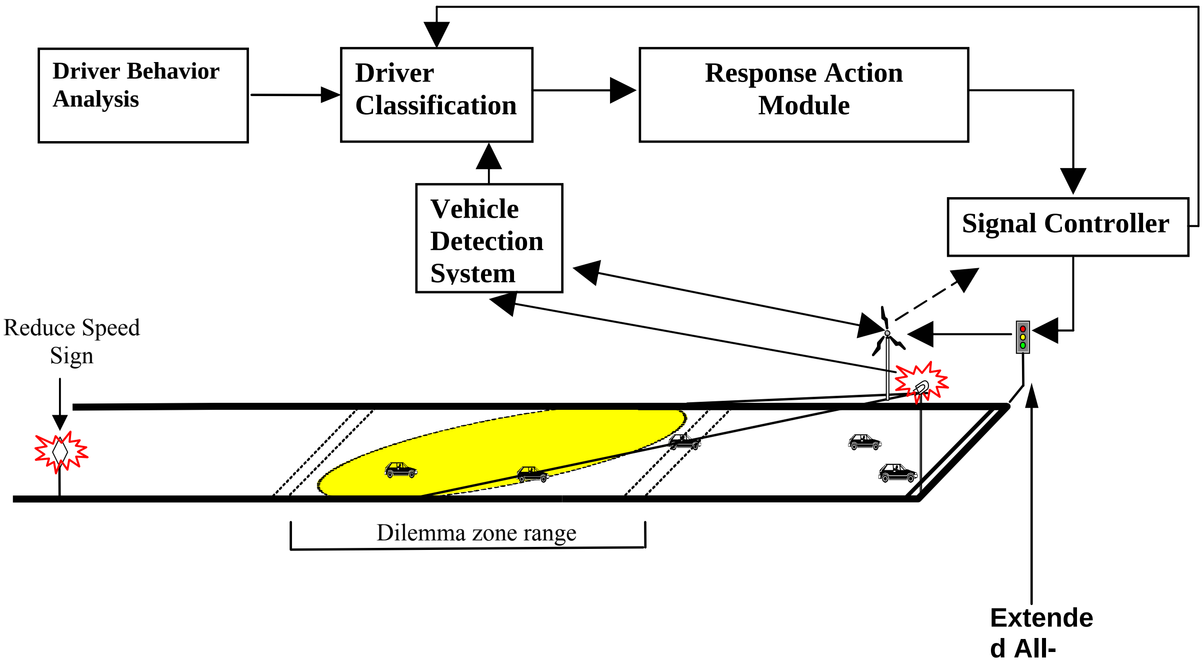
Dilemma zone alarming and eliminating systems

As evidenced in the previous empirical results, simply extending the yellow phase cannot eliminate all the dilemma zones due to their dynamic natures. To contend with the safety issues caused by the distribution of those dilemma zones, one can apply the research results from this study in the following two types of dilemma zone eliminating system designs:

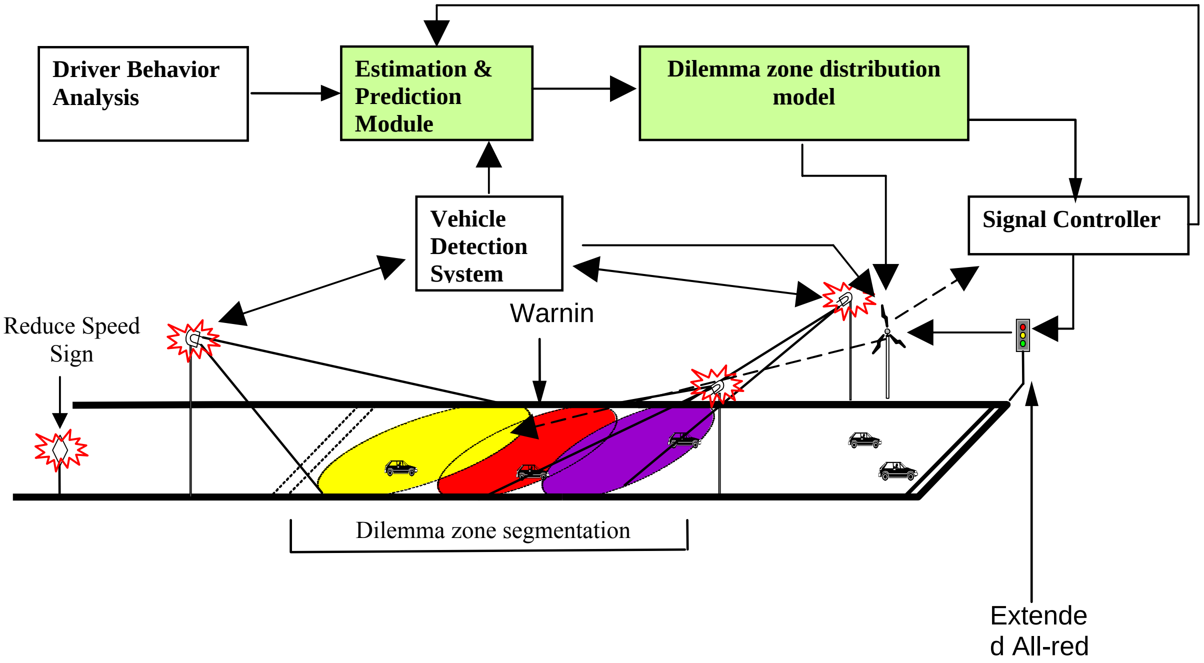
Type-I design consists of the driver behavior analysis module, vehicle detection module, and the signal control module. It is proposed to ensure that those drivers trapped into the dilemma zone can receive an extended yellow or all-red phase to clear the intersection safely (see Figure 6-2a). The vehicle detection module provides the system with the target vehicle's speed and position information. The driver analysis module can then determine whether this vehicle would be trapped in a dilemma zone. The signal control module will then be activated to extend the all-red phase to prevent any potential accident, and may also issue a ticket to the driver for red light violation if he/she decides to run over the intersection.

Compared with the Type-I system, Type-II design consists of one additional module for driver type classification and computation of the dilemma zone (see Figure 6-2b). In the field operations, the system shall first identify those vehicles approaching the intersection at the speeds exceeding 10 percent of the average flow speed, and then activate the classification and prediction module to compute the locations of their dilemma zones. The system will extend the all-red phase only if the target vehicle is trapped into its own range of dilemma zone. The primary difference from the Type-I design is that the Type-II system can precisely divide the wide range of dilemma zone into several subzones with each corresponding one type of driving group, so that it can minimize any possible false alarm.

Figure 6-2 Dilemma zone alarming and eliminating system design



(a) Type – I design



(b) Type – II design

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Appendix- I: The Estimation Results of Stage 1 Test

Table I-1: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 2	Test 3
C	14.4654 [0.000]	13.0739 [0.000]	12.6694 [0.000]
AVGSPEED[-]	-.142181 [0.000]	-.245070 [0.000]	-.075008 [0.083]
VOLUME[-]	-.018242 [0.000]	-.022886 [0.000]	-.022684 [0.000]
SPLIT[+]	5.51308 [0.197]	11.6640 [0.033]	11.2933 [0.039]
MIDL[+]	.249692 [0.300]	.027610 [0.920]	.076430 [0.778]
PLATOON[+]	.139622 [0.661]	.399299 [0.302]	.441093 [0.256]
I_SPEED[+]		.160116 [0.000]	
PER_ABOVE[+]			5.45206 [0.000]
MU3	5.89216 [0.000]	7.62507 [0.000]	7.56062 [0.000]

- The number in each parenthesis denotes the significant level

Table I-2: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 4	Test 5
C	14.4654 [0.000]	14.9998 [0.000]	15.8064 [0.000]
AVGSPEED[-]	-.142181 [0.000]	-.157410 [0.000]	-.157410 [0.000]
VOLUME[-]	-.018242 [0.000]	-.018631 [0.000]	-.018631 [0.000]
SPLIT[+]	5.51308 [0.197]	4.88053 [0.257]	4.88053 [0.257]
MIDL [+]	.249692 [0.300]	.394476 [0.123]	.394476 [0.123]
PLATOON[+]	.139622 [0.661]	.056031 [0.864]	.056031 [0.864]
MALE[+]		.806592 [0.003]	
FEMALE[-]			-.806592 [0.003]
MU3	5.89216 [0.000]	6.15816 [0.000]	6.15816 [0.000]

* The number in each parenthesis denotes the significant level

Table I-3: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 6	Test 7	Test 8
C	14.4654 [0.000]	15.5948 [0.000]	16.1952 [0.000]	14.6232 [0.000]
AVGSPEED[-]	-.142181 [0.000]	-.149985 [0.000]	-.153446 [0.000]	-.140204 [0.000]
VOLUME[-]	-.018242 [0.000]	-.019436 [0.000]	-.019111 [0.000]	-.018406 [0.000]
SPLIT[+]	5.51308 [0.197]	4.36337 [0.339]	4.24511 [0.334]	5.63359 [0.196]
MIDL[+]	.249692 [0.300]	.148678 [0.562]	.138872 [0.579]	.252490 [0.303]
PLATOON[+]	.139622 [0.661]	.068211 [0.848]	.097789 [0.775]	.119764 [0.713]
YOUNG[+]		1.03513 [0.000]		
SENIOR[-]			-.998161 [0.006]	
MIDDLE[-]				-.473184 [0.066]
MU3	5.89216 [0.000]	6.46282 [0.000]	6.23606 [0.000]	5.98585 [0.000]

* The number in each parenthesis denotes the significant level

Table I-4: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 9	Test 10
C	14.4654 [0.000]	14.5190 [0.000]	16.8569 [0.000]
AVGSPEED[-]	-.142181 [0.000]	-.143526 [0.000]	-.171810 [0.000]
VOLUME[-]	-.018242 [0.000]	-.018433 [0.000]	-.019677 [0.000]
SPLIT[+]	5.51308 [0.197]	5.99860 [0.168]	5.57357 [0.236]
MIDL [+]	.249692 [0.300]	.254383 [0.297]	.273664 [0.300]
PLATOON[+]	.139622 [0.661]	.136149 [0.675]	-.162709 [0.667]
PASSENGER[-]		-.555346 [0.143]	
PHONE[-]			-1.73790 [0.000]
MU3	5.89216 [0.000]	6.00719 [0.000]	6.64538 [0.000]

* The number in each parenthesis denotes the significant level

Table I-5: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17
C	14.4654 [.000]	14.6107 [.000]	14.7290 [.000]	14.4510 [.000]	15.4606 [.000]	14.1261 [.000]	14.5228 [.000]	14.4666 [.000]
AVGSPEED[-]	-.142181 [.000]	-.142529 [.000]	-.129712 [.000]	-.144021 [.000]	-.151165 [.000]	-.118471 [.000]	-.142345 [.000]	-.141970 [.000]
VOLUME[-]	-.018242 [.000]	-.018309 [.000]	-.018397 [.000]	-.018277 [.000]	-.019343 [.000]	-.018370 [.000]	-.018259 [.000]	-.018282 [.000]
SPLIT[+]	5.51308 [.197]	5.41171 [.207]	4.39107 [.314]	5.89591 [.173]	5.12538 [.246]	4.60111 [.312]	5.41620 [.207]	5.57239 [.193]
MIDL[+]	.249692 [.300]	.239647 [.323]	.282181 [.252]	.279062 [.252]	.329882 [.190]	.164203 [.513]	.249969 [.300]	.238438 [.325]
PLATOON[+]	.139622 [.661]	.143963 [.651]	.190733 [.563]	.122616 [.702]	.166742 [.611]	.084311 [.796]	.136552 [.669]	.135355 [.671]
SEDAN[-]		-.098128 [.680]						
VAN[-]			-.838027 [.012]					
SUV[-]				-.294315 [.317]				
PU[+]					1.36159 [.005]			
SPORTCAR[+]						1.72456 [.001]		
TRUCK[-]							-.360565 [.770]	

BUS[-]								-.712801 [.650]
MU3	5.89216 [.000]	5.91127 [.000]	6.01232 [.000]	5.92552 [.000]	6.17933 [.000]	6.18853 [.000]	5.89191 [.000]	5.89486 [.000]

* The number in each parenthesis denotes the significant level

Table I-6: Estimation results of MD193@MD201

Parameter Coefficient [P value]	Test 1	Test 18	Test 19	Test 20	Test 21
C	14.4654 [0.000]	12.9228 [.000]	14.8556 [.000]	14.4691 [.000]	13.9449 [.000]
AVGSPEED[-]	-.142181 [0.000]	-.127828 [.000]	-.138399 [.000]	-.140794 [.000]	-.141308 [.000]
VOLUME[-]	-.018242 [0.000]	-.018114 [.000]	-.018876 [.000]	-.018174 [.000]	-.017706 [.000]
SPLIT[+]	5.51308 [0.197]	7.12461 [.129]	6.14469 [.168]	5.34174 [.213]	6.15491 [.154]
MIDL[+]	.249692 [0.300]	.189041 [.465]	.216521 [.382]	.254316 [.292]	.237380 [.330]
PLATOON[+]	.139622 [0.661]	.209148 [.544]	.195940 [.556]	.136760 [.668]	.128206 [.692]
JAP[+]		1.26835 [.097]			
US[-]			-.757131 [.113]		
EUR[-]				-.283792 [.540]	
KOR[-]					-.897355 [.077]
MU3	5.89216 [0.000]	6.29903 [.000]	6.14310 [.000]	5.89113 [.000]	5.84674 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%

Table I-7: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 2	Test 3
C	6.92613 [.000]	4.89367 [.000]	4.86613 [.000]
AVGSPEED[-]	-.042843 [.004]	-.121648 [.000]	-.018429 [.003]
VOLUME[-]	-.480521E-02 [.000]	-.467980E-02 [.000]	-.472597E-02 [.000]
MIDL[-]	-.247581 [.113]	-.140084 [.414]	-.117000 [.498]
PLATOON[-]		-.234430 [.287]	-.154230 [.487]
I_SPEED[+]		.140585 [.000]	
PER_ABOVE[+]			4.77872 [.000]
MU3	3.64770 [.000]	4.42728 [.000]	4.41841 [.000]

* The number in each parenthesis denotes the significant level

Table I-8: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 4	Test 5
C	6.92613 [.000]	6.58313 [.000]	6.58313 [.000]
AVGSPEED[-]	-.042843 [.004]	-.043939 [.004]	-.043939 [.004]
VOLUME[-]	-.480521E-02 [.000]	-.496035E-02 [.000]	-.496035E-02 [.000]
MIDL [-]	-.247581 [.113]	-.158073 [.327]	-.158073 [.327]
PLATOON[-]	-.520679 [.008]	-.473543 [.019]	-.473543 [.019]
MALE[+]		.733515 [.000]	
FEMALE[-]			-.733515 [.000]
MU3	3.64770 [.000]	3.80494 [.000]	3.80494 [.000]

* The number in each parenthesis denotes the significant level

Table I-9: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 6	Test 7	Test 8
C	6.92613 [.000]	7.03889 [.000]	7.68500 [.000]	6.95917 [.000]
AVGSPEED[-]	-.042843 [.004]	-.046274 [.003]	-.039673 [.012]	-.043120 [.003]
VOLUME[-]	-.480521E-02 [.000]	-.515262E-02 [.000]	-.515396E-02 [.000]	-.479774E-02 [.000]
MIDL[-]	-.247581 [.113]	-.274313 [.100]	-.312113 [.065]	-.245502 [.116]
PLATOON[-]	-.520679 [.008]	-.586989 [.006]	-.668057 [.003]	-.518704 [.008]
YOUNG[+]		1.08399 [.000]		
SENIOR[-]			-1.45373 [.000]	
MIDDLE[-]				-.093700 [.575]
MU3	3.64770 [.000]	4.18654 [.000]	4.21369 [.000]	3.65044 [.000]

* The number in each parenthesis denotes the significant level

Table I-10: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 9	Test 10
C	6.92613 [.000]	7.37906 [.000]	7.32576 [.000]
AVGSPEED[-]	-.042843 [.004]	-.043519 [.004]	-.045995 [.002]
VOLUME[-]	-.480521E-02 [.000]	-.501016E-02 [.000]	-.500358E-02 [.000]
MIDL [-]	-.247581 [.113]	-.250987 [.118]	-.207093 [.195]
PLATOON[-]	-.520679 [.008]	-.555816 [.007]	-.559046 [.006]
PASSENGER[-]		-.838583 [.000]	
PHONE[-]			-1.04827 [.000]
MU3	3.64770 [.000]	3.85296 [.000]	3.76860 [.000]

* The number in each parenthesis denotes the significant level

Table I-11: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17
C	6.92613 [.000]	6.91515 [.000]	7.15944 [.000]	7.01366 [.000]	6.94687 [.000]	6.73776 [.000]	6.97639 [.000]	6.92582 [.000]
AVGSPEED[-]	-.042843 [.004]	-.043036 [.003]	-.043516 [.004]	-.042385 [.004]	-.044971 [.002]	-.038754 [.011]	-.043681 [.003]	-.042832 [.004]
VOLUME[-]	-.480521E-02 [.000]	-.490548E-02 [.000]	-.490386E-02 [.000]	-.484408E-02 [.000]	-.478465E-02 [.000]	-.472432E-02 [.000]	-.479252E-02 [.000]	-.480585E-02 [.000]
MIDL[-]	-.247581 [.113]	-.261778 [.095]	-.185979 [.245]	-.263881 [.093]	-.216459 [.171]	-.296780 [.064]	-.259312 [.098]	-.247300 [.114]
PLATOON[-]	-.520679 [.008]	-.510903 [.010]	-.524591 [.009]	-.510112 [.010]	-.526466 [.008]	-.547498 [.007]	-.539462 [.007]	-.520247 [.008]
SEDAN[+]		.234282 [.141]						
VAN[-]			-.859493 [.000]					
SUV[-]				-.267644 [.147]				
PU[+]					.376319 [.192]			
SPORTCAR[+]						1.09208 [.000]		
TRUCK[-]							-.400978 [.346]	
BUS[+]								.075699 [.967]
MU3	3.64770 [.000]	3.65758 [.000]	3.76088 [.000]	3.67101 [.000]	3.67200 [.000]	3.82407 [.000]	3.65850 [.000]	3.64782 [.000]

* The number in each parenthesis denotes the significant level

Table I-12: Estimation results of MD650@Metzerott Rd.

Parameter Coefficient [P value]	Test 1	Test 18	Test 19	Test 20	Test 21
C	6.92613 [.000]	6.59699 [.000]	7.00516 [.000]	6.91849 [.000]	6.96499 [.000]
AVGSPEED[-]	-.042843 [.004]	-.039778 [.008]	-.040818 [.006]	-.043006 [.004]	-.043608 [.003]
VOLUME[-]	-.480521E-02 [.000]	-.467143E-02 [.000]	-.478595E-02 [.000]	-.469233E-02 [.000]	-.481664E-02 [.000]
MIDL[-]	-.247581 [.113]	-.325196 [.043]	-.287808 [.070]	-.266779 [.091]	-.226182 [.152]
PLATOON[-]	-.520679 [.008]	-.525266 [.009]	-.536386 [.007]	-.521618 [.009]	-.501330 [.011]
JAP[+]		.575704 [.101]			
US[-]			-.256678 [.104]		
EUR[-]				-.538267 [.247]	
KOR[-]					-.363388 [.307]
MU3	3.64770 [.000]	3.74406 [.000]	3.66601 [.000]	3.67131 [.000]	3.65880 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%

Table I-13: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 2	Test 3
C	6.99942 [.000]	6.73527 [.000]	6.89840 [.000]
AVGSPEED[-]	-.064393 [.012]	-.133910 [.001]	-.037525 [.019]
VOLUME[-]	-.986508E-02 [.000]	-.010243 [.001]	-.010460 [.002]
MIDL[+]	.236010 [.460]	.052838 [.881]	-.377498E-02 [.992]
PLATOON[-]	-.103039 [.872]	-.054360 [.935]	.012092 [.986]
I_SPEED[+]		.094888 [.022]	
PER_ABOVE[+]			4.00187 [.007]
MU3	4.27006 [.000]	4.81258 [.000]	5.07526 [.000]

Table I-14: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 4	Test 5
C	6.99942 [.000]	6.62498 [.000]	6.62498 [.000]
AVGSPEED[-]	-.064393 [.012]	-.065325 [.012]	-.065325 [.012]
VOLUME[-]	-.986508E-02 [.000]	-.962979E-02 [.000]	-.962979E-02 [.000]
MIDL [+]	.236010 [.460]	.201572 [.539]	.201572 [.539]
PLATOON[-]	-.103039 [.872]	-.201818 [.766]	-.201818 [.766]
MALE[+]		.669335 [.062]	
FEMALE[-]			-.669335 [.062]
MU3	4.27006 [.000]	4.42283 [.000]	4.42283 [.000]

* The number in each parenthesis denotes the significant level

Table I-15: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 6	Test 7	Test 8
C	6.99942 [.000]	7.77242 [.000]	7.52758 [.000]	7.41309 [.000]
AVGSPEED[-]	-.064393 [.012]	-.085554 [.004]	-.067119 [.013]	-.069850 [.008]
VOLUME[-]	-.986508E-02 [.000]	-.011027 [.000]	-.010359 [.000]	-.984180E-02 [.000]
MIDL[+]	.236010 [.460]	.051709 [.885]	.141098 [.671]	.204406 [.533]
PLATOON[-]	-.103039 [.872]	-.086626 [.902]	-.020459 [.977]	-.162818 [.797]
YOUNG[+]		1.43132 [.006]		
SENIOR[-]			-1.03805 [.022]	
MIDDLE[-]				-.520600 [.128]
MU3	4.27006 [.000]	5.05718 [.000]	4.50212 [.000]	4.35459 [.000]

Table I-16: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 9	Test 10
C	6.99942 [.000]	7.20530 [.000]	7.34539 [.000]
AVGSPEED[-]	-.064393 [.012]	-.066009 [.011]	-.065633 [.012]
VOLUME[-]	-.986508E-02 [.000]	-.010083 [.000]	-.998213E-02 [.001]
MIDL [+]	.236010 [.460]	.203587 [.529]	.210624 [.522]
PLATOON[-]	-.103039 [.872]	-.068460 [.917]	-.246051 [.704]
PASSENGER[-]		-.357585 [.360]	
PHONE[-]			-.892131 [.045]
MU3	4.27006 [.000]	4.28676 [.000]	4.50575 [.000]

* The number in each parenthesis denotes the significant level

Table I-17: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17
C	6.99942 [.000]	7.00267 [.000]	7.29816 [.000]	7.02154 [.000]	6.66559 [.000]	6.80899 [.000]	7.69681 [.000]	7.01118 [.000]
AVGSPEED[-]	-.064393 [.012]	-.064535 [.012]	-.065791 [.011]	-.064663 [.012]	-.060438 [.019]	-.064009 [.016]	-.069702 [.009]	-.064785 [.011]
VOLUME[-]	-.986508E-02 [.000]	-.987620E-02 [.000]	-.990158E-02 [.001]	-.992517E-02 [.000]	-.940244E-02 [.001]	-.962009E-02 [.001]	-.010943 [.000]	-.987955E-02 [.000]
MIDL[+]	.236010 [.460]	.233452 [.470]	.153955 [.642]	.217533 [.514]	.295797 [.367]	.383431 [.257]	.159185 [.631]	.240747 [.451]
PLATOON[-]	-.103039 [.872]	-.102975 [.872]	-.128122 [.852]	-.090906 [.887]	-.232441 [.724]	-.075763 [.907]	-.167397 [.798]	-.100332 [.875]
SEDAN[+]		.016033 [.961]						
VAN[-]			-.671862 [.102]					
SUV[+]				.081160 [.846]				
PU[+]					.599180 [.232]			
SPORTCAR[+]						1.13905 [.062]		
TRUCK[-]							-1.88081 [.034]	
BUS[+]								.643358 [.786]
MU3	4.27006 [.000]	4.27052 [.000]	4.42699 [.000]	4.27949 [.000]	4.32668 [.000]	4.38853 [.000]	4.52801 [.000]	4.26981 [.000]

Table I-18: Estimation results of MD410@Belcrest Rd.

Parameter Coefficient [P value]	Test 1	Test 18	Test 19	Test 20	Test 21
C	6.99942 [.000]	6.49178 [.000]	6.96367 [.000]	8.66668 [.000]	7.17836 [.000]
AVGSPEED[-]	-.064393 [.012]	-.056631 [.033]	-.062587 [.016]	-.080992 [.005]	-.067224 [.009]
VOLUME[-]	-.986508E-02 [.000]	-.968250E-02 [.000]	-.976030E-02 [.000]	-.011881 [.000]	-.010181 [.000]
MIDL[+]	.236010 [.460]	.213895 [.515]	.240436 [.451]	.209790 [.546]	.254303 [.428]
PLATOON[-]	-.103039 [.872]	-.151576 [.822]	-.092970 [.885]	-.456495 [.509]	-.081090 [.899]
JAP[+]		.828049 [.028]			
US[-]			-.116786 [.709]		
EUR[-]				-2.32346 [.000]	
KOR[+]					1.63091 [.503]
MU3	4.27006 [.000]	4.49131 [.000]	4.26060 [.000]	4.93368 [.000]	4.30126 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%

Table I-19: Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 2	Test 3
C	4.09894 [.000]	2.35360 [.041]	2.21846 [.054]
AVGSPEED[-]	-.252140E-02 [.016]	-.097521 [.007]	.056713 [.058]
VOLUME[-]	-.722151E-02 [.000]	-.636200E-02 [.001]	-.594401E-02 [.003]
MIDL[+]	.212436 [.384]	-.157311 [.572]	-.158817 [.569]
PLATOON[-]	-.301672 [.247]	-.148358 [.607]	-.061444 [.833]
I_SPEED[+]		.157230 [.000]	
PER_ABOVE[+]			4.95946 [.000]
MU3	3.34090 [.000]	4.04597 [.000]	4.05061 [.000]

* The number in each parenthesis denotes the significant level

Table I-20: Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 4	Test 5
C	4.09894 [.000]	3.83994 [.000]	4.26431 [.000]
AVGSPEED[-]	-.252140E-02 [.016]	.628293E-03 [.079]	.628293E-03 [.079]
VOLUME[-]	-.722151E-02 [.000]	-.731690E-02 [.000]	-.731690E-02 [.000]
MIDL [+]	.212436 [.384]	.185647 [.452]	.185647 [.452]
PLATOON[-]	-.301672 [.247]	-.287205 [.275]	-.287205 [.275]
MALE[+]		.424371 [.086]	
FEMALE[-]			-.424371 [.086]
MU3	3.34090 [.000]	3.42369 [.000]	3.42369 [.000]

* The number in each parenthesis denotes the significant level

Table I-21:Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 6	Test 7	Test 8
C	4.09894 [.000]	3.98808 [.000]	4.59419 [.000]	4.21575 [.000]
AVGSPEED[-]	-.252140E-02 [.016]	-.119346E-02 [.062]	-.832896E-02 [.036]	.625477E-03 [.080]
VOLUME[-]	-.722151E-02 [.000]	-.761842E-02 [.000]	-.752689E-02 [.000]	-.723161E-02 [.000]
MIDL[+]	.212436 [.384]	.083808 [.746]	.219696 [.383]	.152991 [.539]
PLATOON[-]	-.301672 [.247]	-.528735 [.060]	-.328596 [.220]	-.383710 [.153]
YOUNG[+]		.949227 [.001]		
SENIOR[-]			-.948481 [.005]	
MIDDLE[-]				-.392384 [.128]
MU3	3.34090 [.000]	3.64796 [.000]	3.48475 [.000]	3.38721 [.000]

* The number in each parenthesis denotes the significant level

Table I-22:Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 9	Test 10
C	4.09894 [.000]	4.02867 [.000]	4.76541 [.000]
AVGSPEED[-]	-.252140E-02 [.016]	.209245E-02 [.032]	-.010395 [.080]
VOLUME[-]	-.722151E-02 [.000]	-.718061E-02 [.000]	-.755236E-02 [.000]
MIDL [+]	.212436 [.384]	.252601 [.306]	.164786 [.516]
PLATOON[-]	-.301672 [.247]	-.308820 [.239]	-.426070 [.125]
PASSENGER[-]		-.485264 [.123]	
PHONE[-]			-1.39403 [.001]
MU3	3.34090 [.000]	3.38280 [.000]	3.59823 [.000]

* The number in each parenthesis denotes the significant level

Table I-23:Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17
C	4.09894 [.000]	4.16660 [.000]	4.44360 [.000]	4.28848 [.000]	4.02818 [.000]	3.88696 [.000]	4.10292 [.000]	4.09894 [.000]
AVGSPEED[-]	-.252140 E-02 [.016]	-.485231 E-02 [.041]	-.165064 E-02 [.047]	-.477089 E-02 [.044]	-.241212 E-02 [.020]	.293049 E-02 [.008]	-.234965 E-02 [.022]	-.252140 E-02 [.016]
VOLUME[-]	-.722151 E-02 [.000]	-.753506 E-02 [.000]	-.743438 E-02 [.000]	-.741278 E-02 [.000]	-.712228 E-02 [.000]	-.726982 E-02 [.000]	-.723127 E-02 [.000]	-.722151 E-02 [.000]
MIDL[+]	.212436 [.384]	.217979 [.373]	.236777 [.354]	.234794 [.339]	.242934 [.328]	.147291 [.558]	.209571 [.392]	.212436 [.384]
PLATOON[-]	-.301672 [.247]	-.314732 [.231]	-.486557 [.084]	-.240358 [.368]	-.302779 [.246]	-.204589 [.443]	-.306512 [.242]	-.301672 [.247]
SEDAN[+]		.262506 [.275]						
VAN[-]			-1.40162 [.001]					
SUV[-]				-.328403 [.265]				
PU[+]					.339458 [.453]			
SPORTCAR[+]						1.34884 [.005]		
TRUCK[-]							-.151208 [.852]	
BUS								N/A
MU3	3.34090 [.000]	3.37539 [.000]	3.58309 [.000]	3.37140 [.000]	3.35374 [.000]	3.50726 [.000]	3.34033 [.000]	3.34090 [.000]

Table I-24: Estimation results of MD410@Adelphi Rd.

Parameter Coefficient [P value]	Test 1	Test 18	Test 19	Test 20	Test 21
C	4.09894 [.000]	4.12750 [.000]	4.11747 [.000]	4.59912 [.000]	4.10200 [.000]
AVGSPEED[-]	-.252140E-02 [.016]	-.010196 [.082]	-.292243E-02 [.004]	-.170568E-03 [.094]	-.339954E-02 [.088]
VOLUME[-]	-.722151E-02 [.000]	-.704656E-02 [.000]	-.718653E-02 [.000]	-.840740E-02 [.000]	-.699420E-02 [.000]
MIDL[+]	.212436 [.384]	.145607 [.561]	.208843 [.395]	.243762 [.335]	.158554 [.521]
PLATOON[-]	-.301672 [.247]	-.348256 [.193]	-.305601 [.244]	-.279676 [.302]	-.270303 [.304]
JAP[+]		.591761 [.023]			
US[-]			-.032279 [.893]		
EUR[-]				-1.27277 [.005]	
KOR[-]					-1.39777 [.072]
MU3	3.34090 [.000]	3.44881 [.000]	3.33949 [.000]	3.55739 [.000]	3.35855 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%

Table I-25:Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 2	Test 3
C	11.6709 [.000]	10.4709 [.000]	10.3445 [.000]
AVGSPEED[-]	-.148311 [.000]	-.203705 [.000]	-.121294 [.007]
VOLUME[-]	-.734775E-02 [.000]	-.607872E-02 [.000]	-.596805E-02 [.000]
MIDL[-]	-.053577 [.862]	-.134507 [.678]	-.128300 [.692]
I_SPEED[+]		.081412 [.014]	
PER_ABOVE[+]			3.93577 [.012]
MU3	4.29207 [.000]	4.56408 [.000]	4.52565 [.000]

Table I-26:Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 4	Test 5
C	11.6709 [.000]	11.5244 [.000]	11.9050 [.000]
AVGSPEED[-]	-.148311 [.000]	-.149704 [.000]	-.149704 [.000]
VOLUME[-]	-.734775E-02 [.000]	-.739194E-02 [.000]	-.739194E-02 [.000]
MIDL [-]	-.053577 [.862]	-.033527 [.914]	-.033527 [.914]
MALE[+]		.380594 [.225]	
FEMALE[-]			-.380594 [.225]
MU3	4.29207 [.000]	4.31220 [.000]	4.31220 [.000]

* The number in each parenthesis denotes the significant level

Table I-27:Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 6	Test 7	Test 8
C	11.6709 [.000]	11.8183 [.000]	11.6677 [.000]	11.9778 [.000]
AVGSPEED[-]	-.148311 [.000]	-.156488 [.000]	-.147608 [.000]	-.150746 [.000]
VOLUME[-]	-.734775E-02 [.000]	-.715740E-02 [.000]	-.703399E-02 [.000]	-.738632E-02 [.000]
MIDL[-]	-.053577 [.862]	-.065549 [.837]	-.067218 [.829]	-.044993 [.884]
YOUNG[+]		.857417 [.032]		
SENIOR[-]			-.587505 [.169]	
MIDDLE[-]				-.355345 [.279]
MU3	4.29207 [.000]	4.66972 [.000]	4.33909 [.000]	4.38183 [.000]

* The number in each parenthesis denotes the significant level

Table I-28: Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 9	Test 10
C	11.6709 [.000]	11.5298 [.000]	11.7669 [.000]
AVGSPEED[-]	-.148311 [.000]	-.140093 [.001]	-.149224 [.000]
VOLUME[-]	-.734775E-02 [.000]	-.748874E-02 [.000]	-.713945E-02 [.000]
MIDL [-]	-.053577 [.862]	-.020676 [.947]	-.043203 [.890]
PASSENGER[-]		-.844777 [.062]	
PHONE[-]			-.923430 [.069]
MU3	4.29207 [.000]	4.44784 [.000]	4.32596 [.000]

* The number in each parenthesis denotes the significant level

Table I-29:Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17
C	11.6709 [.000]	11.6806 [.000]	13.6498 [.000]	11.7543 [.000]	11.4432 [.000]	11.7479 [.000]	11.9635 [.000]	11.6709 [.000]
AVGSPEED[-]	-.148311 [.000]	-.148505 [.000]	-.171836 [.001]	-.146896 [.000]	-.144479 [.001]	-.149454 [.001]	-.152967 [.000]	-.148311 [.000]
VOLUME[-]	-.734775E-02 [.000]	-.736775E-02 [.000]	-.820073E-02 [.000]	-.751222E-02 [.000]	-.726590E-02 [.000]	-.740280E-02 [.000]	-.759480E-02 [.000]	-.734775E-02 [.000]
MIDL[-]	-.053577 [.862]	-.055159 [.858]	-.025965 [.937]	-.091173 [.772]	-.081329 [.793]	-.124603 [.702]	-.017061 [.956]	-.053577 [.862]
SEDAN[+]		.024686 [.937]						
VAN[-]			-1.69758 [.003]					
SUV[-]				-.223584 [.557]				
PU[+]					.361091 [.522]			
SPORTCAR[+]						1.27289 [.009]		
TRUCK[+]							2.22837 [.366]	
BUS								*
MU3	4.29207 [.000]	4.29797 [.000]	4.97318 [.000]	4.34226 [.000]	4.29367 [.000]	4.58400 [.000]	4.33280 [.000]	4.29207 [.000]

* The number in each parenthesis denotes the significant level

Table I-30: Estimation results of MD193@Mission Dr.

Parameter Coefficient [P value]	Test 1	Test 18	Test 19	Test 20	Test 21
C	11.6709 [.000]	11.3968 [.000]	11.6829 [.000]	11.5832 [.000]	11.6323 [.000]
AVGSPEED[-]	-.148311 [.000]	-.144477 [.000]	-.146512 [.000]	-.143307 [.001]	-.147739 [.000]
VOLUME[-]	-.734775E-02 [.000]	-.735419E-02 [.000]	-.727677E-02 [.000]	-.764090E-02 [.000]	-.733006E-02 [.000]
MIDL[-]	-.053577 [.862]	-.048780 [.875]	-.087796 [.780]	.028769 [.928]	-.071231 [.821]
JAP[+]		.349053 [.307]			
US[-]			-.186103 [.576]		
EUR[-]				-.901401 [.232]	
KOR[+]					.188743 [.800]
MU3	4.29207 [.000]	4.41329 [.000]	4.33030 [.000]	4.37980 [.000]	4.28220 [.000]

* The highlighted cell denotes the statistical significant level of less than 10%

Appendix-II

Table II-1: Collective analysis results of MD650@Metzerott Rd.

Individual driver and vehicle related factors	MALE	FEMALE	YOUNG	SENIOR	MIDDLE
MALE	N/A	N/A	N/A	N/A	N/A
FEMALE	N/A	N/A	N/A	N/A	N/A
YOUNG	+ [.000]	+ [.020]	N/A	N/A	N/A
SENIOR	- [.006]	- [.000]	N/A	N/A	N/A
MIDDLE	+ [.059]	- [.001]	N/A	N/A	N/A
PASSENGER	- [.020]	- [.000]	- [.658]	- [.000]	- [.056]
PHONE	- [.035]	- [.001]	- [.344]	- [.004]	- [.015]
SEDAN	+ [.161]	+ [.782]	+ [.010]	- [.000]	+ [.062]
VAN	- [.213]	- [.000]	+ [.910]	- [.000]	- [.005]
SUV	+ [.001]	- [.000]	+ [.197]	- [.000]	- [.907]
PU	+ [.192]	N/A	+ [.189]	+ [.198]	- [.432]
SPORTCAR	+ [.037]	+ [.004]	+ [.000]	- [.877]	- [.745]
TRUCK	- [.346]	N/A	+ [.702]	- [.221]	- [.379]
BUS	+ [.967]	N/A	N/A	N/A	+ [.967]
JAP	+ [.000]	- [.985]	+ [.000]	- [.000]	+ [.044]
US	+ [.331]	- [.000]	+ [.042]	- [.003]	- [.066]
EUR	+ [.898]	- [.007]	+ [.673]	- [.001]	+ [.973]
KOR	- [.352]	- [.644]	+ [.160]	- [.026]	- [.356]

Table II-2: Collective analysis results of MD410@Belcrest Rd.

Individual driver and vehicle related factors	MALE	FEMALE	YOUNG	SENIOR	MIDDLE
MALE	N/A	N/A	N/A	N/A	N/A
FEMALE	N/A	N/A	N/A	N/A	N/A
YOUNG	+ [.012]	+ [.453]	N/A	N/A	N/A
SENIOR	- [.911]	- [.002]	N/A	N/A	N/A
MIDDLE	- [.477]	- [.178]	N/A	N/A	N/A
PASSENGER	- [.485]	- [.554]	+ [.975]	- [.260]	- [.760]
PHONE	+ [.560]	- [.006]	- [.979]	- [.048]	- [.283]
SEDAN	- [.771]	+ [.674]	+ [.726]	+ [.518]	- [.525]
VAN	+ [.587]	- [.006]	+ [.707]	- [.002]	- [.679]
SUV	+ [.093]	- [.124]	+ [.320]	- [.395]	- [.768]
PU	+ [.232]	N/A	+ [.062]	- [.316]	+ [.703]
SPORTCAR	+ [.125]	+ [.332]	+ [.025]	- [.799]	- [.684]
TRUCK	- [.034]	N/A	N/A	+ [.985]	- [.022]
BUS	+ [.786]	N/A	N/A	+ [.786]	*
JAP	+ [.064]	+ [.386]	+ [.085]	- [.908]	+ [.221]
US	+ [.492]	- [.155]	+ [.051]	- [.220]	- [.083]
EUR	- [.193]	- [.001]	- [.786]	- [.999]	- [.973]
KOR	*	+ [.503]	N/A	N/A	+ [.503]

Table II-3: Collective analysis results of MD410@Adelphi Rd.

Individual driver and vehicle related factors	MALE	FEMALE	YOUNG	SENIOR	MIDDLE
MALE	N/A	N/A	N/A	N/A	N/A
FEMALE	N/A	N/A	N/A	N/A	N/A
YOUNG	+ [.012]	+ [.156]	N/A	N/A	N/A
SENIOR	- [.029]	- [.113]	N/A	N/A	N/A
MIDDLE	+ [.347]	- [.003]	N/A	N/A	N/A
PASSENGER	- [.263]	- [.336]	- [.704]	- [.035]	- [.680]
PHONE	- [.232]	- [.002]	- [.096]	- [.085]	- [.022]
SEDAN	- [.987]	+ [.181]	+ [.030]	- [.097]	+ [.911]
VAN	- [.405]	- [.001]	+ [.780]	N/A	- [.001]
SUV	+ [.035]	- [.000]	+ [.826]	- [.051]	- [.447]
PU	+ [.489]	+ [.770]	+ [.404]	- [.966]	+ [.672]
SPORTCAR	+ [.216]	+ [.011]	+ [.017]	+ [.985]	+ [.144]
TRUCK	- [.852]	N/A	N/A	N/A	- [.852]
BUS	N/A	N/A	N/A	N/A	N/A
JAP	+ [.017]	+ [.651]	+ [.009]	+ [.404]	- [.693]
US	+ [.680]	- [.495]	+ [.063]	- [.062]	- [.300]
EUR	- [.193]	- [.006]	- [.914]	- [.003]	- [.169]
KOR	N/A	- [.072]	N/A	N/A	+ [.659]

Table II-4: Collective analysis results of MD193@Mission Dr.

Individual driver and vehicle related factors	MALE	FEMALE	YOUNG	SENIOR	MIDDLE
MALE	N/A	N/A	N/A	N/A	N/A
FEMALE	N/A	N/A	N/A	N/A	N/A
YOUNG	+ [.026]	+ [.091]	N/A	N/A	N/A
SENIOR	- [.951]	- [.087]	N/A	N/A	N/A
MIDDLE	+ [.644]	- [.034]	N/A	N/A	N/A
PASSENGER	- [.660]	- [.035]	- [.309]	- [.609]	- [.149]
PHONE	- [.716]	- [.037]	- [.244]	N/A	- [.168]
SEDAN	+ [.921]	- [.994]	- [.751]	+ [.300]	- [.801]
VAN	- [.052]	- [.030]	- [.526]	- [.032]	- [.036]
SUV	+ [.352]	- [.084]	+ [.925]	- [.203]	+ [.816]
PU	+ [.522]	N/A	+ [.205]	- [.688]	- [.696]
SPORTCAR	+ [.129]	+ [.033]	+ [.003]	N/A	- [.989]
TRUCK	+ [.366]	N/A	+ [.366]	N/A	N/A
BUS	N/A	N/A	N/A	N/A	N/A
JAP	+ [.520]	+ [.565]	+ [.147]	+ [.943]	- [.649]
US	+ [.143]	- [.018]	+ [.477]	- [.220]	- [.728]
EUR	- [.595]	- [.294]	- [.518]	- [.657]	- [.110]
KOR	N/A	+ [.032]	N/A	- [.136]	N/A

*The highlighted cell denotes the statistical significant level of less than 10%.