Evaluation of a Prototype System for the Automatic Capture of School Bus Passing Violations

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ABSTRACT

It is illegal to pass a stopped school bus when the vehicle's stop-arm is extended and the red lights are flashing. Public opinion on this issue is very clear. A random phone survey of the public conducted by the National Highway Traffic Safety Administration (NHTSA) reported that more than 90 percent of respondents rated "passing a school bus that has its red lights flashing and the stop arm in full view" as a somewhat or extremely dangerous driving behavior (Boyle, Dienstfrey, and Sothoron, 1998). Despite this public opinion, there is evidence that the number of vehicles that illegally pass school buses each day is substantial. Based on data collected throughout the state of Illinois, the Illinois Department of Transportation (1996) estimated that more than 10,000 vehicles illegally pass school buses every day. Similar findings were reported in Florida (Center for Urban Transportation Research, 1996).

To address this problem, NHTSA sponsored a research effort aimed at developing an automated system for detecting and recording the license plates of vehicles as well as their drivers who illegally pass school buses. The overall objective of this research was to develop a prototype system that would automatically detect and record vehicles that illegally pass school buses (i.e., bus' stop-arm is extended and lights are flashing). Based on the results of technical, administrative, and legal feasibility analyses, system specifications were developed and a prototype unit was built. The prototype system was then field-tested in a variety of real-world conditions in both a controlled setting and on an actual school bus route. The results of the field test proved the prototype system to be comparable with other automated enforcement systems. Testing showed that recorded images were more identifiable when the violation occurred in the lane next to the school bus. In addition, frontal facial recordings were found to be 1.5 times more useful then profile recordings. It must be stressed that the purpose of the field test was to gather data that could be used in support of design recommendations and changes for the next generation of the system.

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DEDICATION

This thesis is dedicated to my mother, Claudette Gaskins, and my grandmother, Betty Lee. You have been involved with my education before I entered elementary school. Your support has instilled the value of education within me. May this thesis represent the fruits of your labor.

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CHAPTER 1: INTRODUCTION

1.1 Problem Overview

It is illegal to pass a stopped school bus when its stop-arm is extended and lights are flashing. Though this may be common knowledge to many motorists, the number of vehicles that illegally pass school buses each day is staggering. For example, the Illinois Department of Transportation (1996) estimates that, in the State of Illinois, over 11,000 vehicles illegally pass school buses every day that school is in session.

An article on the School Transportation News website (School Transportation News, School Bus Safety, 2001b) indicates that there are about 20 billion boardings and de-boardings of school buses throughout the United States each year. Given that the loading and unloading zone is the most dangerous place around a school bus (School Transportation News, School Bus Safety, 2001a), children who are transported by school buses face a significant safety problem when entering and exiting the vehicle. The National Highway Traffic Safety Administration (NHTSA, 1998) estimates that approximately 75 percent of school bus-related fatalities occur outside of the school bus. In some cases, the cause of the incident is an illegal passing maneuver made by the driver of another vehicle; that is, passing a stopped school bus with the stop-arm extended and with lights flashing. The Pupil Transportation Unit of the Kansas Department of Education conducted a national statistics survey on school bus related fatalities. Reportedly, during a 31 school year period, there were 385 fatalities that were caused by a passing vehicle (School Transportation News, School Bus Safety, 2001a). While no direct information could be attained for the lane position of those passing vehicles, a study involving school bus passing violation counts (Institute for Transportation Research and Education, 2000), showed that an average of 61.7 percent of violations occurred on a two-lane roadway.

There are several sources of data that highlight the magnitude of this problem. For example, incident data collected from the states of Florida and Illinois show that a significant number of vehicles illegally pass school buses. In Florida, a 1996 report written by the Center for Urban Transportation Research indicates that, state-wide, an estimated 10,000 vehicles illegally pass school buses every school day. As noted, data from the State of Illinois show a similar result; the Illinois Department of Transportation (1996) estimates that over 11,000 vehicles illegally pass school buses per school day. A more recent study conducted in North Carolina estimates that between 1,000 and 2,000 violations occur daily across the state of North Carolina (Institute for Transportation Research and Education, 2000).

Public opinion on this issue is very clear. The results from a survey sponsored by NHTSA found that respondents rated “passing school buses with red lights flashing and the stop-arm extended” as the most dangerous driving behavior in which a motorist can be involved (Boyle, Dienstfrey, and Sothoron, 1998). Ninety-nine percent of respondents indicated this behavior to be either “extremely dangerous” (95 percent) or “somewhat dangerous” (4 percent).

State estimates of the number of vehicles that illegally pass school buses per day, in combination with survey results indicating the public's strong, negative attitude toward this behavior, suggest that an effort to ameliorate the illegal passing of school buses is warranted. To this end, NHTSA sponsored a research project to develop a prototype system, using advanced technology, that would automatically detect and record a variety of information about the violating vehicle (e.g., license plate number, driver’s face) and the incident (e.g., date of incident, time of day).

1.2 Objectives

The overall objective of this research was to develop a prototype system that would automatically detect and record vehicles that illegally pass school buses (i.e., bus’ stop-arm is extended and lights are flashing). There were four primary steps in meeting this objective:

1. Determine the feasibility of developing and implementing a prototype system using advanced technology that would automatically document the identity of drivers and their vehicles that illegally pass stopped school buses;

2. If feasible, build a prototype unit;
3. Design and conduct a proof-of-concept field test to determine system adequacy, including its accuracy and reliability; and
4. Develop a set of recommendations for further development, research, and demonstration of the approach in a field operational setting.

The research reported here is considered the first step of a potentially larger demonstration project. However, before a larger demonstration project can occur, the feasibility of developing such a system, and its potential usefulness as determined through limited field-testing, must be determined.

1.3 Thesis Layout

The remaining parts of this thesis are as follows: Chapter 2 presents a literature review of automated enforcement systems that are currently in use and the feasibility of implementing such a system in the school bus domain. Chapter 3 details the methods of testing the prototype system, processing the data, and analyzing the results. Chapter 4 provides a full description of the prototype system's specifications and components. Chapter 5 shows and discusses the results from the field tests. Chapter 6 summarizes the analysis. Chapter 7 focuses on the recommendations that might lead a prototype system to become a finished system that could be deployed and tested in a larger demonstration project.

CHAPTER 2: LITERATURE REVIEW

2.1 Comparable Systems

In developing an understanding of automated enforcement technology and how this technology might apply to the school bus domain, it is worthwhile to consider related automated enforcement technologies. There are several related examples of automated camera systems that record vehicles in violation of traffic laws. Three such systems are briefly highlighted below: Red-light Running cameras, Railroad Grade-Crossing cameras, and Automated Speed Enforcement cameras. A fourth system, which is targeted for the school bus domain, is also described.

2.1.1 Red-Light Running Cameras

Red-light cameras were first installed in New York City in 1991 (Csaba, 1999). The system uses two cameras to photograph the driver and the rear license plate. The date and time of the violation, as well as the vehicle speed and the interval after the light turned red are also recorded. Since its initial deployment in New York, several states have implemented camera and video usage in an attempt to increase motorist and pedestrian safety. Currently, approximately 50 cities in ten states operate 250 cameras to reduce red-light running. The results from the implementation of these systems are favorable. For example, after the introduction of *Safe*Light, a program that deployed red-light cameras at various intersections in Charlotte, North Carolina, a reduction was seen in the number of crashes (-19.3 percent) and crash severity (-27.1 percent) at these intersections (Harrington, 2001).

A First-Year Report revealed that the Gatsometer is the system that was used in the *Safe*Light program (City of Charlotte *Safe*Light Project Manager, 2001). This report mentions that, when the cameras were first installed, the system could only issue citations for 33 percent of the recorded violations. Manipulation of the data shows that at the end of year one, improvements in the quality of camera images increased to roughly 44 percent.

2.1.2 Railroad Grade-Crossing Gate Cameras

Like red-light cameras, railroad grade-crossing cameras take a photograph of the front license plate and of the driver of vehicles that evade railroad grade-crossing gates. The type of data recorded on the photographs is similar to the data recorded from red-light cameras; however, elapsed time (in seconds) from activation of the red flashing lights at the crossing is substituted for the interval after the traffic lights turn red. As with red-light cameras, railroad grade-crossing cameras have proven to be effective in reducing violations (McFadden and McGee, 1999). For example, the Los Angeles County Metropolitan Transportation Authority found railroad grade-crossing violations reduced by an average of 68 percent after the deployment of three such cameras.

2.1.3 Automated Speed Enforcement Cameras

The concept of automatically recording speeding vehicles is not new. Early versions of automated speed enforcement systems, which used a stopwatch and a camera, were tested in Massachusetts in 1910 (Lynn, Garber, Ferguson, Lienau, Lau, Alcee, et al, 1992). Modern systems (using radar, etc.) were introduced into the United States in the 1970s, with early field trials conducted in Texas and New Jersey (Blackburn and Gilbert, 1995). Briefly, automated speed enforcement systems record the license plate of speeding vehicles via photographs. Additional data that is typically recorded includes the time, date, speed, and location of the violation. As with other automated enforcement technologies, automated speed enforcement has shown success in reducing crashes associated with speeding. The Insurance Corporation of British Columbia (Insurance Institute for Highway Safety, 1998) conducted a study that indicated a 7 percent decline in crashes with the use of photo radar and a 26 percent reduction in speeding.

In a feasibility study that was conducted on five photo-radar systems (AWA, Gatsometer, TMT, Traffipax, and Trafikanalys), results showed that the effectiveness of the readability of the recorded license plates ranged from 20.8 to 58.6 percent (Lynn, et al, 1992). The Gatsometer, which had an effectiveness of 55.6 percent, is also marketed for enforcement at red-lights and railroad grade crossings. The testing of the Gatsometer additionally revealed that a combination of identifiable license plate images and identifiable facial images were present in 9.1 percent of the recorded images.

2.1.4 School Bus Surveillance Systems

Usually school bus surveillance cameras are located inside the vehicle. The Institute for Transportation and Research (2000) states that Onslow County, North Carolina was first state to utilize this type of system outside of the school bus for the purpose of monitoring illegal school bus passings. The surveillance equipment used was the Silent Witness System SWS310. It recorded violations in VHS analog format; thus, it could record up to nine hours of video. Although the system was capable of recording information such as the time of the violation, speed of bus, activation of both the red and amber warning lights, and the activation of the stop arm deployment, it was not sufficiently technologically advanced to depict the license plate numbers or identity of the driver (Silent Witness, School Bus Safety Systems, 2002b). Another camera style that is currently available for this system is the SWC20 (Silent Witness, School Bus Safety Systems, 2002a). This camera activates recording when the stop arm is deployed.

2.1.5 Summary of Comparable Systems

As described, there have been several successful (successful in terms of reducing violations and crashes) applications of automated enforcement technology. In the first three applications described, all were found to substantially reduce traffic violations. Based on these findings and the data indicating that a large number of illegal school bus passing maneuvers occur every school day, it seems reasonable to pursue the application of automated enforcement in the school bus domain.

2.2 Feasibility Analysis Overview

Each state has its own laws governing the issuance of citations. Some states view the illegal passing of a school bus as a civil matter, while others see it as a criminal offense. At least ten states have passed or are about to pass laws that will allow videotape and photographs to be used to identify those who violate the traffic laws (Gilbert, 1996). According to Blackburn and Gilbert (1995), in order for automated enforcement systems to be acceptable in court several factors must be included: the equipment must be reliable and the photograph or video must clearly identify the violating vehicle, the driver's face, and the license plate. Additionally, the validity of the data obtained from the system should be carefully maintained by following a preset chain of custody.

2.3 Analysis Development

In order to provide insight in the development of the prototype system, Westat facilitated workshops that focused on feasibility analysis. The three areas of feasibility that were covered included technical feasibility analysis, administrative feasibility analysis, and legal feasibility analysis. A brief summary of the findings from Westat's workshops are provided below. A more detailed analysis can be found from Hanowski, Gaskins, Olson, Dingus, Young, Peterson, et al, (2002).

2.3.1 Technical Feasibility Analysis

A technical feasibility panel that was composed of engineers, who were familiar with various areas associated with automated enforcement and vehicle instrumentation systems, evaluated a number of alternative systems before deciding on the proposed prototype. The concept was to incorporate a low cost system with a reliable system. The panel suggested that reliability could be obtained by recording pertinent information that pertains to each violation (i.e., time, date, location, etc.), as well as, recording the violation from various directions.

2.3.2 Administrative Feasibility Analysis

To produce a well administered system that would be known by the public, an administrative panel composed of law enforcement personnel, researchers, school officials with experience in bus operations and pupil transportation safety, and experts in civil and criminal legislation, deemed a joint venture among law enforcement, legal, and legislative representatives and schools a necessity. It was believed that blending the proposed system with law enforcement would increase the effectiveness of reducing illegal school bus passing.

2.3.3 Legal Feasibility Analysis

Federal and state statutes show that legal issues associated with the implementation and administration of an automated school bus enforcement system do exist. However, other enforcement applications (e.g., red-light enforcement, railroad grade-crossing enforcement, photo/radar, etc.) have been successfully implemented. As stated previously, several factors must be included in order for this technology to be accepted in court. The degree at which criminal or civil sanctions will be charged will be dependant on positive identification of the driver.

Results and recommendations of these feasibility analyses provided the groundwork for subsequent phases of the project, including the design, development, and testing of a prototype system.

CHAPTER 3: METHODOLOGY

3.1 Testing the Prototype System

In order to determine the effectiveness of the prototype system, proof-of-concept testing was conducted. The proof-of-concept tests involved a field data gathering effort. It must be stressed that the purpose of the field test was to gather data that could be used in support of design recommendations and changes for the next generation of the system. As outlined previously, it is the next generation of this system that is proposed for any future demonstration projects that may follow the current effort. The results of the field test, along with the design recommendations/changes, are presented later in this report. Before presenting the results, a detailed description of the tests that were conducted is provided.

3.2 Proof-of-Concept Field Test Overview

The prototype system was instrumented on a school bus and then tested. The goal of this test was to determine the accuracy and reliability of the system, the usability of the information recorded, the limitations of the system, and potential capabilities. The results of the test were used to document what system refinements are needed so that it may be used in a larger demonstration project.

System effectiveness was determined through staged or "mock" violations and non-violations (i.e., “trials”). A violation was defined as a situation where the bus was stopped at a designated school bus stop, the bus’ stop-arm was extended and lights were flashing, and a vehicle passed the bus. Experimental vehicles driven by VTTI researchers performed both illegal passing maneuvers and non-passing maneuvers (i.e., where the experimental vehicle stopped appropriately) on the bus instrumented with the prototype system. It should be noted that data were not collected from human subjects. Rather, the data collection involved testing or “exercising” the system.

As will be described later, testing of the system occurred on the VTTI Smart Road and on an actual school bus route in Blacksburg, Virginia. Typical real-world violation conditions were included in the test. The Montgomery County, Virginia, School Board assisted in the tests that occurred on the actual bus route by providing school bus route information and a school bus driver. A Type C school bus, provided by Sonny/Merryman, Inc. of Lynchburg, Virginia, was instrumented with the prototype system. The bus is shown in Figure 1.

Figure 1. VTTI's prototype system for reducing the illegal passing of school buses was mounted on a Type C bus.

A VTTI staff member operated the bus during the Smart Road testing. A bus driver from the Montgomery County, Virginia, School Board was hired to operate the bus for the testing that occurred on the actual school bus route. VTTI researchers drove the experimental vehicles and carried out the testing protocol. It is important to point out that this study was not designed to use naïve subjects. Rather, it was an equipment evaluation experiment in which human drivers played a role. This distinction is important for the following reason: it is assumed that if the prototype system was presented with exactly the same stimulus on two different occasions, the system output for the two occasions would be nearly identical. Thus, the device is "deterministic." The same cannot be said when presenting stimuli to humans. This distinction means that the prototype system need only be exercised over the range for which it is likely to be used.

For the testing that occurred on the actual bus route, it is important to note that the school bus operated in compliance with normal school bus operations. To help ensure this, a licensed school bus driver who was familiar with the route was hired to drive the bus. Despite this being a test of a system instrumented on a school bus, no school children or other riders who were non-VTTI personnel were on the bus during the test.

3.3 Safety Precautions

System testing took place in two phases. Phase I occurred on the Smart Road and Phase II occurred at sites on a school bus route. The Smart Road is a 2.1 mile, closed test track at VTTI that was built using actual roadway specifications (Figure 2). In fact, the Smart Road is designed to be eventually open to public traffic. During the Smart Road testing, researchers had complete control of the roadway and the traffic.

Figure 2. Aerial view of a section of the Smart Road.

In Phase II, limited testing occurred at sites on an actual school bus route in Blacksburg, Virginia. Because these sites were open to traffic, a number of safety precautions were taken for the Phase II tests. These safety precautions are listed below:

1. Local police were notified of the testing. This was important so that the mock violations were not construed as actual violations.
2. Parents along the section of the route used for testing were notified that the testing was to occur. The letter sent to parents is presented in Appendix A.
3. To provide advanced notice to drivers, researchers served as "flagmen" and stood on the side of the road at the front/rear of the testing area holding "Stop/Slow" signs.
4. "Experimental vehicles" signs were posted on the school bus and on the experimental vehicles. Signs were also placed on the school bus stating, "EXPERIMENTAL VEHICLE, TESTING IN PROGRESS." Signing was important so that the public was informed of the testing that was occurring (and knew that actual violations were not taking place).
5. The bus operated in compliance with normal school bus operations. To ensure this, a licensed, experienced school bus driver was hired to drive the bus.
6. Testing occurred at times that had traditionally low traffic volume (i.e., on a Sunday morning).
7. Testing occurred at times when children were *not* waiting for a school bus.
8. Every effort was made to ensure that trials did not occur in the presence of other traffic. To the greatest extent possible, care was taken to wait for traffic to clear before a trial began. This helped minimize occurrences where the general driving public interacted with the experimental vehicles.
9. Test site locations were selected so that there was sufficient line-of-sight for drivers (general public) to see the bus, and so that researchers, the bus driver, and the driver of the experimental vehicle were aware of oncoming traffic.
10. The school bus used in the testing was licensed to operate in the State of Virginia and carried insurance.

3.4 Phase I: Experimental Test Conditions

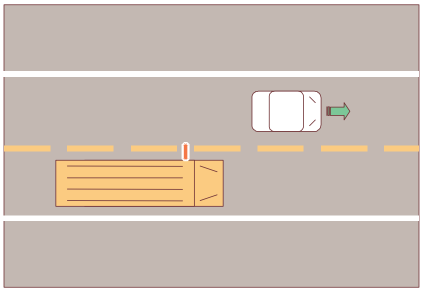
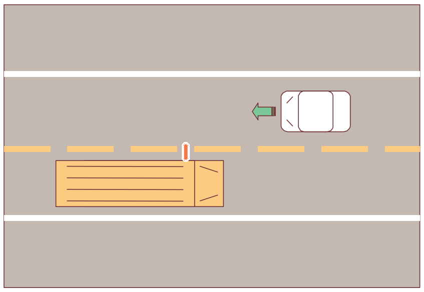
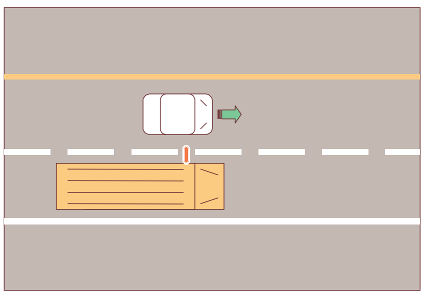
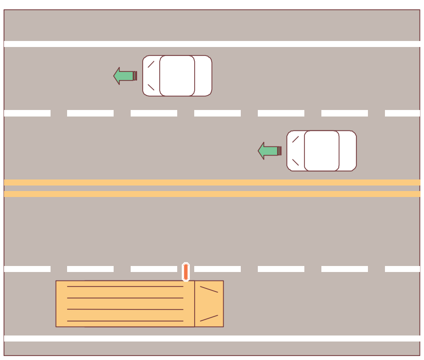
To define the range that the system would typically operate in, three broad "conditions" of operation were identified: Environmental, Violating Vehicle Characteristics, and Bus Stop Characteristics (see Table 1). For each condition, one or more independent variables were identified. It was these variables that were manipulated experimentally for the Phase I Smart Road test, as indicated by the "levels" shown in Table 1. As the weather permitted (further discussion of this is presented later), each Ambient Light variable was tested in the Clear weather condition; the Rain condition only included the Light ambient level. The Violating Vehicle Characteristics and Bus Stop Characteristics were applied to all conditions. Given the contingency that the Directional Light independent variable was tested only in the Light (Ambient Light) and Clear (Weather) conditions, a total of 108 conditions are represented (crossed) in Table 1. Note that this was not a complete factorial design. That is, all conditions were not crossed. For example, the Rain condition was not tested in the Dawn ambient level. However, more than one variable was included for each test, thereby complicating the individual variable analysis (i.e., interactions were present).

Table 1. Conditions involved in testing the prototype system.

Condition	Independent Variable	Level
ENVIRONMENT	Ambient Light	1. Light 2. Dawn 3. Dusk
	Weather	1. Clear 2. Rain
	Directional Light (Light Ambient Level and Clear Weather Only)	1. North 2. South 3. East 4. West
VIOLATING VEHICLE CHARACTERISTICS	Speed of Violating Vehicle	1. Low (10 mph) 2. Moderate (20 mph) 3. High (40 mph)
BUS STOP CHARACTERISTICS	Characteristic Scenarios	1. Overtaking; 2-way traffic, 2 lanes 2. Oncoming; 2-way traffic, 2 lanes 3. Overtaking; 1-way traffic, 2 lanes 4. Oncoming; 2-way traffic, 4 lanes

The Characteristic Scenarios shown in Table 1 are those in which many passing violations occur and in which the prototype system is expected to work effectively (Huey and Llaneras, 2001a). Diagrams of the four Characteristic Scenarios tested in Phase I are shown in Table 2.

Table 2. Four typical scenarios included in the Phase I test.

Scenario	Description
	Overtaking (2-way traffic, 2 lanes)
	Oncoming (2-way traffic, 2 lanes)
	Overtaking (1-way traffic, 2 lanes)
	Oncoming (2-way Traffic, 4 lanes)

Given the conditions shown in Table 1, notice that a vehicle performing an overtaking maneuver will produce the same results whether the characteristics of the road are one-way traffic on two lanes, or two-way traffic on two lanes. For this reason, only one of these scenarios is represented in the testing matrix. With regard to the four-lane situation, testing occurred with the oncoming vehicle in both the third and fourth lanes.

Phase I testing occurred from November 5th, 2001 to December 10th, 2001. Although most of the testing occurred early in November, due to unseasonably dry weather, the rain condition was not tested until December 10th. A total of 255 conditions were tested. As will be described in the Results Section, other conditions presented themselves and, while these are not represented in Table 1 (such as Cloudy Weather), were also tested. Tests were conducted with both light and dark colored vehicles, with multiple (passing) vehicles, and in dark ambient conditions.

In addition to the 108 conditions described in Table 1, and the additional test conditions mentioned above, 14 additional conditions that were believed to be important were also tested. These additional tests provided important data for fully assessing the effectiveness and shortcomings of the system.

- What does the system do if a driver pulls up to the "violation zone" but does not pass? (i.e., test for "false alarms")? That is, if there was no violation, does the system activate anyway? To investigate this, five conditions were included in the Phase I tests:
    - False Alarm, Oncoming, Two-Lane
    - False Alarm, Overtaking, Two-Lane
    - False Alarm, Oncoming, Four-Lane (Lane 3)
    - False Alarm, Oncoming, Four-Lane (Lane 4)
- What does the system do if two vehicles pass simultaneously through the violation zone?
    - Two vehicles, Both Oncoming, Four-Lane (One in Lane 3 and One in Lane 4)
    - Two vehicles, One Oncoming and One Overtaking, Four-Lane (Overtaking in Lane 2 and Oncoming in Lane 3)
    - Two vehicles, One Oncoming and One Overtaking, Four-Lane (Overtaking in Lane 2 and Oncoming in Lane 4)
- What does the system do if two following vehicles pass together in unison through the violation zone?
    - Two vehicles, Both Oncoming, Four-Lane (Both in Lane 3)
    - Two vehicles, Both Oncoming, Four-Lane (Both in Lane 4)

    - Two vehicles, Both Overtaking, 2-Lane (Both in Lane 2)
- What does the system do if two orthogonally traveling vehicles pass through the violation zone?
    - Two vehicles, One Oncoming and One Overtaking, Four-Lane (Overtaking in Lane 2 and Oncoming in Lane 4 moving to Lane 3 while in Violation Zone)
- Do headlights from other vehicles impact system performance?
    - Dawn test, Overtaking, Two-Lane (Headlights from following vehicle in Lane 2)
    - Dawn test, Overtaking, Four-Lane (Headlights from stopped vehicle in Lane 3)
    - Dawn test, Overtaking, Four-Lane (Headlights from stopped vehicle in Lane 4)

In addition, the following system features were assessed:

- What is the maximum distance from the bus that a vehicle license number and driver's profile can be detected/recorded?
- What is the field-of-view of the cameras?
- What are the options for adjusting the coverage of the cameras?
- Can post-processing software be used to "clean" the video image to improve readability of the license plate?

After initial testing, it was determined that the system would not be able to effectively capture the driver's profile for a wide range of vehicles with different eye-heights. Because there is relatively little variation between the distance from the license plate to the ground for an automobile as compared to, for example, a pick-up truck, there was less of a problem for capturing the vehicle's license plate. However, the eye-height distance does vary enough to make it difficult to capture both the profile for drivers of automobiles and pick-up trucks. Because of this, it was determined to set the profile camera to optimally capture the eye-height of automobile drivers. It should be noted that future versions of the system could be designed with the flexibility to capture the violating driver's facial profile at various eye-heights (at an additional hardware expense). However, for the proof-of-concept testing described here, an eye-height that represents the eye-height for a driver in a typical automobile was selected.

With regard to the characteristics of the violating vehicles that were used, testing was conducted with (i) different makes, models, and colors; (ii) with headlights on, off, and with high beams; and (iii) with driver and passenger windows open and closed.

The complete listing of test conditions is presented in Appendix B. For each of the test conditions, the following questions were asked:

- Did the system detect the violation?
- Did the system record the violation?
- Can the license plate of the vehicle be identified from the recording?
- Can the driver's face be identified from the recording?

In addition, the ambient light was recorded at the time of the test (measured in Lux).

3.5 Phase II: Experimental Test Conditions

The Phase II testing occurred at school bus stop sites on an actual bus route in Blacksburg, Virginia. (The route and the test sites are shown on the map in Appendix C.) It was believed that testing the system at stops on an actual bus route would help to validate the results from the Smart Road tests and ensure that the project field tests included actual school bus sites (i.e., provide additional validity to the testing).

A limited number of conditions from Table 1 were included in the Phase II test (see Appendix B for a list of conditions). As shown in Table 1, the Characteristic Scenarios tested for this study included both two-lane and four-lane roads. Both roadway types were included in the Phase II tests. Five different stop sites were included in the test. Because the majority of violations occur on two-lane roadways (Institute for Transportation Research and Education, 2000), and the majority of bus stops in Blacksburg exist on two-lane roads, four of the five test sites were two-lane roads.

As described previously, for safety reasons, attempts were made to limit the number of non-research vehicles that interacted with the school bus. However, because testing occurred on a road open to traffic, there were 33 occurrences of non-research vehicles passing the bus when it was stopped. These data were recorded and the video was evaluated (these were considered additional tests).

Note that for each test, the Ambient Light level and Weather was recorded but not varied. Three speed limits were tested during the Phase II tests: (i) Low (10 mph), (ii) Moderate (the posted speed limit on the road which varied from 15 mph to 35 mph), and (iii) Unknown (speed of non-research vehicles).

The same questions asked for each condition in Phase I were asked again in Phase II. That is:

- Did the system detect the violation?
- Did the system record the violation?
- Can the license plate of the vehicle be identified from the recording?
- Can the driver's face be identified from the recording?

With the Phase I and Phase II tests combined, the system was tested in a total of 255 typical conditions. Although the testing of 108 conditions would have satisfied the minimum requirements of representing all of the operating conditions, opportunities arose to test the system in additional conditions using variables such as Cloudy, Fog, and Dark. While all variable levels were tested at least once for a variety of situations, additional repetitions were conducted to increase the validity of the system. Table 3 shows the number of tests that were conducted for each level of the independent variables. The Dark (Ambient Light) conditions, which were treated separately in order to test the Infrared (I/R) Pulse Source, are shown in Table 4.

Table 3. Conditions tested by the prototype system.

Condition	# Tests Conducted	Condition	# Tests Conducted
Ambient Light		Weather	
Dawn	80	Clear	207
Light	107	Fog	12
Late Afternoon	35	Cloudy	14
Dusk	21	Rain	10
Direction of Light		Bus Stop Characteristics	
North	9	Lane 2	160
South	10	Lane 3	40
East	18	Lane 4	43
West	23	Oncoming	134
Not Recorded	183	Overtaking	109
Speed of Violating Vehicle		Headlights	
Low (10 mph)	99	Headlights-Off	149
Moderate (15-35 mph)	73	Standard Lights	63
High (40 mph)	37	Daytime Running Lights	23
Unknown	34	High Beams	8
Window			
Window-Up	61		
Window-Down	166		
Window-Half Down	3		
Not Recorded	13		

Table 4. Conditions for Dark Ambient Light tested by the prototype system.

Condition	**# Tests Conducted**
Ambient Light	
Dark	12
Weather	
Clear	12
Bus Stop Characteristics	
Lane 2	8
Lane 3	2
Lane 4	2
Oncoming	12
Overtaking	12
Speed of Violating Vehicle	
Low (10 mph)	7
Moderate (20 mph)	5
Headlights	
Standard Lights	10
High Beams	2
Window	
Window-Up	8
Window-Down	4

3.6 Steps in Processing the Test Data

For both the Phase I and Phase II tests, there were two steps in the testing process. First, "drive-bys" occurred when a vehicle illegally passed the school bus (i.e., a mock violation). Second, the video and other data captured by the tests were processed by a research analyst in the lab. As this data processing occurred in the lab after the data had been captured, this step was referred to as "post-processing."

Post-processing consisted of a research analyst reviewing the video and (i) selecting a single frame in which the license plate was most visible, (ii) selecting a single frame in which the driver's profile and frontal facial image was most visible, and (iii) selecting the "tag" information that contained non-video data relevant to the violation such as date, time, etc. In regard to the two frames of captured video, if the license or facial image was not clear or readable, the frame (saved in jpeg format) was imported into the *PhotoShop* software program

(Version 5.5) and “cleaned” (e.g., contrast adjusted) to improve the clarity. The two frames of video and the tag information were then saved into a single *Microsoft PowerPoint* file. Figure 3 provides an example of video frames showing the vehicle/license plate, while Figure 4 shows the video frame of the driver’s profile. An outline of the non-video data (tag information) collected by the system is shown in Table 5.

Figure 3. Video frames of the vehicle/license plate.

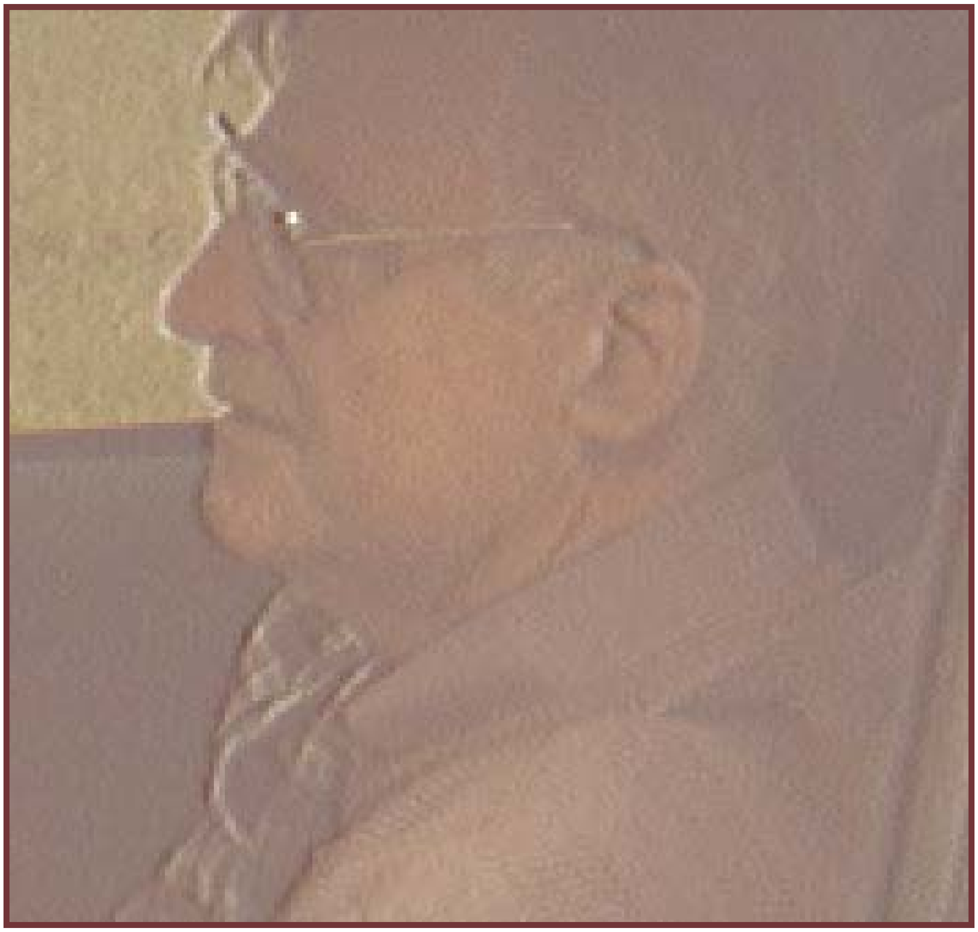


Figure 4. Violating driver's profile.

Table 5. Non-video data collected by the prototype system.

Data File Column	Variable	Description
1	Sync Number	Sync stamp of data corresponding to selected video frame (of license plate).
2	Triggered	0 = Not Triggered 1 = Invalid Trigger (bus driver protocol not followed)[1] 3 = Valid Trigger
3	Trigger Type	1 = Rear to Front (Overtaking) 2 = Front to Rear (Oncoming) 3 = Driver Button (driver can activate system by pressing dash-mounted button)
4	Amber Distance	Distance (ft.) the bus has traveled with amber (warning) lights on.
5	Amber Time	Elapsed time (sec.) that the amber lights have been flashing.
6	Stop Arm Time	Elapsed time (sec.) the stop arm has been extended.
7	Stop Arm Speed	Speed (ft./sec.) of bus when the stop arm was extended.
8	Violation Number	Each violation assigned a unique identifying number.
9	Violation Heading	Heading of violating vehicle (deg.)
10	Violator Speed	Average speed (ft./sec.) of violating vehicle.
11	Violator Offset	Distance (ft.) of the violating vehicle from the bus.
12	Driver button	0 = Off 1 = Depressed (driver button to indicate violation noticed)
13	Amber Light	0 = Off 1 = On
14	Stop Arm	0 = Closed 1 = Deployed
15	Bus Distance	Distance (ft.) bus has traveled.
16	Bus Speed	Speed of bus (ft./sec.)
17	Bus Latitude	Latitude (deg.) of bus as determined through GPS.
18	Bus Longitude	Longitude (deg.) of bus as determined through GPS.
19	Bus Heading	Heading (deg.) of bus as determined through GPS.
20	Date Information	Date (month, day, and year) of data capture.
21	Time Information	Time of data capture.

[1] Prior to a stop, the bus driver must turn on warning lights at least 100 feet before the stop if the posted speed limit is less than 35 mph, and at least 200 feet if the posted speed limit is 35 mph or more. Failure to do so will result in an "invalid trigger."

3.7 Overview of the Measures-of-Effectiveness

One way to measure the effectiveness of current automated enforcement technologies is to look at the reduction in violations (or crashes) as it relates to the number of citations that were issued. Since issuing citations is not a current feature of the prototype system, another measure of performance had to be created. Therefore qualitative analysis was performed in lieu of the issuance of citations. A conservative approach was taken in measuring the prototype system's effectiveness. This was done in an attempt to obtain a system effectiveness that would be equivalent to what is deemed a valid violation for other systems.

One of the primary goals of the analyses was to determine *System Recording Accuracy* (number of successful violation recordings, or "hits", divided by the number of opportunities, or tests). The *System Effectiveness* was determined by assessing the percentage of hits that were "usable." In regard to reading the license plate, usable hits were those where the license plate was not only detected, but could be clearly read (Readability/Discernability rating of 4 or 5, as shown in Figure 5). Similarly, usable hits for driver facial identification were detections in which the driver's face could be clearly identified (Readability/Discernability rating of 4 or 5). The scale values used in assessing Readability/Discernability are listed after the figure. Appendix D includes the protocol used to determine System Effectiveness and provides examples of images (both license plate and facial) rated from Very Low to Very High on the Readability/Discernability scale.

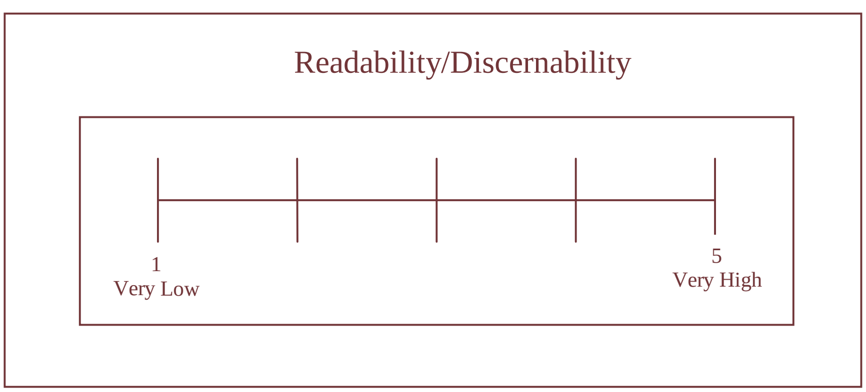


Figure 5. Five-point qualitative scale used to assess Readability/Discernability of each post-processed file.

3.7.1 Rating the License Plate

1 – Can see the entire plate, but may not see license due to glare, blurring, etc.

2 – Can read 1-2 letters/numbers of the license plate.

3 – Can read 3-4 letters/numbers of the license plate.

4 – Can read all letters/numbers.*

5 – Can read the entire plate, this includes all letters/numbers and the state.

*NOTE: letters/numbers does not refer to the state

3.7.2 Rating the Driver Facial Image

1 – Can see a facial image, but with very poor resolution (e.g., may not be clear due to glare).

2 – Can see a dark outline of face, with poor resolution.

3 – Can see a blurred facial image.

4 – Can see outline of driver's face (light image, close-up).

5 – Can see facial image clearly.

CHAPTER 4: PROTOTYPE SYSTEM SPECIFICATIONS

4.1 System Overview

Under the leadership of Andy Peterson, The Virginia Tech Transportation Institute's Hardware Engineering Lab designed and developed the prototype system. One of the key outputs of the feasibility analyses, a set of general recommended design specifications, was used in the design. The system that was identified as being the most promising had the following general characteristics:

- Five cameras: two 110 degree low-resolution cameras for violation detection and image subtraction, and three 640 x 480 high-resolution cameras for capturing front and rear license plates and a face view of the driver;
- A computer with three video channels and a video buffer;
- An infrared pulse source (to illuminate the driver's face in low-light conditions);
- Batteries (or hardwire to the bus' on-board battery); and
- Recording of pertinent non-video violation information.

As shown in the photograph in Figure 6 and in the schematics in Figures 7 and 8, views of the license plate and driver (profile angle) were captured by the high-resolution 640 x 480 violation recording cameras. These were located near the center axis of the bus; each violation recording camera faced a different direction (consistent with its purpose) and was positioned to provide maximum detail and field-of-view. Global views (covering a large portion of the detection zone) were provided by the set of two low-resolution violation detection cameras positioned at opposite ends of the bus in elevated locations. Detection was achieved using these low-resolution cameras by means of image subtraction techniques. The system was automatically activated once the bus' amber warning lights were switched on. Camera images were continually processed upon system activation, but images were only recorded onto the computer when a violation occurred. This was achieved by buffering the video images in memory. Pertinent non-video violation information (date and time, bus and location information, amount of warning time, and latency of the violation relative to extending the stop arm, etc.) was recorded in a data file that was linked to the video files. A detailed description of the major components of the prototype system is provided in the following sections.

Figure 6. School bus used in project.

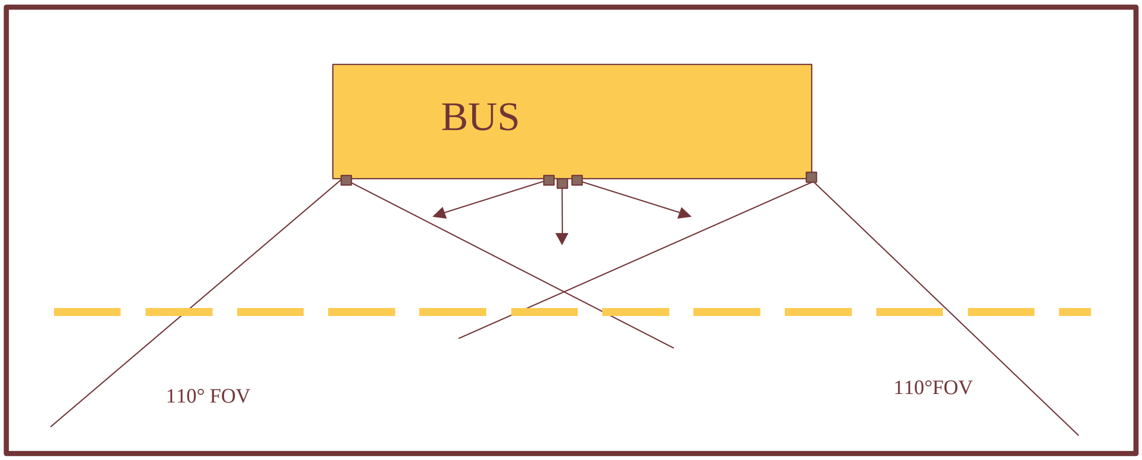


Figure 7. Schematic of the prototype system. Area of coverage is on driver's side.

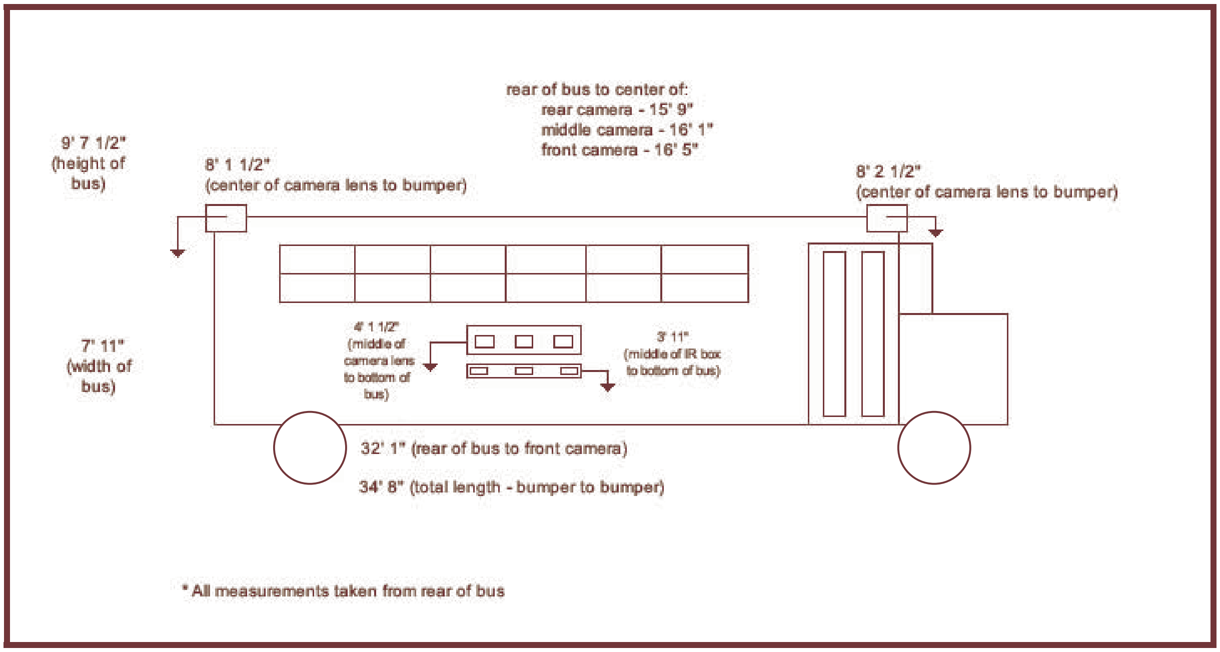


Figure 8. Schematic (side-view) outlining school bus and system components.

4.2 Computer Overview

The five system cameras were controlled by a computer positioned on the front seat of the bus (Figure 9). This computer actually consisted of three separate computers: (i) one master computer, (ii) one computer for the license plate cameras, and (iii) one computer for the driver profile camera.

Figure 9. Computer positioned on a seat at the front of the bus.

Each of the three computers held identical components. For example, each computer was a 1GHz Pentium III, and all had 256 M of RAM and a 40 GB hard drive. Each of the three computers also had a 3.5” Floppy drive and a 52X CD-ROM drive. They also had built-in sound cards, video cards, fax/modem cards, and Ethernet cards. The computers were equipped with FireWire (IEEE 1394) interface cards (AFW-4300), which have a maximum transmission speed of 400 MB per second. The FireWire cards were on a PCI bus. The AFW-4300 cards have three slots, but can only process a total of 30 frames per second.

The three computers were placed in a single unit rack mount system. The rack mount unit had a built-in power supply and was made for the motherboard to be plug-and-play. There were two computer guidelines that led to the decision for this system layout. First, the computers needed to be placed into a single rack mount unit which was approximately 2 inches high and 19-inches long by 19-inches wide. Second, the computers required a minimum of a 1 GHz Pentium III processor in order to function with the FireWire equipment.

4.2.1 Master Computer

The master computer ran and maintained the system, and triggered the system to record violation events. The master computer was equipped with two FireWire cameras that detected the motion of vehicles (violation detection cameras described later). Once the non-video data (described later) were collected, the master computer was used to download it onto a floppy disk.

4.2.2 Profile Computer

The profile computer was used to capture a profile of the driver as the vehicle passed the bus. Only one FireWire camera was connected to the profile computer. As such, the profile computer processed data at 30 frames per second. Once the profile data was collected, it was downloaded onto a zip disk.

4.2.3 License Plate Computer

The license plate computer was used to capture the front and rear license plates of the violating vehicle. This computer had two FireWire cameras connected to it. Each camera was running at

15 frames per second (maximum throughput was 30 frames per second, but with two cameras, the throughput was 15 frames per second per camera). Once the license plate data was collected, it was downloaded onto a zip disk.

4.3 Computer Integration

Figure 10 shows a system block diagram of how all the computers were connected/integrated. A power inverter was installed to provide 120 VAC to the computer equipment. The power inverter received its power from the school bus battery (a 12 VDC system); therefore, the computer could only be powered on if the school bus was running. After the power inverter was installed, the computers were installed and all connections were made. The power cords were plugged into a power strip and the keyboard, mouse, and monitor cables were all connected to a switch box. Since there were three separate computers and only one monitor, keyboard, and mouse, the switch box was turned to either "A," "B," or "C" to allow one computer to be used at a time.

The next step was to connect the computer to the system. This was done using a RS232/RS485 box which was connected to the Master computer serial port. (The other connector of the RS232/RS485 box was linked to the system.) Once the RS232/RS485 box was connected to the system, the other boxes were added to the network, which was capable of supporting 120 nodes. The cameras were then connected to the computer that stored the data. Once the data were collected, they were downloaded to portable memory (floppy and zip disks) for laboratory analysis.

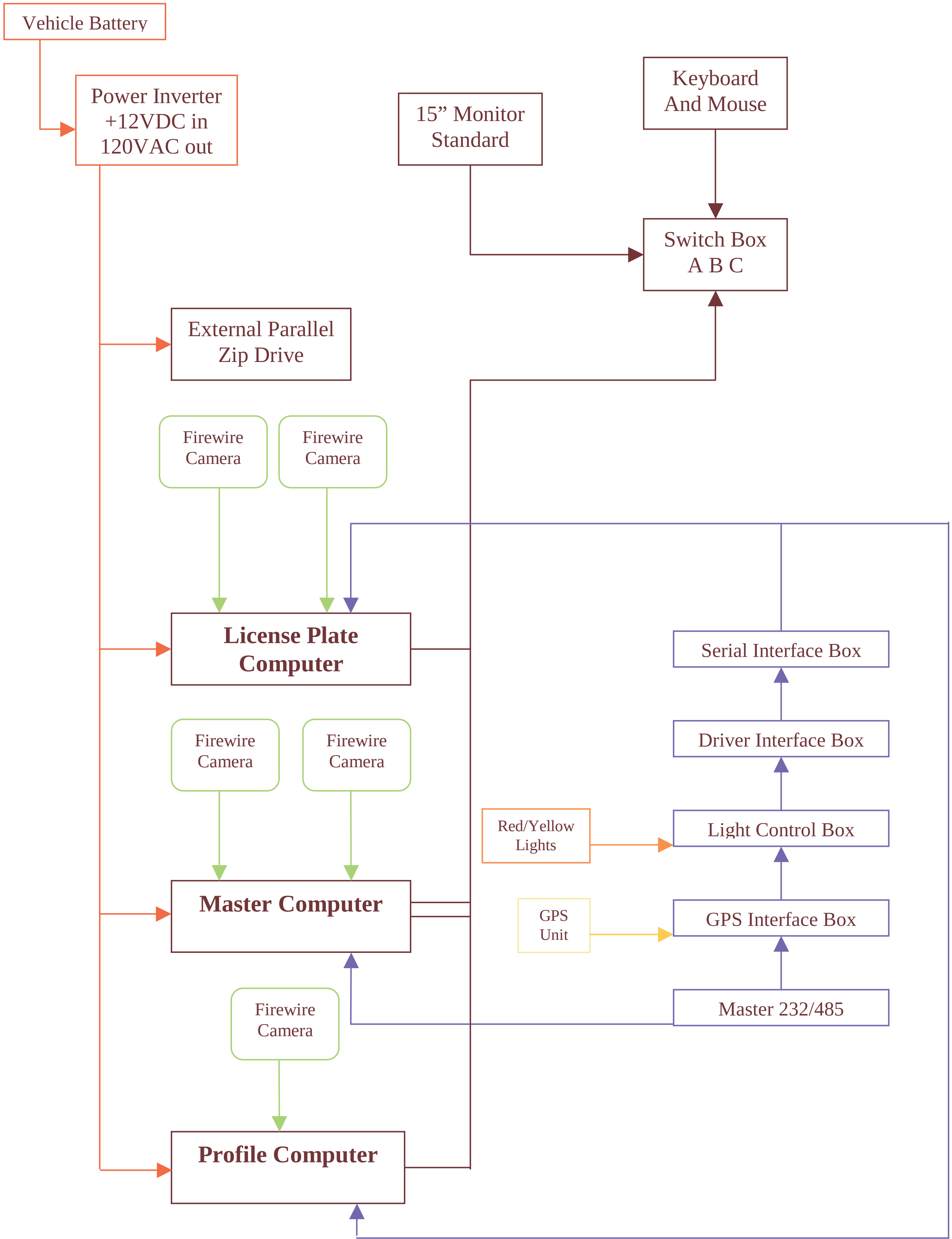


Figure 10. System block diagram.

4.4 Control Boxes

4.4.1 Serial Interface Box

Figure 11 shows a photograph of four of the control boxes used in the prototype system: the serial interface box, the master 232/485 box, the light control box, and the GPS interface box. The first of these boxes, the serial interface box, was used to split the serial network (which was 485) into two nodes on the network, one node for the license plate computer and one node for the profile computer. This box had two connectors: serial network-in and serial network-out.

Figure 11. Four control boxes used in the prototype system.

4.4.2 Master 232/485 Box

The master 232/485 box was used to convert the RS232 network from the computer to the RS485 network the prototype system uses. The master box was the first node on the network and had two connectors, RS232 from the computer, and RS485 out to the serial network.

4.4.3 Light Control Box

The light control box was connected to the red and yellow lights, which signaled the loading and unloading of school bus passengers. The computers were running the entire time the school bus was on its route, but an event was recorded only if the red and yellow lights were on at the time of the violation. The light control box had three connectors: one was connected to the lights on the bus, while the other two were used for serial network-in and serial network-out.

4.4.4 GPS Interface Box

The GPS interface box was used to interface the global positioning system (GPS) with the other school bus equipment. The GPS box tracked the school buses position (e.g., heading) while on its route. This box has three connectors: one is connected to the GPS unit, while the other two are used for serial network-in and serial network-out.

4.4.5 Driver Interface Box

The driver interface box (Figure 12) was used to give the bus driver a visual indicator that the system was working correctly. There were two LEDS on the box, one for a power indicator and one that indicated when the system was recording an event. There was also a momentary push-button on the box in case the system failed to trigger as it should (in which case the driver could manually trigger the system). The driver interface box had two connectors that were used for serial network-in and serial network-out.

Figure 12. Driver interface box.

4.5 System Cameras

4.5.1 Violation Detection Cameras

The violation detection cameras served to trigger the three violation recording cameras that recorded the license plate (x2) and driver profile (x1). Figure 13 shows the location on the bus of the violation detection cameras. As can be seen, there was a single camera on the top front corner on the driver's side and another on the top rear corner of the driver's side. These cameras were secured to the bus by two 60 lb pull magnets. Each camera used a 2.5 mm lens that provided a field-of-view of 110 degrees. A variety of lenses were tested to optimize the field-of-view for this application. Table 6 shows the field-of-view for a 2.5 mm lens from 5 feet to 30 feet. As indicated, the violation detection cameras were used to trigger the recording of an event. Once the yellow and red lights were turned on, these cameras "watched" for movement. When movement was detected, the system was triggered and recording commenced. As described previously, the violation detection cameras were connected to the master computer inside the bus. These cameras also served to record data associated with the violation, including speed of the violating vehicle and the distance offset of the vehicle from the bus. Each time an event was recorded, a corresponding data file with a unique identifying number/title was produced.

Figure 13. Violation detection cameras on front and rear of school bus.

Table 6. Field of view for 2.5 mm lens.

2.5 mm Lens 110 Degree FOV		
Distance	**Horizontal Width**	**Vertical Length**
5 ft	9.6 ft	7.2 ft
10 ft	19.2 ft	14.4 ft
15 ft	28.8 ft	21.6 ft
20 ft	38.4 ft	28.8 ft
25 ft	48 ft	36 ft
30 ft	57.6 ft	43.2 ft

4.5.2 Violation Recording Cameras

As shown in Figures 14 and 15, the three cameras that were used in the recording of the license plate and driver profile were located in a central location on the exterior of the bus (driver's side). A schematic of these cameras is shown in Figure 16. The three cameras were secured by four 60 lb pull magnets, while the mounting box was held on by a metal bracket and two 60 lb pull magnets. As indicated, the violation recording cameras were used to capture the license plate and the profile of the violating vehicle/driver. Within the three-camera configuration of the violation recording cameras, the primary purpose of the front and rear cameras was to capture the license plates. The rear-facing camera used a 16 mm lens (15 degrees field-of-view). The front-facing camera used a slightly larger 12 mm lens (22 degree field-of-view) so that the bus' stop arm could be viewed in the captured video. The center camera field-of-view was perpendicular to the bus and was used to capture a profile of the driver's face as he/she passed by. The profile camera used an 8 mm lens that provided a 35-degree field-of-view. It should be noted that a variety of lenses were tested to optimize the image captured by the cameras. Tables 7 and 8 show the field-of-view for a 12 mm lens and an 8 mm lens, respectively, from 5 feet to 30 feet.

Figure 14. Violation recording cameras positioned in a central location.

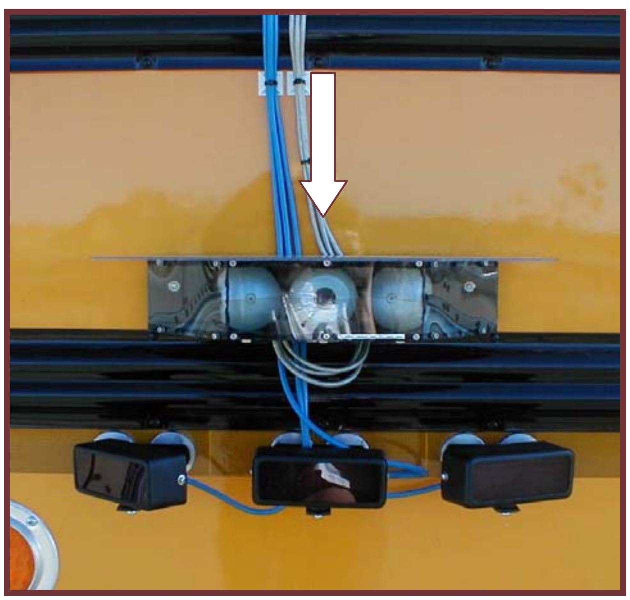


Figure 15. License plate and profile cameras.

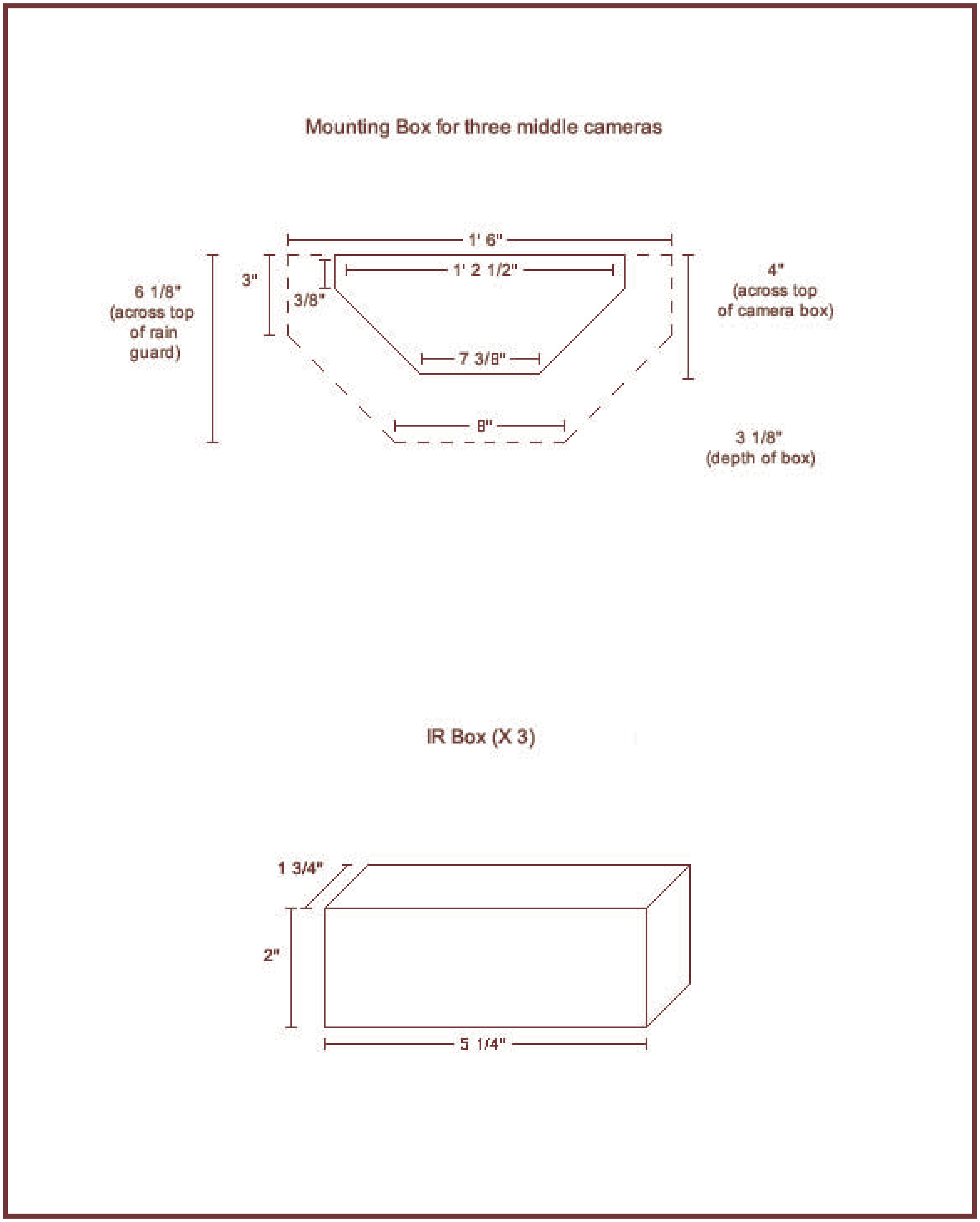


Figure 16. Schematic for the violation recording (middle) cameras and I/R boxes.

Table 7. Field of view for 12 mm lens.

12 mm Lens 22 Degree FOV		
Distance	**Horizontal Width**	**Vertical Length**
5 ft	2 ft	1.5 ft
7 ft	2.8 ft	2.1 ft
8 ft	3.2 ft	2.4 ft
9 ft	3.6 ft	2.7 ft
10 ft	4 ft	3 ft
11 ft	4.4 ft	3.3 ft
12 ft	4.8 ft	3.6 ft
14 ft	5.6 ft	4.2 ft
15 ft	6 ft	4.5 ft
20 ft	8 ft	6 ft
25 ft	10 ft	7.5 ft
30 ft	12 ft	9 ft

Table 8. Field of view for 8 mm lens.

8 mm Lens 35 Degree FOV		
Distance	**Horizontal Width**	**Vertical Length**
5 ft	3 ft	2.3 ft
7 ft	4.2 ft	3.2 ft
8 ft	4.8 ft	3.6 ft
9 ft	5.4 ft	4.1 ft
10 ft	6 ft	4.5 ft
11 ft	6.6 ft	5 ft
12 ft	7.2 ft	5.4 ft
14 ft	8.4 ft	6.3 ft
15 ft	9 ft	6.8 ft
20 ft	12 ft	9 ft
25 ft	15 ft	11.3 ft
30 ft	18 ft	13.5 ft

4.5.3 Camera Adjustments

4.5.3.1 License Plate Camera

The license plate cameras were adjusted so that the license plate of a violating vehicle, in the lane immediately adjacent to the bus, was in the center of the video frame. To accomplish this, the school bus was parked and a distance of five feet was measured parallel to the bus. Next, a car was positioned at the front and then at the rear of the school bus so that the car was parallel to the school bus. Finally, the angles of the cameras were adjusted to optimize for maximum viewing of the license plate (so that the license plate was in the center of the video image).

4.5.3.2 Profile Camera

The profile camera was adjusted in a similar way. The school bus was parked and a distance of five feet was measured parallel to the bus. Next, a car was placed in line with the profile camera that was mounted on the school bus. As with the license plate camera, the angle of the profile camera was then adjusted to optimize the license plate view.

Since the cameras had to be manually adjusted, a standard height was selected that seemed reasonable to record the profile of drivers in many automobiles that might pass by the bus. In the initial tests of the system, it was determined that if the camera was adjusted for pickup truck drivers, then automobile drivers would be missed. The opposite was also true; optimizing for automobiles lead to the profile camera being angled too low for pickup trucks. It was decided that since there are more automobiles than pickup trucks on the road, the optimal approach would be to set the camera for automobiles.

4.6 Infrared Pulse Source

An infrared (I/R) pulse source was mounted on the outside of the bus directly beneath the three violation recording cameras (Figure 17). The purpose of the I/R source was to illuminate the passing vehicle when there was not enough daylight to capture the vehicle without a secondary light source. The I/R light source had the following specifications: (i) weight was 11.5 ounces, (ii) power was 12 volts DC, (iii) current draw was 900 milliamps per unit, (iv) range was 40 feet, (v) emission angle was 45 degree horizontal, and (vi) light emitted was 880 nanometer wavelength.

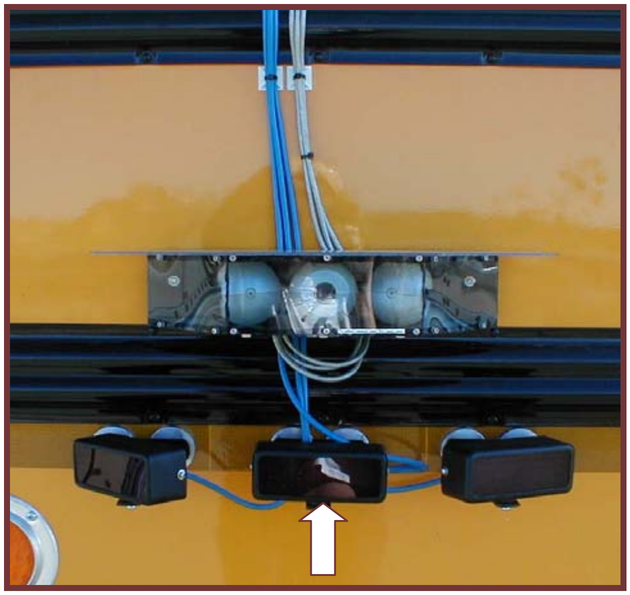


Figure 17. Three infrared pulse sources mounted on side of bus.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Overview

The detailed results from the prototype testing are presented in three sections. First, the findings from Phase I that was conducted on the Smart Road are presented. Second, the results from the Phase II actual route tests are presented. Third, the data from both phases are combined and the results presented. For each of the three sections, System Recording Accuracy, Readability/Discernability of the recording, and System Effectiveness are discussed for the variables manipulated in the tests.

Due to the length of the analysis, a summary of the system effectiveness results with page references is provided in Table 9.

Table 9. Phase I Summary of System Effectiveness

Condition	License Plate Effectiveness (%)	Facial Image Effectiveness (%)	Reference
Overall	51.5	11.0	Page 44
Lane 2	75.9	17.3	Page 47
Lane 3	9.4	0.0	
Lane 4	3.7	0.0	
Oncoming	30.4	10.8	Page 50
Overtaking	77.3	11.3	
Low Speed	53.8	11.4	Page 52
Moderate Speed	54.7	13.5	
High Speed	41.2	6.1	
Dawn	45.0	10.5	Page 55
Light	61.7	9.0	
Late Afternoon	52.9	25.9	
Dusk	5.3	0.0	
Dark	---	---	Page 73
Clear	43.9	12.2	Page 59
Fog	87.5	16.7	
Cloudy	100.0	0.0	
Rain	80.0	0.0	
North	55.6	0.0	Page62
South	44.4	11.1	
East	56.3	6.7	
West	52.4	26.1	
Not Recorded	50.9	9.3	
Headlights-Off	49.4	13.1	Page67
Standard Lights	54.7	7.8	
Daytime Running Lights	41.2	9.5	
High Beams	75.0	12.5	
Window-Up	75.9	10.3	Page70
Window-Down	47.0	11.5	
Window-Half-Down	0.0	0.0	
Not Recorded	50.0	0.0	

5.2 Phase I: Smart Road Tests

The Phase I tests were conducted on the Smart Road. This section outlines the findings from these tests. In the first sub-section, the accuracy, ratings, and effectiveness of the system are considered across all tests, and collapsed over all variables. This provides an overview of the test results irrespective of any independent variables (i.e., gives a global view of the findings). Subsequent sub-sections focus on each of the independent variables that were investigated.

5.2.1 General Results

5.2.1.1 System Recording Accuracy

A total of 183 tests were conducted in Phase I. Of these tests, 165[2] were used in the analysis. Twenty-one of the tests conducted involved multiple vehicles (two vehicles per test), resulting in more than one captured image (with a corresponding qualitative rating) for some of the conditions. Therefore, there were 186 different tests with ratings that were analyzed.

Note that the multiple vehicle tests involved vehicles passing the bus in unison (one vehicle following a lead vehicle), orthogonally (one vehicle passing in one lane while, at the same time, a second vehicle passed while moving from one lane to another), and simultaneously (one vehicle in Lane 2 and one vehicle in Lane 3). The results of these tests were that both vehicles were recorded as illegally passing the bus. However, in some cases where vehicles were positioned orthogonally or passed simultaneously, the vehicle closest to the bus may have blocked the view of the second vehicle. Even though a single test captured images of more than one vehicle, analyses were conducted on the images from both vehicles. As such, due to the multiple vehicle tests, there were more violation images to analyze than actual tests conducted.

The System Recording Accuracy is a measure of the number of violation recordings divided by the number of opportunities. Across the 186 analyzed tests, the System Recording Accuracy was 95.2 percent. That is, a violation recording (recording of the license plate or face) was made by at least one camera for 177 of the 186 vehicles that illegally passed the school bus.

Looking at the System Recording Accuracy as a function of the three violation recording cameras, the individual camera recording accuracies were:

- Rear Camera- 87.0 percent (n=177)
- Front Camera- 68.4 percent (n=177)
- Profile Camera- 83.1 percent (n=177)

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[2] This does not include dark condition tests (n=12), in which the system did not work (described later), or False Alarm tests (n=6), also described later.

Though the recording accuracy for the cameras was fairly high (at least one camera recorded the violation in 95.2 percent of the tests), the system did not record all violations. What caused the system to miss some of the violations? There are several reasons to explain why a violation was not recorded. One reason was that the video recording was not full motion; that is, the system was constrained at capturing either 15 frames/sec (front and rear camera), or 30 frames per/sec (profile camera). As such, for a small percentage of the tests, the frame that contained a license plate or face image was not always captured. A second cause for missed captures was that when the system first detected a violation, approximately 20 frames of blank video passed before an image was visible on the tape. These 20 frames were due to the system (cameras) pausing to adjust to the ambient light level. If a vehicle passed the bus during these 20 frames, no recording of the violation was made. A third reason for missed violations, specifically missed violations from the front camera, was that a lens with a relatively wide field-of-view was used on the front camera. The reason for this was the intent to record the flashing lights and stop arm with the front camera. With a wide field-of-view, the front camera was not directly focused on the license plate area, as was the case for the rear camera. As such, the front camera did not always capture an image of the license plate (thus reducing the recording accuracy for the front camera). Nonetheless, it is suggested that recording the stop-arm is an important feature associated with the system, and thus was a necessary tradeoff that had to be made.

The System Recording Accuracy was also determined from the recordings of the driver's frontal face through the windshield from the front and rear cameras. The System Recording Accuracy for this situation was 54.8 percent; that is, 97 recordings of the driver's frontal face where made over the 177 tests where the violation was recorded. It should be noted that no attempt was made to capture an image of the driver's frontal face in the system set-up; the focus was on capturing the driver's profile. It is believed that this percentage could be improved significantly in the next iteration of the system design by focusing a camera (perhaps additional cameras) at the driver's front windshield area. In the tests reported here, the rear camera was directed low to capture the vehicle's license plate, and the front camera was directed to capture the stop-arm and license plate.

5.2.1.2 Qualitative Ratings

Qualitative ratings to reflect readability/discernability were made for the clearest image that could be selected from a recording. These ratings ranged from very low quality (1) to very high quality (5). Ratings were made on 518 unique images. The mean ratings for these images were:

- License Plate- Rear Camera- 2.69 (n=154)
- License Plate- Front Camera- 3.16 (n=120)
- Driver Face- Profile Camera- 1.85 (n=147)
- Driver Face- Windshield- 1.95 (n=97) (note that these were collected from the Rear and/or Front Cameras)

An examination was also made of the "best" license plate image for a given test, using video data captured from either the rear or front camera. The qualitative rating only including this best license plate image was 2.98 (n = 167[3]).

It should be noted that an attempt was made to enhance a subset of the images using the *PhotoShop* software program. If it was believed that an image could be enhanced, an attempt was made to do so. However, the attempt at enhancement did not always improve the qualitative rating of the image (the enhancement never made the image less readable/discernable, but it did not always make it any better). An attempt was made to enhance 166 images. Of these, noticeable improvements in the image quality were made to only 16 images (9.6 percent); no improvement was observed for the remaining 150 images. For these 16 improved images, the qualitative rating was raised by an average of 1.0 point for each image (i.e., when enhancement was successful, the quality of the image improved, on average, by 20 percent). This finding suggests that the process of image enhancement should be examined further if there is a follow-on phase to the project.

5.2.1.3 System Effectiveness

System Effectiveness is defined as captured images that had qualitative readability/discernability ratings of "4" or "5" (i.e., a high quality image was recorded). Looking at both the un-enhanced

[3] 167 of the 177 tests where a violation was recorded had a captured license plate.

and enhanced images, 51 images had a rating of "4" and 35 images had a rating of "5" in the 167 tests that had a ratable license plate image. As such, the Overall System Effectiveness for capturing a clear image of the license plate, across all tests, was 51.5 percent. Although this value is lower than expected, it seems valid given how the system was designed. That is, the system was optimized to capture violating vehicles in the lane directly adjacent to the bus (i.e., Passing Lane 2, to address the most common violations). As such, and as will be detailed later, the System Effectiveness rating varied substantially as a function of the lane that the violating vehicle was in. The System Effectiveness for the three lanes that were tested was: (i) Lane 2, lane next to bus = 75.9 percent; (ii) Lane 3, one lane over from bus = 9.4 percent; and (iii) Lane 4, two lanes over from bus = 3.7 percent. From these findings, it is clear that the system was relatively effective for capturing violations in the lane immediately adjacent to the bus, but the effectiveness dropped off precipitously for lanes farther away from the bus.

Of the 177 tests that had valid recordings, 164 had ratable driver facial images (either profile or frontal image). Of these, nine images were rated a "4," and nine were rated a "5." Therefore, the Overall System Effectiveness for capturing the driver's facial image, across all tests, was 11.0 percent. As in the System Effectiveness for the license plate images, looking at the System Effectiveness of the driver's facial image as a function of the lane position of the violating vehicle, the breakdown of effectiveness results was (i) Lane 2, lane next to bus = 17.3 percent; (ii) Lane 3, one lane over from bus = 0.0 percent; and (iii) Lane 4, two lanes over from bus = 0.0 percent. As when capturing readable license plate images, the system was most effective in capturing the driver's facial image when the driver was in the lane immediately adjacent to the bus.

5.2.2 Passing Lane Scenario

5.2.2.1 System Recording Accuracy

Three Passing Lanes Scenarios were investigated: (i) Lane 2, the lane next to the bus, (ii) Lane 3, one lane over from the bus, and (iii) Lane 4, two lanes over from the bus. Recall, that 186 tests were analyzed in Phase I. System Recording Accuracy, as a function of passing lane, was as follows: (i) 94.9 percent for Lane 2, where 111 of the 117 tests that were conducted in Lane 2 had a valid recording; (ii) 97.1 percent for Lane 3, where 34 of the 35 tests that were conducted in Lane 3 had a valid recording; and (iii) 94.1 percent for Lane 4, where 32 of the 34 tests that were conducted in Lane 4 had a valid recording.

The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 10. (Note that in addition to parsing the accuracy values by cameras, a breakdown of the results for capturing the driver's facial image through the windshield is also presented).

Table 10. System Recording Accuracy results for the images from each camera, as a function of the Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Lane 2	86.5	111	87.4	111	81.1	111	59.5	111
Lane 3	94.1	34	58.8	34	85.3	34	55.9	34
Lane 4	81.3	32	15.6	32	87.5	32	34.4	32

5.2.2.2 System Effectiveness

The mean qualitative ratings of the images for each passing lane, as a function of the individual camera recordings, are shown in Table 11. Note that images from individual tests that had a quality rating of "4" or "5" were used to determine System Effectiveness.

Table 11. Qualitative ratings for each camera recording as a function of Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Lane 2	3.41	96	3.59	95	2.05	90	2.18	67
Lane 3	1.81	32	1.65	20	1.83	29	1.58	19
Lane 4	1.12	26	1.20	5	1.21	28	1.18	11

Of the 167 tests that had a ratable license plate image, 108 were in Passing Lane 2, 32 were in Passing Lane 3, and 27 were in Passing Lane 4. Of the of 108 Passing Lane 2 tests, 48 images were rated a "4" and 34 were rated a "5." Two images were rated a "4" and one was rated a "5" for the 32 Passing Lane 3 tests. For the 27 Passing Lane 4 tests, one image was rated a “4” and none were rated a “5.” Since System Effectiveness is defined as the percentage of violation captures that would be usable (i.e., an image that has a qualitative rating of 4 or 5), then the System Effectiveness for capturing the license plate of the violating vehicle was 75.9, 9.4, and 3.7 percent for Passing Lane 2, Passing Lane 3, and Passing Lane 4, respectively. A breakdown of the data used to determine these effectiveness ratings is presented in Table 12.

Table 12. System effectiveness for capturing high quality license plate images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	2- Lane Next to Bus	82	108	75.9
	3- One Lane Over From Bus	3	32	9.4
	4- Two Lanes Over from Bus	1	27	3.7

Of the 177 tests of valid recordings, 164 had ratable driver facial images. Of these 164 images, 104 were captured in Lane 2 tests, 31 were captured in Lane 3 tests, and 29 were captured in Lane 4 tests. For the Lane 2 tests, nine of the images were rated a “4” and nine were rated a “5;” thus, System Effectiveness for Lane 2 was 17.3 percent. For the Lane 3 and Lane 4 tests, none of the images were rated “4” or “5;” therefore, System Effectiveness was 0.0 percent for both of these lanes. Table 13 shows the breakdown of effectiveness ratings for each Passing Lane. Based on the System Effectiveness results from the license plate and driver facial image recordings, the system was found to be relatively effective for capturing images of violating vehicles that were in the lane directly adjacent to the bus; however, it was relatively ineffective in recording quality images when the violating vehicle passed the bus in lanes that were further away.

Table 13. System effectiveness for capturing high quality and driver facial images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	2- Lane Next to Bus	18	104	17.3
	3- One Lane Over From Bus	0	31	0.0
	4- Two Lanes Over from Bus	0	29	0.0

5.2.3 Violation Passing Scenario

5.2.3.1 System Recording Accuracy

Two Violation Passing scenarios were investigated: (i) Oncoming and (ii) Overtaking. System Recording Accuracy was 95.3 percent for the Oncoming scenario, where 102 of the 107 tests were recorded. For the Overtaking scenario, System Recording Accuracy was 94.9 percent, where 75 of the 79 tests were recorded. The results from the System Recording Accuracy, as a function of the camera recordings, are shown in Table 14.

Table 14. System Recording Accuracy results for the images from each camera as a function of Violation Passing Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	88.2	102	46.1	102	81.4	102	54.9	102
Overtaking	85.3	75	98.7	75	85.3	75	54.7	75

5.2.3.2 System Effectiveness

The mean qualitative ratings of the images for each Passing Scenario, as a function of the camera recordings, are shown in Table 15.

Table 15. Qualitative ratings for each camera recording as a function of Violation Passing Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	2.05	90	2.78	47	1.74	83	1.91	56
Overtaking	3.58	64	3.41	73	2.00	64	2.00	41

Of the 167 tests that had a ratable license plate image, 92 were in the Oncoming scenario and 75 were in the Overtaking scenario. Across the 92 Oncoming scenario tests, 16 images were rated a "4" and 12 were rated a "5." Thirty-five images in the 75 Overtaking scenario tests were rated a "4" and 23 were rated a "5." The System Effectiveness for capturing the license plate of the violating vehicle, across all tests, was 30.4 percent (28 images rated "4" or "5" divided by 92 ratable tests) for the Oncoming scenario, and 77.3 percent (58 images rated a "4" or "5" divided by 75 ratable tests) for the Overtaking scenario. Note that this percentage represents System Effectiveness for all 167 tests, including tests where the vehicle was as far as two lanes away from the bus. Table 16 parses the System Effectiveness percentages as a function of the passing lane of the violating vehicle. As can be seen, regardless of the scenario, the primary factor in the effectiveness of the system in capturing a high quality license plate image was the lane position of the violating vehicle.

Table 16. System effectiveness for capturing high quality license plate images as a function of Violation Passing Scenario.

<table>
<tr><th></th><th>Violation Passing Scenario</th><th>Lane #</th><th># Images Rated 4 or 5</th><th># Tests Conducted With Ratable Images</th><th>System Effectiveness %</th></tr>
<tr><td rowspan="4">License Plate Image</td><td>Oncoming</td><td>2</td><td>24</td><td>33</td><td>72.7</td></tr>
<tr><td>Oncoming</td><td>3</td><td>3</td><td>32</td><td>9.4</td></tr>
<tr><td>Oncoming</td><td>4</td><td>1</td><td>27</td><td>3.7</td></tr>
<tr><td>Overtaking</td><td>2</td><td>58</td><td>75</td><td>77.3</td></tr>
</table>

Of the 164 ratable facial images, 93 were in the Oncoming scenario and 71 were in the Overtaking scenario. Of the 93 Oncoming scenario tests that had a ratable facial image, three images were rated a “4” and seven were rated a “5.” For the 71 Overtaking scenario tests, six had a rating of “4” and two had a rating of “5.” The System Effectiveness for capturing the driver’s face, across all tests, was 10.8 percent (10 images rated “4” or “5” divided by 93 ratable tests) for the Oncoming scenario, and 11.3 percent (eight images rated a “4” or “5” divided by 71 ratable tests) for the Overtaking scenario. Note that this percentage represents System Effectiveness for all 164 tests with a ratable facial image. Table 17 parses the System Effectiveness percentages as a function of the passing lane of the violating vehicle. As with the breakdown of effectiveness ratings for the license plate recordings, the significant impact of lane position on capturing a high quality image is very clear.

Table 17. System effectiveness for capturing high quality driver facial images as a function of Violation Passing Scenario.

	Violation Passing Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Oncoming	2	10	33	30.3
	Oncoming	3	0	31	0.0
	Oncoming	4	0	29	0.0
	Overtaking	2	8	71	11.3

5.2.4 Speed of Violating Vehicle

5.2.4.1 System Recording Accuracy

Three speeds for the violating vehicle were investigated: (i) Low Speed (10 mph), (ii) Moderate Speed (20 mph), and (iii) High Speed (40 mph). System Recording Accuracy was 96.6 percent for Low Speed, in which 84 of the 87 tests were recorded. For the Moderate Speed, System Recording Accuracy was 91.9 percent, in which 57 of the 62 tests were recorded. For the High Speed, System Recording Accuracy was 97.3 percent, in which 36 of the 37 tests were recorded. The results from the System Recording Accuracy are shown in Table 18.

Table 18. System Recording Accuracy results for the images from each camera as a function of Speed of Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low	89.3	84	73.8	84	89.3	84	63.1	84
Moderate	86.0	57	68.4	57	80.7	57	52.6	57
High	83.3	36	55.6	36	72.2	36	38.9	36

5.2.4.2 System Effectiveness

The mean qualitative ratings of the images for each violating vehicle speed, as a function of the camera recordings, are shown in Table 19.

Table 19. Qualitative ratings for each camera recording as a function of Speed of Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low	2.74	75	3.26	61	1.34	75	1.98	53
Moderate	2.82	49	3.21	39	1.72	46	1.93	30
High	2.37	30	2.80	20	1.42	26	1.86	14

Of the 167 tests that had a ratable license image, 80 were in the Low Speed condition, 53 were in the Moderate Speed condition, and 34 were in the High Speed condition. Across the 80 Low Speed tests, 19 images were rated a "4" and 24 were rated a "5." For the 53 Moderate Speed tests, 20 images were rated a "4" and nine were rated a "5." For the 34 High Speed tests, 12 images were rated a "4" and two were rated a "5." Based on these values, the System Effectiveness for capturing the license plate of the violating vehicle was 53.8, 54.7, and 41.2 percent for Low Speed, Moderate Speed, and High Speed, respectively. Table 20 breaks down the effectiveness ratings for the license plate images for each speed, as a function of the lane that the violating vehicle was in. Across all lanes, the system performed best in capturing quality license plate images in the Low Speed condition.

Table 20. System effectiveness for capturing high quality license plate images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Low	2	39	51	76.5
	Low	3	3	17	17.6
	Low	4	1	12	8.3
	Moderate	2	29	36	80.6
	Moderate	3	0	9	0.0
	Moderate	4	0	8	0.0
	High	2	14	21	66.7
	High	3	0	6	0.0
	High	4	0	7	0.0

Of the 164 ratable facial images, 79 were in the Low Speed condition, 52 were in the Moderate Speed condition, and 33 were in the High Speed condition. Across the 79 Low Speed tests, five images were rated a “4” and four images were rated a “5”. Three images were rated a “4” in the 52 Moderate Speed tests, and four were rated a “5.” For the 33 High Speed tests, one image was rated a “4” and one was rated a “5.” Across all lane positions, the System Effectiveness for capturing the driver facial image was 11.4, 13.5, and 6.1 percent for Low Speed, Moderate Speed, and High Speed, respectively. Table 21 outlines the System Effectiveness ratings for the three speeds as a function of lane position. Notice that for all speeds and for both license plate and driver facial images, the system performed the best in Lane 2.

Table 21. System effectiveness for capturing high quality driver facial images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Low	2	9	50	18.0
	Low	3	0	16	0.0
	Low	4	0	13	0.0
	Moderate	2	7	35	20.0
	Moderate	3	0	9	0.0
	Moderate	4	0	8	0.0
	High	2	2	19	10.5
	High	3	0	6	0.0
	High	4	0	8	0.0

5.2.5 Ambient Conditions

For this study, "Dawn" was defined as the time prior to, and shortly after, sunrise[4] (approximately 7:00 a.m.). "Dusk" was defined as the time prior to, and shortly after, sunset (approximately 5:15 p.m.). "Light" was defined as the hours between Dawn and Dusk prior to 3:00 p.m., and "Late Afternoon" was defined as the hours between Dawn and Dusk after 3:00 p.m.

5.2.5.1 System Recording Accuracy

Five Ambient Conditions were investigated: (i) Dawn, (ii) Light, (iii) Late Afternoon, (iv) Dusk, and (v) Dark. Table 22 shows the average values of the light readings for Phase I.

[4] It is important to point out that the data were collected in November and December 2001 in Blacksburg, Virginia.

Table 22. Measure of Light recordings for the tests as a function of Ambient Condition.

Ambient Condition	Average Light (klx)
Dawn	1.180
Light	42.407
Late Afternoon	4.281
Dusk	0.235
Dark	0.002

Although reliable data were collected for the first four conditions listed, the system did not work in the Dark condition; a discussion of the failure of the system in the Dark condition is presented later. System Recording Accuracy was 87.0 percent for the Dawn condition, where 20 of the 23 tests were recorded. For the Light condition, System Recording Accuracy was 94.4 percent, where 101 of the 107 tests were recorded. System Recording Accuracy was 100.0 percent for the Late Afternoon condition, where all of the 35 conducted tests were recorded. For the Dusk condition, System Recording Accuracy was 100.0 percent, where all of the 21 tests conducted were recorded. The results from the System Recording Accuracy are shown in Table 23.

Table 23. System Recording Accuracy results for the images from each camera as a function of Ambient Condition.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Ambient Condition	Mean	n	Mean	n	Mean	n	Mean	n
Dawn	90.0	20	85.0	20	90.0	20	70.0	20
Light	86.1	101	72.3	101	86.1	101	62.4	101
Late Afternoon	94.3	35	48.6	35	68.6	35	42.9	35
Dusk	76.2	21	61.9	21	85.7	21	23.8	21

5.2.5.2 System Effectiveness

The mean qualitative ratings of the images for each Ambient Condition, as a function of the camera recordings, are shown in Table 24.

Table 24. Qualitative ratings for each camera recording as a function of Ambient Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Ambient Condition	Mean	n	Mean	n	Mean	n	Mean	n
Dawn	2.11	18	3.35	17	1.61	18	1.57	14
Light	3.03	87	3.11	73	1.84	87	1.88	63
Late Afternoon	2.72	33	4.53	17	2.58	24	2.73	15
Dusk	1.19	16	1.46	13	1.17	18	1.60	5

Of the 167 tests that had a ratable license plate image, 20 were in the Dawn condition, 94 were in the Light condition, 34 were in the Late Afternoon condition, and 19 were in the Dusk condition. Across the 20 Dawn tests, six images were rated a "4" and three were rated a "5." For the 94 Light tests, 38 images were rated a "4" and 20 were rated a "5." Six images were rated a "4" and 12 were rated a "5" of the 34 Late Afternoon tests. For the 19 Dusk tests, one image was rated a "4" but none were rated a "5." The System Effectiveness for capturing the license plate of the violating vehicle was 45.0, 61.7, 52.9, and 5.3 percent for Dawn, Light, Late Afternoon, and Dusk, respectively. Table 25 shows the System Effectiveness ratings parsed as a function of the lane that the violating vehicle was in.

Table 25. System effectiveness for capturing high quality license plate images as a function of Ambient Condition.

	Ambient Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Dawn	2	9	16	56.3
	Dawn	3	0	2	0.0
	Dawn	4	0	2	0.0
	Light	2	54	56	96.4
	Light	3	3	21	14.3
	Light	4	1	17	5.9
	Late Afternoon	2	18	22	81.8
	Late Afternoon	3	0	6	0.0
	Late Afternoon	4	0	6	0.0
	Dusk	2	1	14	7.1
	Dusk	3	0	3	0.0
	Dusk	4	0	2	0.0

Of the 164 ratable facial images, 19 were in the Dawn condition, 100 were in the Light condition, 27 were in the Late Afternoon condition, and 18 were in the Dusk condition. Across the 19 Dawn tests, two images were rated a “4” and none were rated a “5.” For the 100 Light tests, four images were rated a “4” and five were rated a “5.” For the 27 Late Afternoon tests, three images were rated a “4” and four were rated a “5.” Across the 18 Dusk tests, no images were rated “4” or “5.” The System Effectiveness for capturing the driver’s face was 10.5, 9.0, 25.9, and 0.0 percent for Dawn, Light, Late Afternoon, and Dusk, respectively. Table 26 shows the effectiveness ratings as a function of the violating vehicle’s passing lane. As with the previous variables, the violating vehicle’s lane position impacted the effectiveness of capturing a high quality license plate or driver facial image.

Table 26. System effectiveness for capturing high quality driver facial images as a function of Ambient Condition.

	Ambient Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Dawn	2	2	15	13.3
	Dawn	3	0	2	0.0
	Dawn	4	0	2	0.0
	Light	2	9	57	15.8
	Light	3	0	23	0.0
	Light	4	0	20	0.0
	Late Afternoon	2	7	18	38.9
	Late Afternoon	3	0	4	0.0
	Late Afternoon	4	0	5	0.0
	Dusk	2	0	14	0.0
	Dusk	3	0	2	0.0
	Dusk	4	0	2	0.0

5.2.6 Weather Conditions

5.2.6.1 System Recording Accuracy

Four Weather Conditions were investigated: (i) Clear, (ii) Fog, (iii) Cloudy, and (iv) Rain. System Recording Accuracy for the Clear condition was 96.0 percent, where 144 of the 150 tests were recorded. For the Fog condition, System Recording Accuracy was 100.0 percent, where all of the 12 tests conducted were recorded. For the Cloudy condition, System Recording Accuracy was 78.6 percent, where 11 of the 14 tests were recorded. For the Rain condition, System Recording Accuracy was 100.0 percent, in which all of the 10 tests conducted were recorded. The results from the System Recording Accuracy are shown in Table 27. The accuracy levels were moderately high across the four Weather Conditions, except for Fog (rear camera). This was likely due to the adjustment difficulties for the rear camera for this particular condition.

Table 27. System Recording Accuracy results for the images from each camera as a function of Weather Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Weather Condition	Mean	n	Mean	n	Mean	n	Mean	n
Clear	92.4	144	66.7	144	79.2	144	63.2	144
Fog	0.0	12	58.3	12	100.0	12	16.7	12
Cloudy	100.0	11	90.9	11	100.0	11	36.4	11
Rain	100.0	10	70.0	10	100.0	10	0.0	10

5.2.6.2 System Effectiveness

The mean qualitative ratings of the images for each Weather Condition, as a function of the camera recordings, are shown in Table 28.

Table 28. Qualitative ratings for each camera recording as a function of Weather Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Weather Condition	Mean	n	Mean	n	Mean	n	Mean	n
Clear	2.46	133	3.01	96	1.83	114	2.01	91
Fog	N/A	N/A	3.57	7	2.58	12	1.00	2
Cloudy	4.09	11	3.90	10	1.55	11	1.00	4
Rain	3.80	10	3.86	7	1.70	10	N/A	N/A

Of the 167 ratable license plate images, 139 were in the Clear condition, seven were in the Fog condition, 11 were in the Cloudy condition, and 10 were in the Rain condition. Across the 139 Clear tests, 29 images were rated a “4” and 32 were rated a “5.” For the seven Fog tests, six images were rated a “4” and none were rated a “5.” For the 11 Cloudy tests, 10 images were rated a “4” and one was rated a “5.” For the 10 Rain tests, six images were rated a “4” and two were rated a “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 43.9, 87.5, 100.0, and 80.0 percent for Clear, Fog, Cloudy, and Rain, respectively. Table 29 shows the System Effectiveness as a function of Lane Position.

Table 29. System effectiveness for capturing high quality license plate images as a function of Weather Condition.

	Weather Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Clear	2	58	84	69.0
	Clear	3	2	30	6.7
	Clear	4	1	25	4.0
	Fog	2	6	6	100.0
	Fog	3	0	0	0.0
	Fog	4	0	1	0.0
	Cloudy	2	11	11	100.0
	Cloudy	3	N/A	N/A	N/A
	Cloudy	4	N/A	N/A	N/A
	Rain	2	7	7	100.0
	Rain	3	1	2	50.0
	Rain	4	0	1	0.0

Of the 164 ratable facial images, 131 were in the Clear condition, 12 were in the Fog condition, 11 were in the Cloudy condition, and 10 were in the Rain condition. Across the 131 Clear tests, seven images were rated a “4” and nine were rated a “5.” For the 12 Fog tests, two images were rated a “4” and none were rated a “5.” For the 11 Cloudy tests, no images were rated a “4” or a “5,” and no images were rated a “4” or a “5” for the 10 Rain tests. The System Effectiveness for capturing the driver facial image was 12.2, 16.7, 0.0, and 0.0 percent for Clear, Fog, Cloudy, and Rain, respectively. Table 30 shows the System Effectiveness as a function of lane position.

Table 30. System effectiveness for capturing high quality driver facial images as a function of Weather Condition.

	Weather Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Clear	2	16	78	20.5
	Clear	3	0	27	0.0
	Clear	4	0	26	0.0
	Fog	2	2	8	25.0
	Fog	3	0	2	0.0
	Fog	4	0	2	0.0
	Cloudy	2	0	11	0.0
	Cloudy	3	N/A	N/A	N/A
	Cloudy	4	N/A	N/A	N/A
	Rain	2	0	7	0.0
	Rain	3	0	2	0.0
	Rain	4	0	1	0.0

5.2.7 Direction of Light Conditions

The Directional Light variable was examined to determine the impact that various sunlight angles had on the cameras. In essence, this condition looked at how effective the system was when the camera was directly in the sun or partly/fully shaded. Given the time of year and time of day that testing occurred, as well as the position of the bus on the Smart Road, the sun was positioned in the West when the nose of the bus was pointed South (Figure 18).

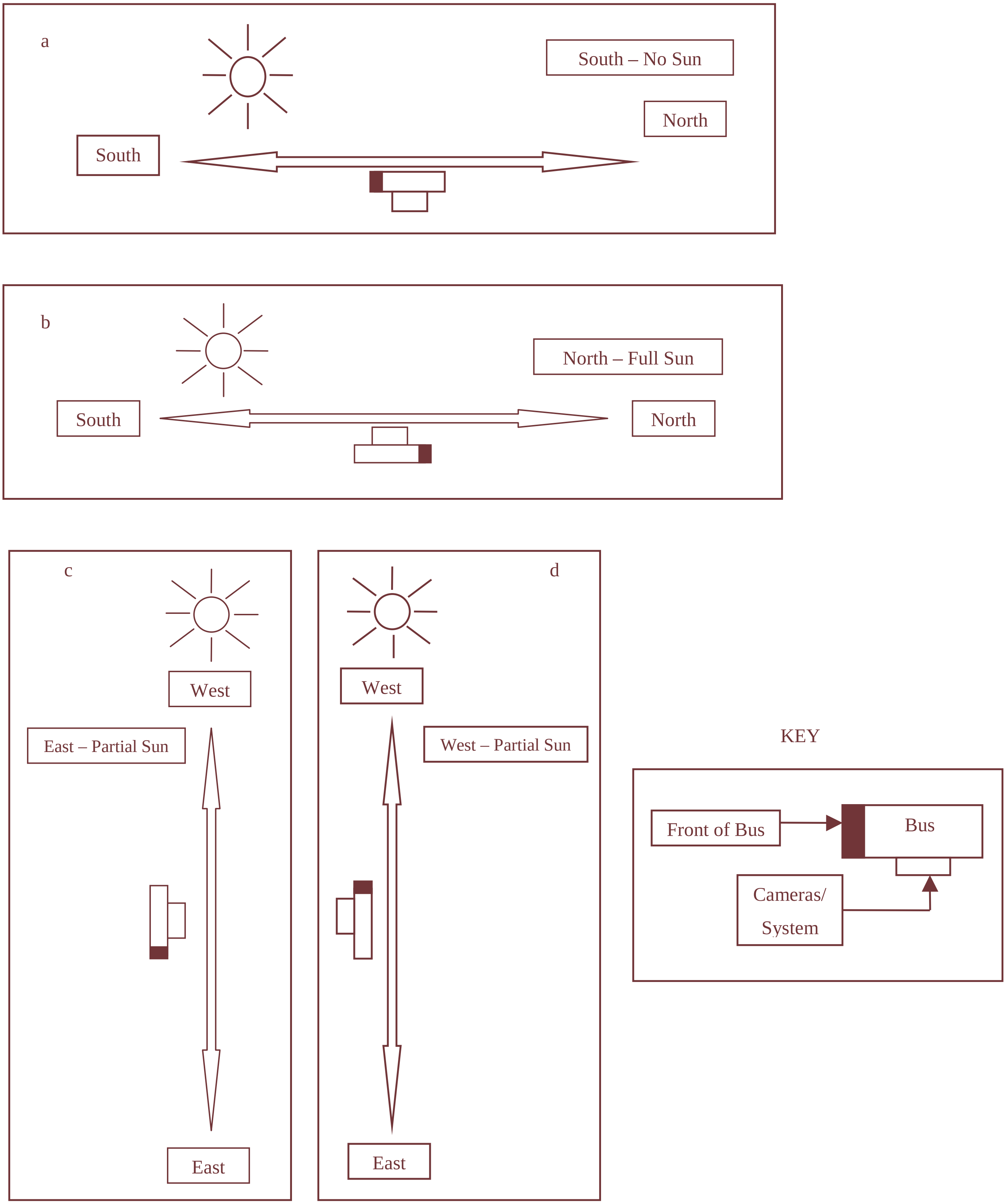

Figure 18. Illustration of Direction of Light conditions: a. South, b. North, c. East, d. West.

As shown in the (a) portion of the previous figure, the system, which was on the left (driver's) side of the bus, was completely shaded in the South condition. Similarly, the North condition refers to the camera in full sunlight. And, the East and West conditions refer to the camera in partial sunlight. It should be noted that this condition was only tested for the Light Ambient Condition in Clear Weather.

5.2.7.1 System Recording Accuracy

As indicated, five Direction of Light conditions were investigated: (i) North, (ii) South, (iii) East, (iv) West, and (v) Not Recorded.[5] System Recording Accuracy was 100.0 percent for the North condition, where all of the nine tests conducted were recorded. For the South condition, System Recording Accuracy was 90.0 percent, in which nine of the ten tests were recorded. For the East condition, System Recording Accuracy was 88.9 percent, where 16 of the 18 tests were recorded. For the West condition, System Recording Accuracy was 100.0 percent, where all 23 of the tests conducted were recorded. System Recording Accuracy was 95.2 percent for the Not Recorded condition, in which 120 of the 126 tests were recorded. The results from the System Recording Accuracy for each Direction of Light, as a function of the different camera recordings, are shown in Table 31.

Table 31. System Recording Accuracy results for the images from each camera as a function of Direction of Light.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Direction of Light	Mean	n	Mean	n	Mean	n	Mean	n
North	100.0	9	77.8	9	66.7	9	66.7	9
South	100.0	9	77.8	9	88.9	9	66.7	9
East	100.0	16	62.5	16	68.8	16	75.0	16
West	87.0	23	44.9	23	78.3	23	100.0	23
Not Recorded	83.3	120	66.7	120	86.7	120	41.7	120

[5] For example, the tests where the Direction of Light as Not Recorded included conditions such as Cloudy, Fog, Rain, Dark, etc.

5.2.7.2 System Effectiveness

The mean qualitative ratings of the images for each Direction of Light, as a function of the camera recordings, are shown in Table 32.

Table 32. Qualitative ratings for each camera recording as a function of Direction of Light.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Direction of Light	Mean	n	Mean	n	Mean	n	Mean	n
North	2.33	9	3.28	7	1.50	6	1.33	6
South	2.55	9	3.14	7	1.50	8	2.17	6
East	3.19	16	3.50	10	2.18	11	1.92	12
West	2.95	20	2.77	17	1.95	18	2.39	23
Not Recorded	2.60	100	3.21	79	1.85	104	1.80	50

Of the 167 ratable license plate images, nine were in the North condition, nine were in the South condition, 16 were in the East condition, 21 were in the West condition, and 112 were in the Not Recorded condition. Across the nine tests in the North direction, three images were rated a “4” and two were rated a “5.” For the nine tests in the South direction, three images were a “4” and one was rated a “5.” Of the 16 tests in the East direction, five images were rated a “4” and four were rated a “5.” For the 21 tests in the West direction, four images were rated a “4” and seven were rated a “5.” For the 112 tests in the Not Recorded condition, 36 images were rated a “4” and 21 were rated a “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 55.6, 44.4, 56.3, 52.4, and 50.9 percent for North, South, East, West, and Not Recorded, respectively. Table 33 shows the System Effectiveness ratings for the three lane positions that were tested.

Table 33. System effectiveness for capturing high quality license plate images as a function of Direction of Light.

	Direction of Light Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	North	2	5	5	100.0
	North	3	0	2	0.0
	North	4	0	2	0.0
	South	2	4	4	100.0
	South	3	0	2	0.0
	South	4	0	3	0.0
	East	2	9	10	90.0
	East	3	0	4	0.0
	East	4	0	2	0.0
	West	2	11	11	100.0
	West	3	0	6	0.0
	West	4	0	4	0.0
	Not Recorded	2	53	78	67.9
	Not Recorded	3	3	18	16.7
	Not Recorded	4	1	16	6.3

Of the 164 ratable facial images, nine were in the North condition, nine were in the South condition, 15 were in the East condition, 23 were in the West condition, and 108 were in the Not Recorded condition. Across the nine tests in the North direction, no images were rated a “4” or a “5.” For the nine tests in the South direction, one image was rated a “4” and none were rated a “5.” For the 15 tests in the East direction, no images were rated a “4” and one was rated a “5.” For the 23 tests in the West direction, two images were rated a “4” and four were rated a “5.” For the 108 tests in the Not Recorded condition, six images were rated a “4” and four were rated a “5.” The System Effectiveness for capturing the driver facial image was 0.0, 11.1, 6.7, 26.1, and 9.3 percent for North, South, East, West, and Not Recorded, respectively. Table 34 shows the effectiveness breakdown for each lane position.

Table 34. System effectiveness for capturing high quality driver facial images as a function of Direction of Light.

	Direction of Light Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	North	2	0	5	0.0
	North	3	0	2	0.0
	North	4	0	2	0.0
	South	2	1	4	25.0
	South	3	0	2	0.0
	South	4	0	3	0.0
	East	2	1	9	11.1
	East	3	0	4	0.0
	East	4	0	2	0.0
	West	2	6	11	54.5
	West	3	0	6	0.0
	West	4	0	6	0.0
	Not Recorded	2	10	75	13.3
	Not Recorded	3	0	17	0.0
	Not Recorded	4	0	16	0.0

5.2.8 Headlight Scenario

5.2.8.1 System Recording Accuracy

Four Headlight Scenarios were investigated: (i) Headlights-Off, (ii) Standard Lights, (iii) Daytime Running Lights, and (iv) High Beams. System Recording Accuracy was 95.9 percent, where 94 of the 98 tests were recorded in the Headlights-Off scenario. For the Standard Lights scenario, System Recording Accuracy was 93.0 percent, where 53 of the 57 tests were recorded. For the Daytime Running Lights scenario, System Recording Accuracy was 95.7 percent, where 22 of the 23 tests were recorded. For the High Beams scenario, System Recording Accuracy was 100.0 percent, where all of the eight tests conducted were recorded. The results from the System Recording Accuracy for each Headlight Scenario, as a function of the different camera recordings, are shown in Table 35.

Table 35. System Recording Accuracy results for the images from each camera as a function of the Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	91.5	94	67.0	94	75.5	94	68.1	94
Standard Lights	90.6	53	73.6	53	90.6	53	41.5	53
Daytime Running Lights	63.6	22	50.0	22	90.9	22	40.9	22
High Beams	75.0	8	100.0	8	100.0	8	25.0	8

5.2.8.2 System Effectiveness

The mean qualitative ratings of the images for each Headlight Scenario, as a function of the camera recordings, are shown in Table 36.

Table 36. Qualitative ratings for each camera recording as a function of Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	2.68	86	2.99	62	1.90	71	2.10	64
Standard Lights	2.73	48	3.31	39	1.65	48	1.41	22
Daytime Running Lights	2.36	14	3.36	11	2.00	20	2.22	9
High Beams	3.17	6	3.63	8	2.25	8	2.00	2

Of the 167 ratable license plate images, 89 were in the Headlights-Off scenario, 53 were in the Standard Lights scenario, 17 were in the Daytime Running Lights scenario, and eight were in the High Beams scenario. Across the 89 Headlights-Off tests, 19 images were rated a “4” and 25 were rated a “5.” For the 53 Standard Lights tests, 25 images were rated a “4” and four were rated a “5.” For the 17 Daytime Running Lights tests, four images were rated a “4” and three were rated a “5.” For the eight High Beams tests, three images were rated a “4” and three were rated a “5.” Using these values, the System Effectiveness for capturing the license plate of the violating vehicle was 49.4, 54.7, 41.2, and 75.0 percent, for Headlights-Off, Standard Lights, Daytime Running Lights, and High Beams, respectively. Table 37 shows the effectiveness ratings for each lane position.

Table 37. System effectiveness for capturing high quality license plate images as a function of Headlight Scenario.

	Headlight Scenarios	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Headlights-Off	2	41	53	77.4
	Headlights-Off	3	2	20	10.0
	Headlights-Off	4	1	16	6.3
	Standard Lights	2	28	37	75.7
	Standard Lights	3	1	8	12.5
	Standard Lights	4	0	8	0.0
	Daytime Running Lights	2	7	10	70.0
	Daytime Running Lights	3	0	4	0.0
	Daytime Running Lights	4	0	3	0.0
	High Beams	2	6	8	75.0
	High Beams	3	N/A	N/A	N/A
	High Beams	4	N/A	N/A	N/A

Of the 164 ratable facial images, 84 were in the Headlights-Off scenario, 51 were in the Standard Lights scenario, 21 were in the Daytime Running Lights scenario, and eight were in the High Beams scenario. Across the 84 Headlights-Off tests, five images were rated a “4” and six were rated a “5.” For the 51 Standard Lights tests, three images were rated a “4” and one was rated a “5.” For the 21 Daytime Running Lights tests, no images were rated a “4” and two were rated a “5.” For the eight High Beam tests, one image was rated a “4” and none were rated a “5.” The System Effectiveness for capturing the driver’s face was 13.1, 7.8, 9.5, and 12.5 percent for Headlights-Off, Standard Lights, Daytime Running Lights, and High Beams, respectively. Table 38 shows a breakdown of the effectiveness ratings for each lane position.

Table 38. System effectiveness for capturing high quality driver facial images as a function of Headlight scenario.

	Headlight Scenarios	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Headlights-Off	2	11	48	22.9
	Headlights-Off	3	0	18	0.0
	Headlights-Off	4	0	18	0.0
	Standard Lights	2	4	36	11.1
	Standard Lights	3	0	8	0.0
	Standard Lights	4	0	7	0.0
	Daytime Running Lights	2	2	12	16.7
	Daytime Running Lights	3	0	5	0.0
	Daytime Running Lights	4	0	4	0.0
	High Beams	2	1	8	12.5
	High Beams	3	N/A	N/A	N/A
	High Beams	4	N/A	N/A	N/A

5.2.9 Driver/Passenger Window Position Status

Tests were conducted with the driver and passenger windows both up and down. This variable was included to determine system effectiveness in recording the driver profile under these two conditions. Of interest in the Oncoming tests was the position status of the driver's window, while the position status of the passenger window was of interest in the Overtaking test. Note that, hypothetically, the status of the windows has no impact on capturing the driver's face from the front (i.e., through the windshield). However, it was important to determine the effect that glass (not tinted) had on the profile recordings.

5.2.9.1 System Recording Accuracy

Four Window Position Statuses were investigated: (i) Window-Up, (ii) Window-Down, (iii) Window-Half-Down, and (iv) Not Recorded (inadvertent). For the Window-Up scenario, System Recording Accuracy was 93.5 percent, where 29 of the 31 tests were recorded. For the Window-Down scenario, System Recording Accuracy was 96.6 percent, where 144 of the 149 tests were recorded. For the Window-Half-Down scenario, System Recording Accuracy was 100.0 percent, in which both of the tests conducted were recorded. For the Not Recorded tests, System Recording Accuracy was 50.0 percent, where two of the four tests were recorded. The results from the System Recording Accuracy for each Window Position Status, as a function of the different camera recordings, are shown in Table 39.

Table 39. System Recording Accuracy results for the images from each camera as a function of Window Position Status.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Window Position Status	Mean	n	Mean	n	Mean	n	Mean	n
Window-Up	100.0	29	75.9	29	82.8	29	55.2	29
Window-Down	84.0	144	68.1	144	83.3	144	55.6	144
Window-Half-Down	100.0	2	50.0	2	100.0	2	50.0	2
Not Recorded	100.0	2	0.0	2	100.0	2	0.0	2

5.2.9.2 System Effectiveness

The mean qualitative ratings of the images for each Window Position Status, as a function of the camera recordings, are shown in Table 40.

Table 40. Qualitative ratings for each camera recording as a function of Window Position Status.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Window Position Status	Mean	n	Mean	n	Mean	n	Mean	n
Window-Up	3.58	29	3.50	22	1.80	24	2.06	16
Window-Down	2.48	121	3.11	97	1.87	119	1.94	80
Window-Half-Down	1.50	2	1.00	1	1.50	2	1.00	1
Not Recorded	3.50	2	N/A	N/A	1.50	2	N/A	N/A

Of the 167 ratable license plate images, 29 were in the Window-Up condition, 134 were in the Window-Down condition, two were in the Window-Half-Down condition, and two were in the Not Recorded condition. Across the 29 Window-Up tests, 15 images were rated a “4” and seven were rated a “5.” For the 134 Window-Down tests, 35 images were rated a “4” and 28 were rated a “5.” For the two Window-Half-Down tests, no images were rated a “4” or “5.” For the two Not Recorded tests, one image was rated a “4” and no images had a rating of “5.” The

System Effectiveness for capturing the license plate of the violating vehicle was 75.9, 47.0, 0.0, and 50.0 percent for Window-Up, Window-Down, Window-Half-Down, and Not Recorded, respectively. Table 41 shows the effectiveness data parsed by the position of the passing lane.

Table 41. System effectiveness for capturing high quality license plate images as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Window-Up	2	21	21	100.0
	Window-Up	3	1	4	25.0
	Window-Up	4	0	4	0.0
	Window-Down	2	60	85	70.6
	Window-Down	3	2	27	7.4
	Window-Down	4	1	22	4.5
	Window-Half-Down	2	0	1	0.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	0	1	0.0
	Not Recorded	2	1	1	100.0
	Not Recorded	3	0	1	0.0
	Not Recorded	4	N/A	N/A	N/A

Of the 164 ratable facial images, 29 were in the Window-Up condition, 131 were in the Window-Down condition, two were in the Window-Half-Down condition, and two tests were in the Not Recorded condition. Across the 29 Window-Up tests, two images were rated a “4” and one was rated a “5.” For the 131 Window-Down tests, seven images were rated a “4” and eight were rated a “5.” For the two Window-Half-Down tests, neither image was rated a “4” or “5.” For the two Not Recorded tests, neither image was rated a “4”or a “5.” The System Effectiveness for capturing the driver’s face was 10.3, 11.5, 0.0, and 0.0 percent for Window-Up, Window-Down, Window-Half-Down, and Not Recorded, respectively. Table 42 shows the effectiveness data for each passing lane.

Table 42. System effectiveness for capturing high quality driver facial images as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Window-Up	2	3	21	14.3
	Window-Up	3	0	4	0.0
	Window-Up	4	0	4	0.0
	Window-Down	2	15	81	18.5
	Window-Down	3	0	26	0.0
	Window-Down	4	0	24	0.0
	Window-Half-Down	2	0	1	0.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	0	1	0.0
	Not Recorded	2	0	1	0.0
	Not Recorded	3	0	1	0.0
	Not Recorded	4	N/A	N/A	N/A

5.2.10 Infrared Pulse Source

Twelve tests were conducted in Phase I to analyze the Infrared (I/R) Pulse Source that was incorporated into the system. The outcome of these tests showed that the I/R Pulse that was used was ineffective in sufficiently bathing the license plate or driver in enough light for the cameras to capture a usable image. For nine of the tests, the license plate image was not ratable. For 11 of the tests, a ratable profile image was recorded. In these tests, the image ratings were “1” (very low quality). Because of the poor quality of the recordings, the enhancement process was ineffective in improving the quality of the images.

A second interesting result from the Dark tests with the I/R Pulse Source was that the system was unable to detect the passing vehicle for tests conducted when the violating vehicle had the High Beams on. It is suspected that the very bright lights, coupled with the dark surroundings, made it impossible for the camera lens to adjust properly.

5.2.11 Phase I Summary

A total of 186 tests were conducted in Phase I. Considering that the system did not capture the violations for a small number of these tests (e.g., Dark tests), and that some of the tests included multiple vehicles which, in effect, provided extra opportunities to test the system, there ended up being a total of 177 tests that could be analyzed.

As detailed in the Phase I results, the findings were parsed a number of different ways with the purpose of gaining a clear understanding of the conditions in which the system worked and did not work. While there were several interesting findings from the Phase I tests, there were six particularly noteworthy results. First, the System Recording Accuracy was very high. As indicated in the previous paragraph, the system recorded a violation in 177 of 186 tests conducted (95.2 percent). This very high accuracy clearly demonstrates the system's reliability in identifying and recording violating vehicles.

A second important finding was that the measure of System Effectiveness, which included high quality images selected from the violation capture video, was very high (75.9 percent) for capturing license plates in the lane immediately adjacent to the bus, and was 100.0 percent effective for several of the specific conditions tested in this adjacent lane (Cloudy, Rain, Fog, North light, South light, West light). However, system effectiveness diminished greatly as testing moved away from the bus (in lanes 3 and 4). The poor performance of the system for these outside lanes is not surprising since it (i.e., camera lenses) was optimized for vehicles close to the bus. It is suggested that because of line-of-sight considerations, the lane next to the bus is, by far, the most important lane of coverage for the system.

The third noteworthy finding is that, as with capturing a readable license plate image, the ability of the system to capture a discernable image of the driver's face was determined by the distance that the vehicle was away from the bus. That is, when the violating vehicle was in the lane next to the bus, the prototype system did relatively well at capturing a discernable driver facial image. For example, very high quality facial images were found for the lane next to the bus for the Oncoming scenario (30.3 percent) and for the West Direction of Light (partial sun) condition

(54.5 percent). However, for tests further away from the bus, the system was unable to adequately capture the driver's face.

A fourth finding, related to the capture of the driver's facial image, was that a surprising number of frontal facial images were captured by the front and rear cameras. In fact, though unintentional, 54.8 percent of the front and rear camera violation recordings contained a frontal image of the driver's face.

The fifth result was that the post-processing enhancement was effective in improving the quality of a small subset of images. This finding suggests the system does not necessarily have to capture crystal clear images directly, and improvements to the image quality can be made to the violation capture data later in the lab.

The sixth, and perhaps most important, finding from the Phase I tests was that the system proved to be very robust under a variety of experimental conditions. That is, the variable conditions that were manipulated had relatively little impact on the effectiveness of the system. However, there were two exceptions to this: tests that occurred in lanes other than the lane directly adjacent to the bus, and night (Dark) testing. As discussed, the system worked relatively well under all conditions that had some level of daylight and that occurred in the lane directly adjacent to the bus. From a practical standpoint, as most school bus routes are on two-lane roads (Institute for Transportation Research and Education, 2000), and many of the boardings and de-boardings occur during daylight hours, these conditions may be less important in assessing the ultimate effectiveness of an automated violation detection system.

5.3 Phase II: Actual Route Tests

The Phase II tests were conducted on actual school bus routes during Dawn and Clear conditions. As described previously, all tests were conducted on bus routes in Blacksburg, Virginia. As with the presentation of the Phase I results, the discussion of the Phase II findings is divided into six sub-sections. In the first sub-section, the accuracy, ratings, and effectiveness of the system are each considered across all tests, and collapsed over all variables. The subsequent sub-sections focus on the independent variables that were investigated.

Due to the length of the analysis, a summary of the system effectiveness results with page references is provided in Table 43.

Table 43. Phase II Summary of System Effectiveness

Condition	License Plate Effectiveness (%)	Facial Image Effectiveness (%)	Reference
Overall	58.5	9.4	Page 76
Lane 2	79.5	12.8	Page 78
Lane 3	0.0	0.0	
Lane 4	0.0	0.0	
Oncoming	29.2	16.0	Page 80
Overtaking	82.8	3.6	
Low Speed	80.0	18.2	Page 83
Moderate Speed	66.7	11.1	
Unknown Speed	50.5	6.1	
Headlights-Off	54.2	8.5	Page 85
Standard Lights	100.0	16.7	
Window-Up	55.6	3.7	Page 87
Window-Down	81.3	25.0	
Window-Half-Down	100.0	0.0	
Not Recorded	22.2	0.0	

5.3.1 General Results

5.3.1.1 System Recording Accuracy

A total of 55 tests were conducted in Phase II. Of these tests, 45[6] were used in the analysis. Seven of the tests involved multiple vehicles and resulted in more than one data point (i.e., system test) for a given variable condition. Specifically, four tests involved two vehicles (n = 8), one test involved three vehicles (n = 3), and two tests involved four vehicles (n = 8). Therefore, 57 unique tests, with recordings that had ratable images, were analyzed. Considering all 57 tests, the System Recording Accuracy for Phase II was 96.5 percent. That is, a violation recording was made by at least one camera for 55 of the 57 (96.5 percent) vehicles that illegally passed the school bus.

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[6] This does not include False Alarms (n=10), described later.

The System Recording Accuracy, as a function of the three cameras, was as follows:

- Rear Camera- 90.9 percent (n = 55)
- Front Camera- 72.7 percent (n = 55)
- Profile Camera- 94.5 percent (n = 55)

Although the recording accuracy for the cameras was fairly high (M = 96.5 percent), the system did not record all violations. As discussed in Phase I, causes of missed violations included dropped images due to system limitations (i.e., not full motion video), the time for the cameras to adjust to the ambient conditions, and the wide field-of-view captured by the front camera. In addition, as discovered in the Phase II tests, missed violations were also attributed to the geometry of the road (one of the actual route sites was on a curve) in that the detection cameras did not pick up vehicles that approached at off angles. Additionally, the system was found to be triggered when non-vehicles (e.g., pedestrians) passed by; note that this resulted in false alarms rather than missed recordings.

5.3.1.2 Qualitative Ratings

Qualitative ratings of the images in terms of readability/discernability were made for all of the recorded images. Recall, these ratings ranged from very low quality (1) to very high quality (5). Ratings were made on 159 unique images. The mean ratings for the images were:

- License Plate - Rear Camera= 3.02 (n=50)
- License Plate - Front Camera= 1.83 (n=40)
- Driver Face - Profile Camera= 1.77 (n=52)
- Driver Face – Windshield= 1.71 (n=17)

An examination was also made of the "best" license plate image for a given test, using video data captured from either the rear or front camera. The qualitative rating only including this best license plate image was 3.00 (n = 53[7]).

[7] 53 of the 57 tests where a violation was recorded had a captured license plate.

As in Phase I, enhancement was attempted on a subset of the images using tools within the *PhotoShop* software program. The enhancement process lead to an improvement in only one of the images (pre-enhancement = 3.0; post-enhancement = 4.0).

5.3.1.3 System Effectiveness

Recall, System Effectiveness was defined as the percentage of captured images that had a qualitative readability/discernability rating of “4” or “5.” For the 53 tests that had a ratable license plate image, 26 images had a rating of “4” and five images had a rating of “5.” As such, the Overall System Effectiveness for capturing a clear image of the license plate was 58.5 percent. Looking at the System Effectiveness as a function of the violating vehicle passing lane, the ratings were: (i) Lane 2, lane next to bus = 79.5 percent; (ii) Lane 3, one lane over from bus = 0.0 percent; and (iii) Lane 4, two lanes over from bus = 0.0 percent. As was clear from the results in Phase I, the system was very effective in capturing high quality license plate images for vehicles passing in the lane immediately adjacent to the bus. However, the system was ineffective in capturing quality license plate images for vehicles passing in outside lanes.

In the 53 tests that had a ratable driver facial image, there were four profile images rated a “4” and one image rated a “5.” Therefore, the Overall System Effectiveness for capturing the driver’s image was 9.4 percent. Breaking down the System Effectiveness ratings for the driver’s face image, as a function of the lane position of the violating vehicle, the results were (i) Lane 2, lane next to bus = 12.8 percent, (ii) Lane 3, one lane over from bus = 0.0 percent, and (iii) Lane 4, two lanes over from bus = 0.0 percent. Note that no “usable” frontal facial images were obtained through the windshield in the Phase II tests.

5.3.2 Passing Lane Scenario

5.3.2.1 System Recording Accuracy

Three Passing Lanes were investigated in Phase II: (i) Passing Lane 2, lane next to the bus, (ii) Passing Lane 3, one lane over from the bus, and (iii) Passing Lane 4, two lanes over from the bus. System Recording Accuracy for Passing Lane 2 was 95.3 percent, where 41 of the 43 test had a valid recording; 100.0 percent for Passing Lane 3, where all five of the tests conducted had a valid recording; and 100.0 percent for Passing Lane 4, where all nine of the tests conducted had a valid recording. The results from the System Recording Accuracy are shown in Table 44.

Table 44. System Recording Accuracy results for the images from each camera, as a function of Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Lane 2	87.8	41	78.0	41	92.7	41	36.6	41
Lane 3	100.0	5	60.0	5	100.0	5	20.0	5
Lane 4	100.0	9	55.6	9	100.0	9	11.1	9

5.3.2.2 System Effectiveness

The mean qualitative ratings of the images for each passing lane, as a function of the camera recordings, are shown in Table 45.

Table 45. Qualitative ratings for each camera recording as a function of Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Lane 2	3.70	36	2.03	32	1.95	38	1.73	15
Lane 3	2.00	5	1.00	3	1.80	5	2.00	1
Lane 4	1.00	9	1.00	5	1.00	9	1.00	1

Of the 53 tests that had a ratable license plate image, 39 were in Passing Lane 2, five were in Passing Lane 3, and nine were in Passing Lane 4. For the 39 Passing Lane 2 tests, 26 images were rated “4” and five were rated “5.” For the five tests in Passing Lane 3, and the nine tests in Passing Lane 4, no images were rated either “4” or “5.” Therefore, the System Effectiveness for capturing the license plate of the violating vehicle was 79.5, 0.0 and 0.0 percent for Passing Lane 2, Passing Lane 3 and Passing Lane 4, respectively. The data used to determine System Effectiveness is presented in Table 47.

Table 46. System effectiveness for capturing high quality license plate images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	2- Lane Next to Bus	31	39	79.5
	3- One Lane Over From Bus	0	5	0.0
	4- Two Lanes Over from Bus	0	9	0.0

Of the 53 tests that had a ratable driver facial image, 39 were in Passing Lane 2, five were in Passing Lane 3, and nine were in Passing Lane 4. For Lane 2 tests, four of the images were rated a "4" and one image was rated a "5." For Lane 3 and Lane 4 tests, none of the images were rated a "4" or "5." Therefore, the System Effectiveness for capturing the driver's face was 12.8 percent for Passing Lane 2, and 0.0 percent for Passing Lanes 3 and 4. The data used to determine the System Effectiveness as a function of the passing lanes is presented in Table 47. As in the Phase I tests, the actual route tests showed that the system was most effective in capturing driver facial images in Lane 2.

Table 47. System effectiveness for capturing high quality and driver facial images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	2- Lane Next to Bus	5	39	12.8
	3- One Lane Over From Bus	0	5	0.0
	4- Two Lanes Over from Bus	0	9	0.0

5.3.3 Violation Passing Scenario

5.3.3.1 System Recording Accuracy

Two violation passing scenarios were investigated: (i) Oncoming and (ii) Overtaking. System Recording Accuracy in the Oncoming scenario was 96.3 percent, where 26 of the 27 tests conducted were recorded. For the Overtaking scenario, System Recording Accuracy was 96.7

percent, in which 29 of the 30 tests were recorded. The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 48.

Table 48. System Recording Accuracy results for the images from each camera, as a function of Violation Passing Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	92.3	26	50.0	26	96.2	26	38.5	26
Overtaking	89.7	29	93.1	29	93.1	29	24.1	29

5.3.3.2 System Effectiveness

The mean qualitative ratings of the images for each Passing Scenario, as a function of the camera recordings, are shown in Table 49.

Table 49. Qualitative ratings for each camera recording as a function of Violation Passing scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	2.04	24	1.92	13	1.80	25	1.90	10
Overtaking	3.96	26	1.78	27	1.74	27	1.43	7

Of the 53 tests that had a ratable license plate image, 24 were in the Oncoming scenario, and 29 were in the Overtaking scenario. Of the 24 Oncoming tests, seven images were rated a “4” and no images were rated a “5.” For the 29 Overtaking scenario tests, 19 images were rated a “4” and five were rated a “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 29.2 and 82.8 percent for the Oncoming and Overtaking scenarios, respectively. Table 50 shows the System Effectiveness ratings parsed by the passing lane of the violating vehicle.

Table 50. System effectiveness for capturing high quality license plate images as a function of Violation Passing Scenario.

	Violation Passing Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Oncoming	2	7	10	70.0
	Oncoming	3	0	5	0.0
	Oncoming	4	0	9	0.0
	Overtaking	2	24	29	82.8

Of the 53 tests that had a ratable driver facial image, 25 were in the Oncoming scenario and 28 were in the Overtaking scenario. For the 25 Oncoming tests, three images were rated a "4" and one image was rated a "5." For the 28 Overtaking scenario tests, one image was rated a "4" and none were rated a "5." Therefore, the System Effectiveness for capturing the driver's face was 16.0 percent for Oncoming scenario and 3.6 percent for the Overtaking scenario. Table 51 breaks out the System Effectiveness ratings by lane position.

Table 51. System effectiveness for capturing high quality driver facial images as a function of Violation Passing Scenario.

	Violation Passing Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Oncoming	2	4	11	36.4
	Oncoming	3	0	5	0.0
	Oncoming	4	0	9	0.0
	Overtaking	2	1	28	3.6

5.3.4 Speed of Violating Vehicle

5.3.4.1 System Recording Accuracy

Three speed conditions for the violating vehicle were investigated: (i) Low Speed (10 mph), (ii) Moderate Speed (posted speed ranging from 15-35 mph), and (iii) Unknown Speed[8]. System Recording Accuracy was 91.7 percent for Low Speed, where 11 of the 12 tests were recorded. For the Moderate Speed, System Recording Accuracy was 90.9 percent, in which 10 of the 11 tests were recorded. For the Unknown Speed, System Recording Accuracy was 100.0 percent, where all of the 34 tests conducted were recorded. The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 52.

Table 52. System Recording Accuracy results for the images from each camera, as a function of Speed of Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low	90.9	11	54.5	11	90.9	11	63.6	11
Moderate	90.0	10	50.0	10	90.0	10	50.0	10
Unknown	91.2	34	85.3	34	97.1	34	14.7	34

5.3.4.2 System Effectiveness

The mean qualitative ratings of the images for each Violating Vehicle Speed, as a function of the camera recordings, are shown in Table 53.

Table 53. Qualitative ratings for each camera recording as a function of Speed of Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low	3.40	10	3.33	6	2.40	10	2.00	7
Moderate	3.67	9	2.40	5	1.79	9	1.40	5
Unknown	2.74	31	1.41	29	1.58	33	1.67	3

[8] Note that 33 of the tests that comprise this condition involved non-research vehicles, where the vehicle speed was not known.

Of the 53 tests that had a ratable license plate image, 10 were in the Low Speed condition, nine were in the Moderate Speed condition, and 34 were in the Unknown Speed condition. Across the 10 Low Speed tests, six images were rated a "4" and two were rated a "5." For the nine Moderate Speed tests, four images were rated a "4" and two were rated a "5." For the 34 Unknown Speed tests, 16 images were rated a "4" and one was rated a "5." Across all tests, the System Effectiveness for capturing the license plate of the violating vehicle was 80.0, 66.7, and 50.0 percent for Low Speed, Moderate Speed, and Unknown Speed, respectively. Table 54 shows these effectiveness ratings as a function of lane position.

Table 54. System effectiveness for capturing high quality license plate images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Low	2	8	8	100.0
	Low	3	0	1	0.0
	Low	4	0	1	0.0
	Moderate	2	6	8	75.0
	Moderate	3	0	1	0.0
	Moderate	4	N/A	N/A	N/A
	Unknown	2	17	23	73.9
	Unknown	3	0	3	0.0
	Unknown	4	0	8	0.0

Of the 53 tests that had a ratable driver facial image, 11 were in the Low Speed condition, nine were in the Moderate Speed condition, and 33 were in the Unknown Speed condition. In regard to obtaining a high quality image of the driver's face, one image was rated a "4" and one was rated a "5" in the Low Speed condition. For the Moderate Speed condition, one image was rated a "4" and none were rated a "5." For the Unknown Speed condition, two images were rated a "4" and none were rated a "5." The System Effectiveness for capturing the driver's face was 18.2 percent for Low Speed, 11.1 percent for Moderate Speed, and 6.1 percent for Unknown Speed. Table 55 shows the effectiveness data for the various speeds, as a function of lane position.

Table 55. System effectiveness for capturing high quality driver facial images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Low	2	2	9	22.2
	Low	3	0	1	0.0
	Low	4	0	1	0.0
	Moderate	2	1	8	12.5
	Moderate	3	0	1	0.0
	Moderate	4	N/A	N/A	N/A
	Unknown	2	2	22	9.1
	Unknown	3	0	3	0.0
	Unknown	4	0	8	0.0

5.3.5 Headlight Scenario

5.3.5.1 System Recording Accuracy

Two Headlight Scenarios were investigated in the Phase II tests: (i) Headlights-Off and (ii) Standard Lights. In the Headlights-Off Scenario, System Recording Accuracy was 96.1 percent, where 49 of the 51 tests were recorded. For the Standard Lights scenario, System Recording Accuracy was 100.0 percent, where all six of the tests conducted were recorded. The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 56.

Table 56. System Recording Accuracy results for the images from each camera, as a function of the Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	91.8	49	71.4	49	93.9	49	24.5	49
Standard Lights	83.3	6	83.3	6	100.0	6	83.3	6

5.3.5.2 System Effectiveness

The mean qualitative ratings of the images for each Headlight Scenario, as a function of the camera recordings, are shown in Table 57.

Table 57. Qualitative ratings for each camera recording as a function of the Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	2.93	45	1.60	35	1.76	46	1.58	12
Standard Lights	4.00	5	3.40	5	1.83	6	2.00	5

Of the 53 ratable license plate images, 48 were in the Headlights-Off condition and five were in the Standard Lights condition. For 48 Headlights-Off tests, 21 images were rated a “4” and five were rated a “5.” For the five Standard Lights tests, all five images were rated a “4.” The System Effectiveness for capturing the license plate of the violating vehicle, as a function of the headlight status of the violating vehicle, was 54.2 and 100.0 percent for Headlights-Off and Standard Lights, respectively. Table 58 shows the breakdown of the System Effectiveness ratings for each passing lane.

Table 58. System effectiveness for capturing high quality license plate images as a function of Headlight Scenario.

	Head Light Scenarios	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Headlights-Off	2	26	34	76.5
	Headlights-Off	3	0	5	0.0
	Headlights-Off	4	0	9	0.0
	Standard Lights	2	5	5	100.0
	Standard Lights	3	N/A	N/A	N/A
	Standard Lights	4	N/A	N/A	N/A

Of the 53 ratable driver facial images, 47 were in the Headlights-Off condition and six were in the Standard Lights condition. In regard to obtaining a quality image of the driver’s face, three images were rated a “4” and one was rated a “5” for the Headlights-Off scenario. For the Standard Lights condition, one image was rated a “4” and none were rated a “5.” Therefore, the System Effectiveness for capturing the driver’s face was 8.5 percent for Headlights-Off scenario, and 16.7 percent for Standard Lights scenario. Table 59 shows these effectiveness results as a function of passing lane.

Table 59. System effectiveness for capturing high quality facial image as a function of Headlight Scenario.

	Head Light Scenarios	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Headlights-Off	2	4	33	12.1
	Headlights-Off	3	0	5	0.0
	Headlights-Off	4	0	9	0.0
	Standard Lights	2	1	6	16.7
	Standard Lights	3	N/A	N/A	N/A
	Standard Lights	4	N/A	N/A	N/A

5.3.6 Driver/Passenger Window Position Status

As in Phase I, the tests were conducted with the driver and passenger windows both up and down. This variable was included to determine system effectiveness in recording the driver profile under these two conditions. As described in the Phase I results, of interest in the Oncoming tests was the position status of the driver’s window, while the position status of the passenger window was of interest in the Overtaking tests. It was thought that including this variable in the testing would provide information on how effective the system was at capturing profile images through glass.

5.3.6.1 System Recording Accuracy

Four Window Position Statuses were investigated: (i) Window-Up, (ii) Window-Down, (iii) Window-Half-Down, and (iv) Not Recorded (inadvertent). System Recording Accuracy in the Window-Up Scenario was 93.3 percent, where 28 of the 30 tests were recorded. For the Window-Down Scenario, System Recording Accuracy was 100.0 percent, where all 17 of the tests conducted were recorded. For the Window-Half-Down Scenario, System Recording

Accuracy was 100.0 percent, where a single test conducted was recorded. For the Not Recorded tests, System Recording Accuracy was 100.0 percent, where all nine of the tests conducted were recorded. The results from the System Recording Accuracy, as a function of each camera, are shown in Table 60.

Table 60. System Recording Accuracy results for the images from each camera, as a function of Window Position Status.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Window Position Status	Mean	n	Mean	n	Mean	n	Mean	n
Window-Up	85.7	28	71.4	28	96.4	28	14.3	28
Window-Down	94.1	17	58.8	17	88.2	17	58.8	17
Window-Half-Down	100.0	1	100.0	1	100.0	1	100.0	1
Not Recorded	100.0	9	100.0	9	100.0	9	22.2	9

5.3.6.2 System Effectiveness

The mean qualitative ratings of the images for each window position, as a function of the camera recordings, are shown in Table 61.

Table 61. Qualitative ratings for each camera recording as a function of Window Position Status.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Window Position Status	Mean	n	Mean	n	Mean	n	Mean	n
Window-Up	2.96	24	1.35	20	1.48	27	1.75	4
Window-Down	3.81	16	3.30	10	2.47	15	1.70	10
Window-Half-Down	4.00	1	4.00	1	2.00	1	2.00	1
Not Recorded	1.78	9	1.00	9	1.44	9	1.50	2

Of the 53 ratable license plate images, 27 were in the Window-Up tests, 16 were in the Window-Down tests, one was in the Window-Half-Down test, and nine were in the Not Recorded tests. For the 27 Window-Up tests, 14 images were rated a “4” and one was rated a “5.” For the 16 Window-Down tests, nine images were rated a “4” and four were rated a “5.” The one Window-Half-Down test image was rated a “4.” For the nine Not Recorded tests, two images were rated a

“4”and no images were rated a “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 55.6, 81.3, 100.0, and 22.2 percent for Window-Up, Window-Down, Window-Half-Down, and Not Recorded, respectively. Table 62 shows the data parsed by lane position.

Table 62. System effectiveness for capturing high quality license plate images as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Window-Up	2	15	20	75.0
	Window-Up	3	0	2	0.0
	Window-Up	4	0	5	0.0
	Window-Down	2	13	14	92.9
	Window-Down	3	0	2	0.0
	Window-Down	4	N/A	N/A	N/A
	Window-Half-Down	2	1	1	100.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	N/A	N/A	N/A
	Not Recorded	2	2	4	50.0
	Not Recorded	3	0	1	0.0
	Not Recorded	4	0	4	0.0

Of the 53 ratable facial images, 27 were in the Window-Up condition, 16 were in the Window-Down condition, one was in the Window-Half-Down condition, and nine were in the Not Recorded Scenario. For the 27 Window-Up tests, one image was rated a “4” and there were none rated “5.” For the 16 Window-Down tests, three images were rated a “4” and one was rated a “5.” For the one Window-Half-Down test, as well as for the nine Not Recorded tests, no images were rated a “4” or “5.” The System Effectiveness for capturing the driver’s face was 3.7, 25.0, 0.0, and 0.0 percent for Window-Up, Window-Down, Window-Half-Down, and Not Recorded, respectively. Table 63 shows the System Effectiveness broken down by lane position.

Table 63. System effectiveness for capturing high quality facial image as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Window-Up	2	1	20	5.0
	Window-Up	3	0	2	0.0
	Window-Up	4	0	5	0.0
	Window-Down	2	4	14	28.6
	Window-Down	3	0	2	0.0
	Window-Down	4	N/A	N/A	N/A
	Window-Half-Down	2	0	1	0.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	N/A	N/A	N/A
	Not Recorded	2	0	4	0.0
	Not Recorded	3	0	1	0.0
	Not Recorded	4	0	4	0.0

5.3.7 Phase II Summary

From the 55 tests that were conducted in Phase I, 57 data points were recorded where vehicles performed a violation maneuver. There were several important findings taken from these actual route tests. First, the System Recording Accuracy was very high. That is, the system recorded a violation in 55 of the 57 tests conducted (96.5 percent). As in the Phase I Smart Road tests, this very high accuracy clearly demonstrates the reliability of the system in identifying and recording violating vehicles.

The analysis to determine System Effectiveness had several noteworthy findings. Once again, as in the Phase I tests, the ability of the system to capture highly readable license plate images was relatively high for violations that occurred in the lane closest to the bus (79.5 percent). (Recall that this same measure in Phase I was a very similar, 75.9 percent.) Also, as in the Phase I tests, there were certain experimental conditions that involved testing a violation in the lane immediately adjacent to the bus, where the System Effectiveness for capturing high quality license plate images was 100.0 percent (e.g., Low Speed). However, as in the Phase I findings, the effectiveness results diminished greatly as the testing moved away from the bus (the outside lanes). As discussed previously, this is suggested to be considered as less of a concern since most actual school bus routes are on two-lane roads.

Though the system worked effectively in capturing a clear image of the license plate for many of the tests conducted, it was less effective, across the multitude of conditions that were tested, in capturing a clear image of the driver's face. Overall, 12.8 percent of the Lane 2 driver facial images were found to be usable. However, the system was relatively effective in limited situations where the violation occurred in the lane closest to the bus. For example, for Passing Lane 2, the System Effectiveness for recording a facial image was 22.2 percent for the Low Speed condition, 28.6 percent when the window of the violating vehicle was down, and 36.4 percent for the Oncoming scenario.

5.4 Phase I and Phase II Tests Combined

The previous two sections presented the results of individual analyses conducted for Phase I and Phase II. One particularly important finding from these analyses was that the results from the two phases were very similar. Recall that the System Effectiveness in capturing a usable license plate image, for the Lane 2 tests, were within a few percentage points of each other (75.9 percent in Phase I and 79.5 percent in Phase II). As the results are so similar, it was thought to be worthwhile to combine and analyze all tests from Phase I and Phase II and generate results based on a larger data set. The remainder of this section outlines the results from this combined analysis.

Due to the length of the analysis, a summary of the system effectiveness results with page references is provided in Table 64.

Table 64. Phase I and Phase II Combined Summary of System Effectiveness

Condition	License Plate Effectiveness (%)	Facial Image Effectiveness (%)	Reference
Overall	53.2	10.6	Page 92
Lane 2	76.9	16.1	Page 95
Lane 3	8.1	0.0	
Lane 4	2.8	0.0	
Oncoming	30.2	11.9	Page 97
Overtaking	78.8	9.1	
Low Speed	57.8	12.2	Page 99
Moderate Speed	56.5	13.1	
High Speed	41.2	6.1	
Unknown Speed	50.0	6.1	
Dawn	54.8	9.7	Page 101
Light	61.7	9.0	
Late Afternoon	52.9	25.9	
Dusk	5.3	0.0	
Clear	47.9	11.4	Page 105
Fog	87.5	16.7	
Cloudy	100.0	0.0	
Rain	80.0	0.0	
North	55.6	0.0	Page 108
South	44.4	11.1	
East	56.3	6.7	
West	52.4	26.1	
Not Recorded	53.3	9.3	
Headlights-Off	51.1	11.4	Page 111
Standard Lights	58.6	8.8	
Daytime Running Lights	41.2	9.5	
High Beams	75.0	12.5	Page 114
Window-Up	66.1	7.1	
Window-Down	50.7	12.9	
Window-Half-Down	33.3	0.0	
Not Recorded	27.3	0.0	

5.4.1 General Results

5.4.1.1 System Recording Accuracy

A total of 238 tests were conducted in Phase I and Phase II. Considering tests with multiple vehicles, a total of 243 unique tests (with images that were ratable) were used in the analysis. The System Recording Accuracy across both phases was 95.5 percent. That is, a violation recording was made by at least one camera for 232 of the 243 (95.5 percent) vehicles that illegally passed the school bus.

Looking at the System Recording Accuracy as a function of the three violation recording cameras, the individual camera recording accuracies were:

- Rear Camera – 87.9 percent (n=232)
- Front Camera – 69.4 percent (n=232)
- Profile Camera – 85.8 percent (n=232)

The System Recording Accuracy was also determined for the recordings of the driver's frontal face, through the windshield, from the front and rear cameras. The System Recording Accuracy across all phase tests was 49.1 percent. Again, it is stressed that no attempt was made to capture a picture of the driver's frontal face in the system set-up; the focus was on capturing the driver's profile. Despite this, a frontal image of the driver's face was captured in nearly half of the violation captures.

5.4.1.2 Qualitative Ratings

Considering the image readability/discernability subjective ratings where a value of "1" indicated very low quality and a value of "5" indicated very high quality, the mean quality ratings as a function of camera were:

- Rear Camera – 2.78 (n=204)
- Front Camera – 2.84 (n=160)
- Profile Camera – 1.83 (n=199)
- Windshield/Face Image – 1.91 (n=114)

An examination was also made of the "best" license plate image for a given test, using video data captured from either the rear or front camera. The qualitative rating only including this best license plate image was (n = 220).

For the 232 tests that had ratable images, an enhancement was attempted on 200 of them. Of these, the quality improved for 17 images (8.5 percent). This result highlights the fact that it is possible to make improvements to images with less-than-perfect quality. Note that only a limited number of tools in *PhotoShop* program were used in attempting to improve image quality. It is suggested that future research is required to identify additional software programs and tools that could be used to enhance images.

5.4.1.3 System Effectiveness

For the 220 tests that had a ratable license plate image, 77 images had a rating of “4” and 40 images had a rating of “5.” As such, the Overall System Effectiveness for capturing a clear image of the license plate was 53.2 percent. The ratings for System Effectiveness, as a function of the violating vehicle passing lane, were: (i) Lane 2, lane next to bus = 76.9 percent, (ii) Lane 3, one lane over from bus = 8.1 percent, and (iii) Lane 4, two lanes over from bus = 2.8 percent. This shows that the system was very effective in capturing high quality license plate images for vehicles passing in the lane immediately adjacent to the bus; however, it proved less effective in capturing quality license plate images for vehicles passing in outside lanes.

In the 217 tests that had a ratable driver facial image, there were 13 images that rated a “4” and 10 images that rated a “5.” Therefore, the Overall System Effectiveness for capturing the driver’s image was 10.6 percent. Breaking down the System Effectiveness ratings for the driver’s facial image, as a function of the lane position of the violating vehicle, the results were (i) Lane 2, lane next to bus = 16.1 percent, (ii) Lane 3, one lane over from bus = 0.0 percent, and (iii) Lane 4, two lanes over from bus = 0.0 percent. In both phases, and across all tests, the System Effectiveness for capturing a high quality license plate and facial image was greatly reduced for violations that occurred in lanes not immediately adjacent to the bus.

Another way to breakdown the results was to examine the 95 percentile of total tests conducted. (This method is used in other documentations such as the standard ASTM specifications.) This form of analysis eliminates the lower five percent of the data, thereby creating a confidence interval for the system effectiveness. In these regards, the Overall System Effectiveness was ±50.7 percent efficient 95 percent of the time for the license plates and ±10.1 percent efficient 95 percent of the time for facial images.

5.4.2 Passing Lane Scenario

5.4.2.1 System Recording Accuracy

Three Passing Lanes were investigated in Phase II: (i) Passing Lane 2, the lane next to the bus, (ii) Passing Lane 3, one lane over from the bus, and (iii) Passing Lane 4, two lanes over from the bus. System Recording Accuracy in Passing Lane 2 was 95.0 percent, where 152 of the 160 tests had a valid recording; 97.5 percent for Passing Lane 3, where 39 of the 40 tests had a valid recording; and 95.3 percent for Passing Lane 4, where 41 of the 43 tests had a valid recording. The results from the System Recording Accuracy are shown in Table 65.

Table 65. System Recording Accuracy results for the images from each camera as a function of the Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Passing Lane 2	86.8	152	84.2	152	84.2	152	53.9	152
Passing Lane 3	94.9	39	59.0	39	87.2	39	51.3	39
Passing Lane 4	85.4	41	24.4	41	90.2	41	29.3	41

5.4.2.2 System Effectiveness

The mean qualitative ratings of the images for each Passing Lane Scenario, as a function of the individual camera recordings, are shown in Table 66.

Table 66. Qualitative ratings for each camera recording as a function of Passing Lane Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Passing Lane Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Passing Lane 2	3.49	132	3.20	127	2.02	128	2.09	81
Passing Lane 3	1.83	37	1.57	23	1.83	34	1.62	21
Passing Lane 4	1.09	35	1.00	10	1.16	37	1.17	12

Of the 220 tests that had a ratable license plate image, 147 were in Passing Lane 2, 37 were in Passing Lane 3, and 36 were in Passing Lane 4. Across the 147 Passing Lane 2 scenario tests, 74 images were rated a "4" and 39 were rated a "5." For the 37 Passing Lane 3 scenario tests, two images were rated a "4" and one was rated of "5." For the 36 Passing Lane 4 scenario tests, one image was rated a "4" and none were rated a "5." The System Effectiveness for capturing the license plate of the violating vehicle was 76.9, 8.1, and 2.8 percent for Passing Lane 2, Passing Lane 3, and Passing Lane 4 respectively. Table 67 shows the System Effectiveness as a function of passing lane.

Table 67. System effectiveness for capturing high quality license plate images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	2- Lane Next to Bus	113	147	76.9
	3- One Lane Over From Bus	3	37	8.1
	4- Two Lanes Over from Bus	1	36	2.8

Of the 217 tests that had a ratable driver facial image, 143 were in Passing Lane 2, 36 were in Passing Lane 3, and 38 were in Passing Lane 4. For Passing Lane 2 tests, 13 of the images were rated a "4" and 10 were rated a "5." None of the images in Lanes 3 and 4 were rated a "4" or "5." Therefore, the System Effectiveness for capturing the driver's face was 16.1 percent for Passing Lane 2, and 0.0 percent for Passing Lanes 3 and 4. The data used to determine the System Effectiveness as a function of the passing lanes is presented in Table 68. As in the individual Phase I and Phase II tests, the actual route tests showed that the system was most effective in capturing driver facial images in Lane 2.

Table 68. System effectiveness for capturing high quality and driver facial images as a function of Passing Lane Scenario.

	Passing Lane Scenario	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	2- Lane Next to Bus	23	143	16.1
	3- One Lane Over From Bus	0	36	0.0
	4- Two Lanes Over from Bus	0	38	0.0

5.4.3 Violation Passing Scenario

5.4.3.1 System Recording Accuracy

Two Violation Passing Scenarios were investigated: (i) Oncoming and (ii) Overtaking. System Recording Accuracy in the Oncoming scenario was 95.5 percent, in which 128 of the 134 tests were recorded. For the Overtaking scenario, System Recording Accuracy was 95.4 percent, in which 104 of the 109 tests were recorded. The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 69.

Table 69. System Recording Accuracy Results for the images from each camera as a function of the Violation Passing Scenario.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	89.1	128	46.9	128	85.2	128	51.6	128
Overtaking	86.5	104	97.1	104	87.5	104	46.2	104

5.4.3.2 System Effectiveness

The mean qualitative ratings of the images for each Passing Scenario, as a function of the camera recordings, are shown in Table 70.

Table 70. Qualitative ratings for each camera recording as a function of Violation Passing Scenario.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violation Passing Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Oncoming	2.06	114	2.60	60	1.75	108	1.91	66
Overtaking	3.69	90	2.97	100	1.92	91	1.92	48

Of the 220 tests that had a ratable license plate image, 116 were in the Oncoming scenario and 104 were in the Overtaking scenario. Of the 116 Oncoming tests, 23 images were rated a “4” and 12 images were rated a “5.” For the 104 Overtaking scenario tests, 54 images were rated a “4” and 28 were rated a “5.” Therefore, the System Effectiveness for capturing the license plate of the violating vehicle was 30.2 percent for the Oncoming scenario and 78.8 percent for the

Overtaking scenario. Table 71 shows the break down of these findings as a function of the passing lane.

Table 71. System effectiveness for capturing high quality license plate images as a function of Violation Passing Scenario.

	Violation Passing Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Oncoming	2	31	43	72.1
	Oncoming	3	3	37	8.1
	Oncoming	4	1	36	2.8
	Overtaking	2	82	104	78.8

Of the 217 tests that had a ratable driver facial image, 118 were in the Oncoming scenario and 99 were in the Overtaking scenario. For the 118 Oncoming tests, six images were rated a "4" and eight were rated a "5." For the 99 Overtaking scenario tests, seven images were rated a "4" and two were rated a "5." Therefore, the System Effectiveness for capturing the driver's face was 11.9 percent for the Oncoming scenario, and 9.1 percent for the Overtaking scenario. Table 72 breaks down the System Effectiveness ratings by lane position.

Table 72. System effectiveness for capturing high quality driver facial images as a function of Violation Passing Scenario.

	Violation Passing Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Oncoming	2	14	44	31.8
	Oncoming	3	0	36	0.0
	Oncoming	4	0	38	0.0
	Overtaking	2	9	99	9.1

5.4.4 Speed of Violating Vehicle

5.4.4.1 System Recording Accuracy

Four speed scenarios were investigated: (i) Low Speed (10 mph); (ii) Moderate Speed (15 – 35 mph); (iii) High Speed (40 mph); and (iv) Unknown Speed. System Recording Accuracy was 96.0 percent for Low Speed, in which 95 of the 99 tests were recorded. For the Moderate Speed, System Recording Accuracy was 91.8 percent, where 67 of the 73 tests were recorded. For the High Speed, System Recording Accuracy was 97.3 percent, where 36 of the 37 tests were recorded. For the Unknown Speed, System Recording Accuracy was 100.0 percent, in which all of the 34 tests conducted were recorded. The results from the System Recording Accuracy, as a function of the different cameras, are shown in Table 73.

Table 73. System Recording Accuracy results for the images from each camera as a function of Speed of Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low Speed	89.5	95	71.6	95	89.5	95	86.3	95
Moderate Speed	86.6	67	65.7	67	82.1	67	52.2	67
High Speed	83.8	36	55.6	36	72.2	36	38.9	36
Unknown Speed	91.2	34	85.3	34	97.1	34	14.7	34

5.4.4.2 System Effectiveness

The mean qualitative ratings of the images for each Violating Vehicle Speed, as a function of the camera recordings, are shown in Table 74.

Table 74. Qualitative ratings for each camera recording as a function of Speed of the Violating Vehicle.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Violating Vehicle Speed	Mean	n	Mean	n	Mean	n	Mean	n
Low Speed	2.81	85	3.27	67	2.12	85	1.98	60
Moderate Speed	2.95	58	3.11	44	1.72	55	1.86	35
High Speed	2.37	30	2.80	20	1.42	26	1.86	14
Unknown Speed	2.74	31	1.41	29	1.58	33	1.60	5

Of the 220 tests that had a ratable license plate image, 90 were in the Low Speed condition, 62 were in the Moderate Speed condition, 34 were in the High Speed condition, and 34 were in the Unknown Speed condition. Across the 90 Low Speed tests, 25 images were rated a “4” and 26 were rated a “5.” For the 62 Moderate Speed tests, 24 images were rated a “4” and 11 were rated a “5.” For the 34 High Speed tests, 12 images were rated a “4” and two were rated a “5.” For the 34 Unknown Speed tests, 16 images were rated a “4” and one was rated a “5.” Across all tests, the System Effectiveness for capturing the license plate of the violating vehicle was 57.8, 56.5, 41.2, and 50.0 percent for Low Speed, Moderate Speed, High Speed, and Unknown Speed, respectively. Table 75 shows the effectiveness ratings as a function of lane position.

Table 75. System effectiveness for capturing high quality license plate images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Low	2	47	59	79.7
	Low	3	3	18	16.7
	Low	4	1	13	7.7
	Moderate	2	35	44	79.5
	Moderate	3	0	10	0.0
	Moderate	4	0	8	0.0
	High	2	14	21	66.7
	High	3	0	6	0.0
	High	4	0	7	0.0
	Unknown	2	17	23	73.9
	Unknown	3	0	3	0.0
	Unknown	4	0	8	0.0

Of the 217 tests that had a ratable driver facial image, 90 were in the Low Speed condition, 61 were in the Moderate Speed condition, 33 were in the High Speed condition, and 33 were in the Unknown Speed condition. In regard to obtaining a high quality image of the drivers face, six images were rated a “4” and five were rated a “5” in the Low Speed condition. For the Moderate Speed condition, four images were rated a “4” and four were rated a “5.” For the High Speed condition, one image was rated a “4” and one was rated a “5.” For the Unknown Speed condition, two images were rated a “4” and none were rated a “5.” The System Effectiveness for capturing the driver’s face was 12.2 percent for Low Speed, 13.1 percent for Moderate Speed, 6.1 percent for High Speed, and 6.1 percent for Unknown Speed. Table 76 shows the effectiveness data for the various speeds, as a function of lane position.

Table 76. System effectiveness for capturing high quality driver facial images as a function of Speed of Violating Vehicle.

	Violating Vehicle Speed	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Low	2	11	59	18.6
	Low	3	0	17	0.0
	Low	4	0	14	0.0
	Moderate	2	8	43	18.6
	Moderate	3	0	10	0.0
	Moderate	4	0	8	0.0
	High	2	2	19	10.5
	High	3	0	6	0.0
	High	4	0	8	0.0
	Unknown	2	2	22	9.1
	Unknown	3	0	3	0.0
	Unknown	4	0	8	0.0

5.4.5 Ambient Conditions

5.4.5.1 System Recording Accuracy

Five Ambient Conditions were investigated: (i) Dawn, (ii) Light, (iii) Late Afternoon, (iv) Dusk, and (v) Dark. Table 77 shows the average values of the light readings for Phases I and II.

Table 77. Measure of Light recordings for the tests as a function of Ambient Condition.

Ambient Condition	Average Light (klx)
Dawn	5.091
Light	42.407
Late Afternoon	4.281
Dusk	0.235
Dark	0.002

Although reliable data were collected for the first four listed conditions, the system did not work in the Dark Condition; a discussion of the failure of the system in the Dark Condition was presented previously. System Recording Accuracy was 93.8 percent for Dawn Conditions, where 75 of the 80 tests were recorded. For the Light Conditions, System Recording Accuracy was 94.4 percent, where 101 of the 107 tests were recorded. For the Late Afternoon Conditions, System Recording Accuracy was 100.0 percent, in which all of the 35 tests conducted were recorded. This was also true for the Dusk Conditions, where all of the 21 tests conducted were recorded. Table 78 illustrates these results as a function of the Ambient Condition.

Table 78. System Recording Accuracy results for the images from each camera as a function of Ambient Condition.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Ambient Condition	Mean	n	Mean	n	Mean	n	Mean	n
Dawn	90.7	75	76.0	75	93.3	75	41.3	75
Light	86.1	101	73.3	101	86.1	101	62.4	101
Late Afternoon	94.3	35	48.6	35	68.6	35	42.9	35
Dusk	76.2	21	61.9	21	85.7	21	23.8	21

5.4.5.2 System Effectiveness

The mean qualitative ratings of the images for each Ambient Condition, as a function of the camera recordings, are shown in Table 79.

Table 79. Qualitative ratings for each camera recording as a function of Ambient Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Ambient Condition	Mean	n	Mean	n	Mean	n	Mean	n
Dawn	2.79	68	2.28	57	1.73	70	1.65	31
Light	3.06	87	3.11	73	1.84	87	1.88	63
Late Afternoon	2.73	33	4.53	17	2.58	24	2.73	15
Dusk	1.19	16	1.46	13	1.17	18	1.60	5

Of the 220 tests that had a ratable license plate image, 73 were in the Dawn condition, 94 were in the Light condition, 34 were in the Late Afternoon condition, and 19 were in the Dusk condition. Across the 73 Dawn tests, 32 images were rated a "4" and eight were rated a "5." For the 94 Light tests, 38 images were rated a "4" and 20 were rated a "5." For the 34 Late Afternoon tests, six images were rated a "4" and 12 were rated a "5." For the 19 Dusk tests, one image was rated a "4" but none were rated a "5." The System Effectiveness for capturing the license plate of the violating vehicle was 54.8 percent for Dawn, 61.7 percent for Light, 52.9 percent for Late Afternoon, and 5.3 percent for Dusk. Table 80 shows the System Effectiveness ratings parsed as a function of the lane that the violating vehicle was in.

Table 80. System effectiveness for capturing high quality license plate images as a function of Ambient Condition.

	Ambient Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Dawn	2	40	55	72.7
	Dawn	3	0	7	0.0
	Dawn	4	0	11	0.0
	Light	2	54	56	96.4
	Light	3	3	21	14.3
	Light	4	1	17	5.9
	Late Afternoon	2	18	22	81.8
	Late Afternoon	3	0	6	0.0
	Late Afternoon	4	0	6	0.0
	Dusk	2	1	14	7.1
	Dusk	3	0	3	0.0
	Dusk	4	0	2	0.0

Of the 217 ratable facial images, 72 were in the Dawn condition, 100 were in the Light condition, 27 were in the Late Afternoon condition, and 18 were in the Dusk condition. Across the 72 Dawn tests, six images were rated a "4" and one was rated a "5." For the 100 Light tests, four images were rated a "4" and five were rated a "5." For the 27 Late Afternoon tests, three images were rated a "4" and four were rated a "5." For the 18 Dusk tests, no images were rated a "4", or "5." The System Effectiveness for capturing the driver's face was 9.7 percent for Dawn, 9.0 percent for Light, 25.9 percent for Late Afternoon, and 0.0 percent for Dusk. Table 81 shows the effectiveness ratings as a function of the violating vehicle's passing lane. As with the previous variables, the impact of the lane position of the violating vehicle is significant and directly impacts the effectiveness of capturing a high quality license plate or driver facial image.

Table 81. System effectiveness for capturing high quality driver facial images as a function of Ambient Condition.

	Ambient Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Dawn	2	7	54	13.0
	Dawn	3	0	7	0.0
	Dawn	4	0	11	0.0
	Light	2	9	57	15.8
	Light	3	0	23	0.0
	Light	4	0	20	0.0
	Late Afternoon	2	7	18	38.9
	Late Afternoon	3	0	4	0.0
	Late Afternoon	4	0	5	0.0
	Dusk	2	0	14	0.0
	Dusk	3	0	2	0.0
	Dusk	4	0	2	0.0

5.4.6 Weather Conditions

5.4.6.1 System Recording Accuracy

Four Weather Conditions were investigated: (i) Clear, (ii) Fog, (iii) Cloudy, and (iv) Rain. System Recording Accuracy for Clear condition was 96.1 percent, where 199 of the 207 tests were recorded. For the Fog condition, System Recording Accuracy was 100.0 percent, where all of the 12 tests conducted were recorded. For the Cloudy condition, System Recording Accuracy was 78.6 percent, in which 11 of the 14 tests were recorded. For the Rain condition, System Recording Accuracy was 100.0 percent, where all of the 10 tests conducted were recorded. The System Recording Accuracy results, parsed by each camera image, are shown in Table 82.

Table 82. System Recording Accuracy results for the images from each camera as a function of Weather Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Weather Condition	Mean	n	Mean	n	Mean	n	Mean	n
Clear	92.0	199	68.8	199	83.4	199	54.3	199
Fog	0.0	12	58.3	12	100.0	12	16.7	12
Cloudy	100.0	11	90.9	11	100.0	11	36.4	11
Rain	100.0	10	70.0	10	100.0	11	0.0	10

5.4.6.2 System Effectiveness

The mean qualitative ratings of the images for each Weather condition, as a function of the camera recordings, are shown in Table 83.

Table 83. Qualitative Rating results for the license plate images from each camera as a function of Weather Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Weather Condition	Mean	n	Mean	n	Mean	n	Mean	n
Clear	2.64	183	2.66	136	1.80	166	1.96	108
Fog	N/A	N/A	3.57	7	2.58	12	1.00	2
Cloudy	4.09	11	3.90	10	1.55	11	1.00	4
Rain	3.80	10	3.86	7	1.70	10	N/A	N/A

Of the 220 ratable license plate images, 192 were in the Clear condition, seven were in the Fog condition, 11 were in the Cloudy condition, and 10 were in the Rain condition. Across the 192 Clear tests, 55 images were rated a “4” and 37 were rated a “5.” For the seven Fog tests, six images were rated a “4” and none were rated a “5.” For the 11 Cloudy tests, 10 images were rated a “4” and one was rated a “5.” For the 10 Rain tests, six images were rated a “4” and two were rated a “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 47.9 percent for Clear, 87.5 percent for Fog, 100.0 percent for Cloudy, and 80.0 percent for Rain. Table 84 shows the System Effectiveness as a function of lane position.

Table 84. System effectiveness for capturing high quality license plate images as a function of Weather Condition.

	Weather Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Clear	2	89	123	73.4
	Clear	3	2	35	5.7
	Clear	4	1	34	2.9
	Fog	2	6	6	100.0
	Fog	3	0	0	0.0
	Fog	4	0	1	0.0
	Cloudy	2	11	11	100.0
	Cloudy	3	N/A	N/A	N/A
	Cloudy	4	N/A	N/A	N/A
	Rain	2	7	7	100.0
	Rain	3	1	2	50.0
	Rain	4	0	1	0.0

Of the 217 ratable facial images, 184 were in the Clear condition, 12 were in the Fog condition, 11 were in the Cloudy condition, and 10 were in the Rain condition. Across the 184 Clear tests, 11 images were rated a "4" and 10 were rated a "5." For the 12 Fog tests, two images were rated a "4" and none were rated a "5." For the 11 Cloudy tests, no images were rated a "4" or a "5." For the 10 Rain tests, no images were rated a "4" or a "5." The System Effectiveness for capturing the driver facial image was 11.4 percent for Clear, 16.7 percent for Fog, and 0.0 percent for both Cloudy and Rain. Table 85 shows the System Effectiveness as a function of lane position.

Table 85. System effectiveness for capturing high quality driver facial images as a function of Weather Condition.

	Weather Conditions	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Clear	2	21	117	17.9
	Clear	3	0	32	0.0
	Clear	4	0	35	0.0
	Fog	2	2	8	25.0
	Fog	3	0	2	0.0
	Fog	4	0	2	0.0
	Cloudy	2	0	11	0.0
	Cloudy	3	N/A	N/A	N/A
	Cloudy	4	N/A	N/A	N/A
	Rain	2	0	7	0.0
	Rain	3	0	2	0.0
	Rain	4	0	1	0.0

5.4.7 Direction of Light Conditions

5.4.7.1 System Recording Accuracy

Five Direction of Light Conditions were investigated: (i) North, (ii) South, (iii) East, (iv) West, and (v) Not Recorded. System Recording Accuracy was 100.0 percent for the North condition, where all of the nine tests conducted were recorded. For the South condition, System Recording Accuracy was 90.0 percent, in which nine of the ten tests were recorded. For the East condition, System Recording Accuracy was 88.9 percent, where 16 of the 18 tests were recorded. For the West condition, System Recording Accuracy was 100.0 percent, where all 23 of the tests conducted were recorded. For the Not Recorded condition, System Recording Accuracy was 95.6 percent, where 175 of the 183 tests were recorded. The results from the System Recording Accuracy for each Direction of Light, as a function of the different camera recordings, are shown in Table 86.

Table 86. System Recording Accuracy results for the images from each camera as a function of Direction of Light Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Direction of Light Condition	Mean	n	Mean	n	Mean	n	Mean	n
North	100.0	9	66.7	9	66.7	9	66.7	9
South	100.0	9	77.8	9	88.9	9	66.7	9
East	100.0	16	62.5	16	68.8	16	75.0	16
West	87.0	23	73.9	23	78.3	23	100.0	23
Not Recorded	85.7	175	68.6	175	89.1	175	38.3	175

5.4.7.2 System Effectiveness

The mean qualitative ratings of the images for each Direction of Light, as a function of the camera recordings, are shown in Table 87.

Table 87. Qualitative ratings for each camera recording as a function of Direction of Light Condition.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Direction of Light Condition	Mean	n	Mean	n	Mean	n	Mean	n
North	2.33	9	3.14	7	1.50	6	1.33	6
South	2.55	9	3.28	7	1.50	8	2.17	6
East	3.19	16	3.50	10	2.18	11	1.92	12
West	2.95	20	2.77	17	1.95	18	2.39	23
Not Recorded	2.76	150	2.74	119	1.82	156	1.78	67

Of the 220 ratable license plate images, nine were in the North condition, nine were in the South condition, 16 were in the East condition, 21 were in the West condition, and 165 were in the Not Recorded condition. Across the nine tests in the North direction, three images were rated a "4" and two were rated a "5." For the nine tests in the South direction, three images were rated a "4" and one was rated a "5." For the 16 tests in the East direction, five images were rated a "4" and four were rated a "5." For the 21 tests in the West direction, four images were rated a "4" and seven were rated a "5." For the 165 tests in the Not Recorded condition, 62 images were rated a

"4" and 26 images were rated a "5." The System Effectiveness for capturing the license plate of the violating vehicle was 55.6 percent for North, 44.4 percent for South, 56.3 percent for East, 52.4 percent for West, and 53.3 percent for Not Recorded. Table 88 shows the System Effectiveness ratings for the three lane positions that were tested.

Table 88. System effectiveness for capturing high quality license plate images as a function of Direction of Light Condition.

	Direction of Light Condition	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	North	2	5	5	100.0
	North	3	0	2	0.0
	North	4	0	2	0.0
	South	2	4	4	100.0
	South	3	0	2	0.0
	South	4	0	3	0.0
	East	2	9	10	90.0
	East	3	0	4	0.0
	East	4	0	2	0.0
	West	2	11	11	100.0
	West	3	0	6	0.0
	West	4	0	4	0.0
	Not Recorded	2	84	117	71.8
	Not Recorded	3	3	23	13.0
	Not Recorded	4	1	25	4.0

Of the 217 ratable facial images, nine were in the North condition, nine were in the South condition, 15 were in the East condition, 23 were in the West condition, and 108 were in the Not Recorded condition. Across the nine tests in the North Direction, no images were rated a "4" or a "5." For the nine tests in the South direction, one image was rated a "4" and none were rated a "5." For the 15 tests in the East direction, no images were rated a "4" and one was rated a "5." For the 23 tests in the West direction, two images were rated a "4" and four were rated a "5." For the 161 tests in the Not Recorded condition, 10 images were rated a "4" and five were rated a "5." The System Effectiveness for capturing the driver facial image was 0.0 percent for North, 11.1 percent for South, 6.7 percent for East, 26.1 percent for West, and 9.3 percent for the Not Recorded condition. Table 89 shows effectiveness breakdown for each lane position.

Table 89. System effectiveness for capturing high quality driver facial images as a function of Direction of Light Condition.

	Direction of Light Condition	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	North	2	0	5	0.0
	North	3	0	2	0.0
	North	4	0	2	0.0
	South	2	1	4	25.0
	South	3	0	2	0.0
	South	4	0	3	0.0
	East	2	1	9	11.1
	East	3	0	4	0.0
	East	4	0	2	0.0
	West	2	6	11	54.5
	West	3	0	6	0.0
	West	4	0	6	0.0
	Not Recorded	2	15	114	13.2
	Not Recorded	3	0	22	0.0
	Not Recorded	4	0	25	0.0

5.4.8 Headlight Scenario

5.4.8.1 System Recording Accuracy

Four Headlight Scenarios were investigated: (i) Headlights-Off, (ii) Standard Lights, (iii) Daytime Running Lights, and (iv) High Beams. System Recording Accuracy in the Headlights-Off scenario was 96.0 percent, where 143 of the 149 tests were recorded. For the Standard Lights scenario, System Recording Accuracy was 93.7 percent, where 59 of the 63 tests were recorded. For the Daytime Running Lights scenario, System Recording Accuracy was 95.7 percent, where 22 of the 23 tests were recorded. For the High Beams scenario, System Recording Accuracy was 100.0 percent, where all of the eight tests conducted were recorded. The results from the System Recording Accuracy for each Headlight scenario, as a function of the different camera recordings, are shown in Table 90.

Table 90. System Recording Accuracy Results for the images from each Camera as a function of the Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	91.6	143	68.1	143	81.8	143	53.2	143
Standard Lights	89.8	59	74.6	59	91.5	59	45.8	59
Daytime Running Lights	63.6	22	50.0	22	90.9	22	40.9	22
High Beam	75.0	8	100.0	8	100.0	8	25.0	8

5.4.8.2 System Effectiveness

The mean qualitative ratings of the images for each Headlight Scenario, as a function of the camera recordings, are shown in Table 91.

Table 91. Qualitative ratings for each camera recording as a function of Headlight Scenario.

	Rear Camera		Front Camera		Profile Camera		Windshield/Face	
Headlight Scenario	Mean	n	Mean	n	Mean	n	Mean	n
Headlights-Off	2.77	131	2.48	97	1.85	117	2.01	76
Standard Lights	2.85	53	3.32	44	1.67	54	1.52	27
Daytime Running Lights	2.36	14	3.36	11	2.00	20	2.22	9
High Beam	3.17	6	3.63	8	2.25	8	2.00	2

Of the 220 ratable license plate images, 137 were in the Headlights-Off scenario, 58 were in the Standard Lights scenario, 17 were in the Daytime Running Lights scenario, and eight were in the High Beams scenario. Across the 137 Headlights-Off tests, 40 images were rated a “4” and 30 were rated a “5.” For the 58 Standard Lights tests, 30 images were rated a “4” and four were rated a “5.” For the 17 Daytime Running Lights tests, four images were rated a “4” and three were rated a “5.” For the eight High Beams tests, three images were rated a “4” and three were rated a “5.” Using these values, the Effectiveness for capturing the license plate of the violating vehicle was 51.1 percent for Headlights-Off, 58.6 percent for Standard Lights, 41.2 percent for

Daytime Running Lights, and 75.0 percent for High Beams. Table 92 shows the effectiveness ratings for each lane position.

Table 92. System effectiveness for capturing high quality license plate images as a function of Headlight Scenario.

	Headlight Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Headlights-Off	2	67	87	77.0
	Headlights-Off	3	2	25	8.0
	Headlights-Off	4	1	25	4.0
	Standard Lights	2	33	42	78.6
	Standard Lights	3	1	8	12.5
	Standard Lights	4	0	8	0.0
	Daytime Running Lights	2	7	10	70.0
	Daytime Running Lights	3	0	4	0.0
	Daytime Running Lights	4	0	3	0.0
	High Beams	2	6	8	75.0
	High Beams	3	N/A	N/A	N/A
	High Beams	4	N/A	N/A	N/A

Of the 217 ratable facial images, 131 were in the Headlights-Off scenario, 57 were in the Standard Lights scenario, 21 were in the Daytime Running Lights scenario, and eight were in the High Beams scenario. Across the 131 Headlights-Off tests, eight images were rated a “4” and seven were rated a “5.” For the 51 Standard Lights tests, four images were rated a “4” and one was rated a “5.” For the 21 Daytime Running Lights tests, no images were rated a “4” and two were rated a “5.” For the eight High Beam tests, one image was rated a “4” and none were rated a “5.” The System Effectiveness for capturing the driver’s face was 11.4 percent for Headlights-Off, 8.8 percent for Standard Lights, 9.5 percent for Daytime Running Lights, and 12.5 percent for High Beams. Table 93 shows a breakdown of the effectiveness ratings for each lane position.

Table 93. System effectiveness for capturing high quality driver facial images as a function of Headlight Scenario.

	Head Light Scenario	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Headlights-Off	2	15	81	18.5
	Headlights-Off	3	0	23	0.0
	Headlights-Off	4	0	27	0.0
	Standard Lights	2	5	42	11.9
	Standard Lights	3	0	8	0.0
	Standard Lights	4	0	7	0.0
	Daytime Running Lights	2	2	12	16.7
	Daytime Running Lights	3	0	5	0.0
	Daytime Running Lights	4	0	4	0.0
	High Beams	2	1	8	12.5
	High Beams	3	N/A	N/A	N/A
	High Beams	4	N/A	N/A	N/A

In regard to vehicle headlights, it should also be noted that tests were conducted to determine if headlights from other vehicles impacted system performance. That is, did headlights from stopped or following vehicles impact system effectiveness? A number of tests were conducted with various headlight status configurations (e.g., on, off, high beams) for stopped and following vehicles, and no noticeable impact to system effectiveness (based on the headlight status of stopped or following vehicles) was found.

5.4.9 Driver/Passenger Window Position Status

5.4.9.1 System Recording Accuracy

Four Window Position Statuses were investigated: (i) Window-Up, (ii) Window-Down, (iii) Window-Half-Down, and (iv) Not Recorded (inadvertent). System Recording Accuracy in the Window-Up scenario was 93.4 percent, where 57 of the 61 tests were recorded. For the Window-Down scenario, System Recording Accuracy was 97.0 percent, where 161 of the 166 tests were recorded. System Recording Accuracy in the Window-Half-Down scenario was 100.0 percent, where all three of the tests conducted were recorded. For the Not Recorded tests, System Recording Accuracy was 84.6 percent, where 11 of the 13 tests were recorded. The results from the System Recording Accuracy for each Window Position Status, as a function of the different camera recordings, are shown in Table 94.

Table 94. System Recording Accuracy results for the images from each camera as a function of Window Position Status.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Window Position Status	Mean	N	Mean	N	Mean	N	Mean	N
Window-Up	93.0	57	73.7	57	89.5	57	35.1	57
Window-Down	85.1	161	67.1	161	83.2	161	55.9	161
Window-Half-Down	100.0	3	66.7	3	100.0	3	66.7	3
Not Recorded	100.0	11	81.8	11	100.0	11	18.2	11

5.4.9.2 System Effectiveness

The mean qualitative ratings of the images for each Window Position Status, as a function of the camera recordings, are shown in Table 95.

Table 95. Qualitative ratings for each camera recording as a function of Window Position Status.

	Rear Camera		**Front Camera**		**Profile Camera**		**Windshield/Face**	
Window Position Status	Mean	N	Mean	N	Mean	N	Mean	N
Window-Up	3.30	53	2.48	42	1.63	51	2.00	20
Window-Down	2.64	137	3.12	107	1.94	134	1.91	90
Window-Half-Down	2.33	3	2.50	2	1.67	3	1.50	2
Not Recorded	2.09	11	100.0	9	1.46	11	1.50	2

Of the 220 ratable license plate images, 56 were in the Window-Up condition, 150 were in the Window-Down condition, two were in the Window-Half-Down condition, and two were in the Not Recorded Scenario. Across the 56 Window-Up tests, 29 images were rated a “4” and eight were rated a “5.” For the 150 Window-Down tests, 44 images were rated a “4” and 32 were rated a “5.” For the two Window-Half-Down tests, one image was rated a “4” and no images were rated a “5.” For the 11 Not Recorded tests, three images were rated a “4” and no images had a rating of “5.” The System Effectiveness for capturing the license plate of the violating vehicle was 66.1 percent for Window-Up, 50.7 percent for Window-Down, 33.3 percent for Window-Half-Down, and 27.3 percent for Not Recorded. Table 96 shows the effectiveness data parsed by the position of the passing lane.

Table 96. System effectiveness for capturing high quality license plate images as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
License Plate Image	Window-Up	2	36	41	87.8
	Window-Up	3	1	6	16.7
	Window-Up	4	0	9	0.0
	Window-Down	2	73	99	73.7
	Window-Down	3	2	29	6.9
	Window-Down	4	1	22	4.5
	Window-Half-Down	2	1	2	50.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	0	1	0.0
	Not Recorded	2	3	5	60.0
	Not Recorded	3	0	2	0.0
	Not Recorded	4	0	4	0.0

Of the 217 ratable facial images, 56 were in the Window-Up condition, 147 were in the Window-Down condition, three were in the Window-Half-Down condition, and 11 were in the Not Recorded condition. Across the 56 Window-Up tests, three images were rated a "4" and one was rated a "5." For the 147 Window-Down tests, 10 images were rated a "4" and nine were rated a "5." For the three Window-Half-Down tests, as well as for the 11 Not Recorded tests, no images were rated a "4"or a "5." The System Effectiveness for capturing the driver's face was 7.1 percent for Window-Up, 12.9 percent for Window-Down, and 0.0 percent for Window-Half-Down and Not Recorded. Table 97 shows the effectiveness data for each passing lane.

Table 97. System effectiveness for capturing high quality driver facial images as a function of Window Position Status.

	Window Position Status	Lane #	# Images Rated 4 or 5	# Tests Conducted With Ratable Images	System Effectiveness %
Driver Facial Image	Window-Up	2	4	41	9.8
	Window-Up	3	0	6	0.0
	Window-Up	4	0	9	0.0
	Window-Down	2	19	95	20.0
	Window-Down	3	0	28	0.0
	Window-Down	4	0	24	0.0
	Window-Half-Down	2	0	2	0.0
	Window-Half-Down	3	N/A	N/A	N/A
	Window-Half-Down	4	0	1	0.0
	Not Recorded	2	0	5	0.0
	Not Recorded	3	0	2	0.0
	Not Recorded	4	0	4	0.0

5.4.10 False Alarm Tests

A total of 16 false alarm tests were conducted where the approaching vehicle stopped appropriately. The purpose of these tests was to determine how the system would respond when a vehicle approached the school bus and stopped appropriately. Seven of the tests involved an Oncoming vehicle and nine involved an Overtaking vehicle. For eight of the tests, the stopping vehicle did trigger the recording cameras (i.e., a recording was made). However, in review of the video, it could be clearly seen that the vehicle did not pass the bus, but stopped appropriately. Because it is envisioned that the final deployed system will require a human reviewer to validate violations, the presence of a false alarm might not be a serious problem. However, it is recommended that for design iterations of the system, adjustments be made to the detection area of coverage so that fewer non-violation recordings are made. It must be recognized that a trade-off results from making such adjustments to the detection system. These trade-offs may lead to actual violations being missed. In other words, reducing the detection coverage area could result in the violation recording cameras being triggered too late and actual violations missed. Further study and testing is warranted in order to come to an acceptable balance that minimizes the number of recorded non-violations and maximizes the number of recorded valid violations.

5.4.11 Composite Effectiveness

Facial images would not have a functional purpose without the presence of license plate images. Thus, it is important to see the interaction between the recording of useful license plate images and useful facial images. Analysis was performed to determine a new effectiveness rating that was based on both images. The Composite Effectiveness is the percentage of license plate/facial image combinations that have a combined rating of 8[9], 9 or 10. (Figure 19 shows the distribution of combined ratings parsed by lane position.) For Passing Lane 2, the Composite Effectiveness was 14%.

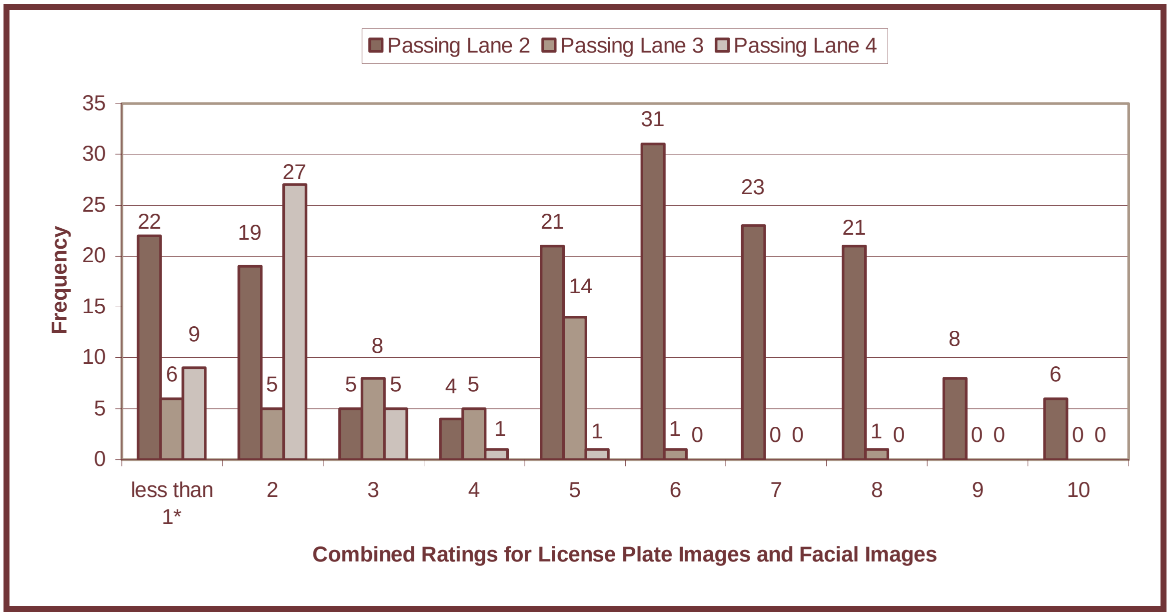

Figure 19. Distribution of Combined Ratings as a function of Passing Lane Scenario.

5.4.12 Combination of Phase I and Phase II Summary

Across both Phases I and II, a total of 238 tests were conducted; 183 of these were conducted in Phase I, and 55 were conducted in Phase II. Because the independent analyses of Phase I and Phase II showed similar findings, it was reasonable to combine the data and conduct analyses on the larger data set. The major findings of the combined analyses are highlighted below.

[9] In order to have a combined rating of 8, each image must have a rating of 4 to be considered useful.

First, considering all tests that were conducted, the Overall System Recording Accuracy was 95.5 percent; that is, for 232 of the 243 tests that were conducted, at least one system camera made a valid recording of the violation. Situations where the system did not work effectively were attributed to: (i) recording limitations of the system in that the system did not record full motion video, (ii) the time required for the cameras to adjust to the ambient conditions resulted in missed violations, (iii) the wide field-of-view lens used for the front camera in order to capture the stop-arm, and (iv) curved roadways where, when violating vehicles did not approach parallel to the bus, triggering was missed or delayed. Nonetheless, for a great majority of the tests that were conducted, the system did detect the violating vehicle and made a valid recording.

A second important finding was that the Overall System Effectiveness, as defined as the percentage of usable images, was 53.2 percent for capturing a high quality image of the violating vehicle's license plate. This percentage included all tests conducted, including those in Passing Lanes 3 and 4 (i.e., up to three lanes away from the bus). Considering only the lane directly adjacent to the bus (the lane that the system was designed for), the System Effectiveness for capturing a usable license plate image jumped to 76.9 percent. A similar result was found for System Effectiveness for capturing usable driver facial images. The System Effectiveness across all lanes was 10.6 percent, but jumped to 16.1 percent when the analysis only included tests with the violating vehicle passing immediately next to the bus. These findings suggest that future versions of the system should focus on the lane immediately next to the bus, which, as pointed out earlier, characterizes the most common violation type.

Another interesting finding involved the capture of a usable image of the driver's face. In the combined Phase I and Phase II results presented, the driver images that were analyzed were the highest quality image from a given test, and could have been either the profile or frontal image from that test. When the relative usability of the two facial views were compared, it was found that approximately 1.5 times more of the front facial images were usable as compared to the profile images. That is, of the 199 profile images that were ratable, 13 of them were usable (nine profile images were rated a "4" and four profile images were rated a "5"). Conversely, of the 114 frontal images that were recorded, 11 were usable (five frontal images were rated a "4" and six frontal images were rated a "5"). Thus, the System Effectiveness for capturing a usable profile image was 6.5 percent, while the System Effectiveness for capturing a frontal image was 9.6 percent. The implications of this finding are discussed in the Conclusions Section.

CHAPTER 6: CONCLUSIONS[10]

6.1 Implications for Prototype Test Results

To address the problem of vehicles illegally passing school buses when the stop-arm is extended and the red lights are flashing, NHTSA sponsored a research project aimed at developing an automated system for detecting and recording the violating driver and license plate. The tasks of the project included assessing current technology, as well as legal and administrative feasibility. Subsequently, if the development of an automated system seemed feasible, there was an additional task to develop a prototype system that detects illegal passing of school buses and records a variety of information about the status of the school bus (stopped with lights flashing and stop-arm extended), the driver's image, the violating vehicle's license plate number, and the incident (e.g., time of day, day of week).

As has been detailed in the body of this report, the information learned during the course of the feasibility phase of the project indicated that the development of an automated enforcement system to address illegal school bus passing is indeed feasible from a technical, administrative, and legal perspective. Based on this finding, a prototype system was developed and tested both on a closed course and in a local neighborhood using drivers who simulated violators. The purpose of this testing was to gather data that could be used to support design recommendations and changes for the next generation of the system. The primary findings from the prototype testing and the implications for the next generation of the system are described below.

6.1.1 High System Recording Accuracy

There were 243 violation tests conducted in the study. Of these, 232 resulted in a valid recording of the violating vehicle; thus, the System Recording Accuracy was 95.5 percent. Although this is a very high percentage, the *Results* section listed instances where the system failed to respond, or responded inappropriately. These instances, and potential fixes for the next generation of the system, are outlined below:

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[10] As of April 5, 2002, the results and recommendations are being reviewed by NHTSA. This section represents a preliminary review of the findings from the prototype testing. A published final report is expected; currently a rough draft is in press (Hanowski, et al., 2002).

- Problem1: Images were missed due to the recording limitations of the system in that the system did not record full motion video.
    - Possible Solutions: The system tested is currently at the technological limit in this respect and, as such, this problem cannot be addressed until technology improves.
- Problem 2: Time required for the cameras to adjust to the ambient conditions resulted in missed violations.
    - Possible Solutions: Add a filter onto the camera lens to aid in adjustment; use software to improve the glare and white-out control; trigger recording cameras earlier to allow for adjustment period (trade-off would be increased number of false alarms).
- Problem 3: Wide field-of-view for front camera captured stop-arm in lieu of being focused on license plate area (resulting in missed license plate images).
    - Possible Solutions: It is suggested that despite missing a few license plates, capturing the stop-arm is an important system feature and thus this is a necessary trade-off.
- Problem 4: Recordings were missed for violating vehicles that approached on a curve.
    - Possible Solutions: This is a difficult problem to address without significantly increasing the number of false alarms. Additional detection cameras could be added to detect approaching vehicles from various angles; however, "noise" would be introduced, and more false alarms (see Problem 5) would be encountered. It may be possible to address this problem through software while maintaining the current hardware configuration.
- Problem 5: System was triggered (false alarms) by non-violating vehicles and non-vehicles (pedestrians).
    - Possible Solutions: Focus system detection cameras on Passing Lane 2 only; improve the software/filter so that recording cameras are activated only when objects resembling vehicles (e.g., template matching) are detected.

6.1.2 High System Effectiveness for Capturing License Plate Images in Passing Lane 2

System Effectiveness was the percentage of usable (high quality) images that were recorded. In terms of System Effectiveness for capturing usable license plate images, the effectiveness rating was 76.9 percent for violating vehicles in Passing Lane 2. When examining the outside passing lanes, the System Effectiveness was much less. If the next generation system is required to capture images from lanes other than Lane 2, one possible solution would be to have separate violation recording cameras dedicated to each lane. Of course, this would substantially increase the number of cameras incorporated into the system (i.e., triple the cameras in the current system), and substantially increase the cost[11] and complexity of the system. The recommended solution for the next generation system is to focus the automated enforcement only on the lane immediately adjacent to the bus. As indicated earlier, this seems to be the most feasible solution because, from a practical standpoint, most school bus routes are on two-lane roads (Institute for Transportation Research and Education, 2000).

In regard to the relatively poor quality license plate images that were recorded in Passing Lane 2 (23.1 percent were rated <4), one of the problems encountered was difficulty with the system in low-light conditions. It is believed that improvements to the system could be made either with filters on the cameras and/or software modifications to alter the contrast of the recordings. In addition, it is suggested that improvements to image quality might be made through post-processing image enhancement; it is recommended that a wider range of software programs and applications be tested in the future.

6.1.3 System Effectiveness for Capturing Driver Facial Images Comparable to Red-Light Cameras

Analysis of the effectiveness of the system in capturing usable driver facial images, the overall effectiveness was 10.6 percent across all tests. However, when only Passing Lane 2 tests were considered, the effectiveness was 16.1 percent. Interestingly, the percentage of usable images from the frontal view was 13.4 percent, as compared to 10.2 percent from the profile view. This finding was surprising given that the system was not designed specifically to capture the driver's frontal image through the windshield.

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[11] Note that the hardware cost associated with the development of a single prototype system was approximately $5500. This is considered relatively inexpensive given that the cost of a single Red-Light system is estimated to be $200K (Huey and Llaneras, 2001a).

What do these results suggest? First, because the driver was sitting in a darkened cab (relative to the outside light) behind glass, System Effectiveness will likely never reach the high percentages found in capturing usable license plate images. However, it is believed that effectiveness could be improved by modifying the system design to capture a frontal image. As shown in Figures 20 and 21, this might be accomplished by eliminating the profile camera and adding two additional front and rear cameras that are directed at the windshield area. Additional benefits of this approach would be: (i) better identification, because, a frontal image seems to be the preferred view for identifying a violating driver as indicated in the legal feasibility analysis; (ii) the system would be effective for capturing images of both automobiles and pick-up truck drivers, as the height of the driver in the cab of the vehicle would be less of an issue, and (iii) tinted glass would be less of an issue (though tinted glass was not thoroughly tested in this study, it is recognized as being potentially problematic for capturing a profile image).

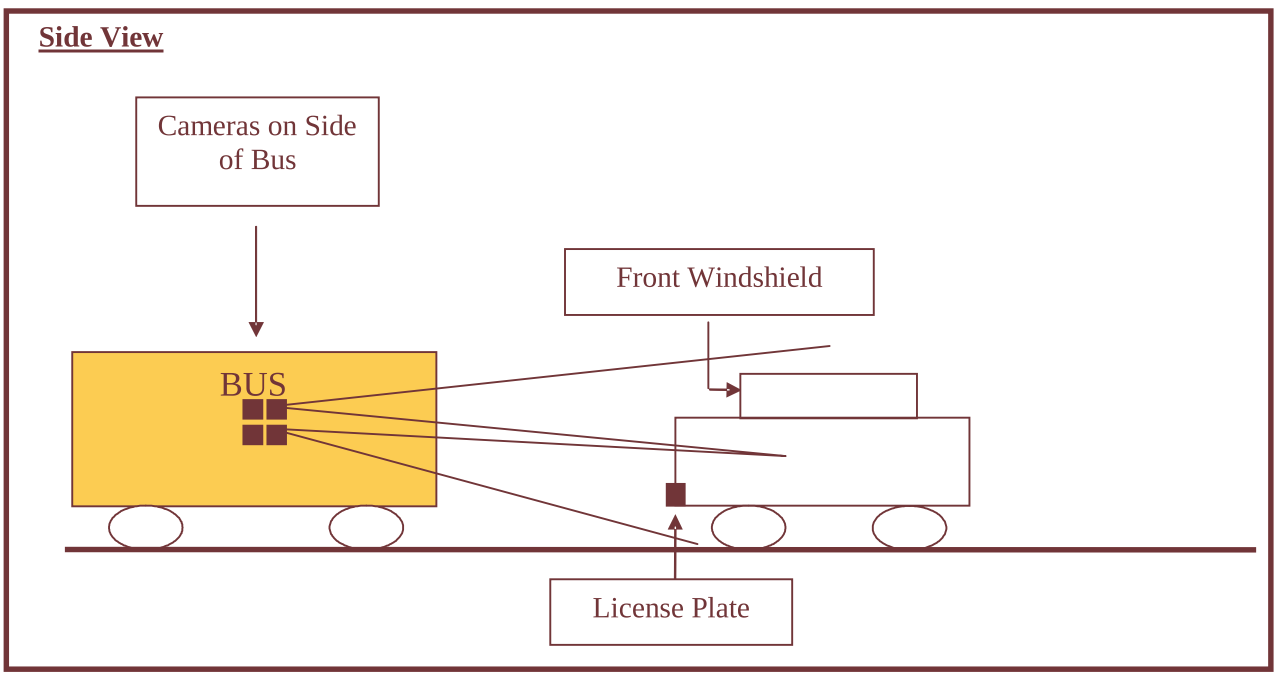

Figure 20. Schematic of the configuration and approximate fields-of-view of the proposed design change to incorporate four violation capture cameras.

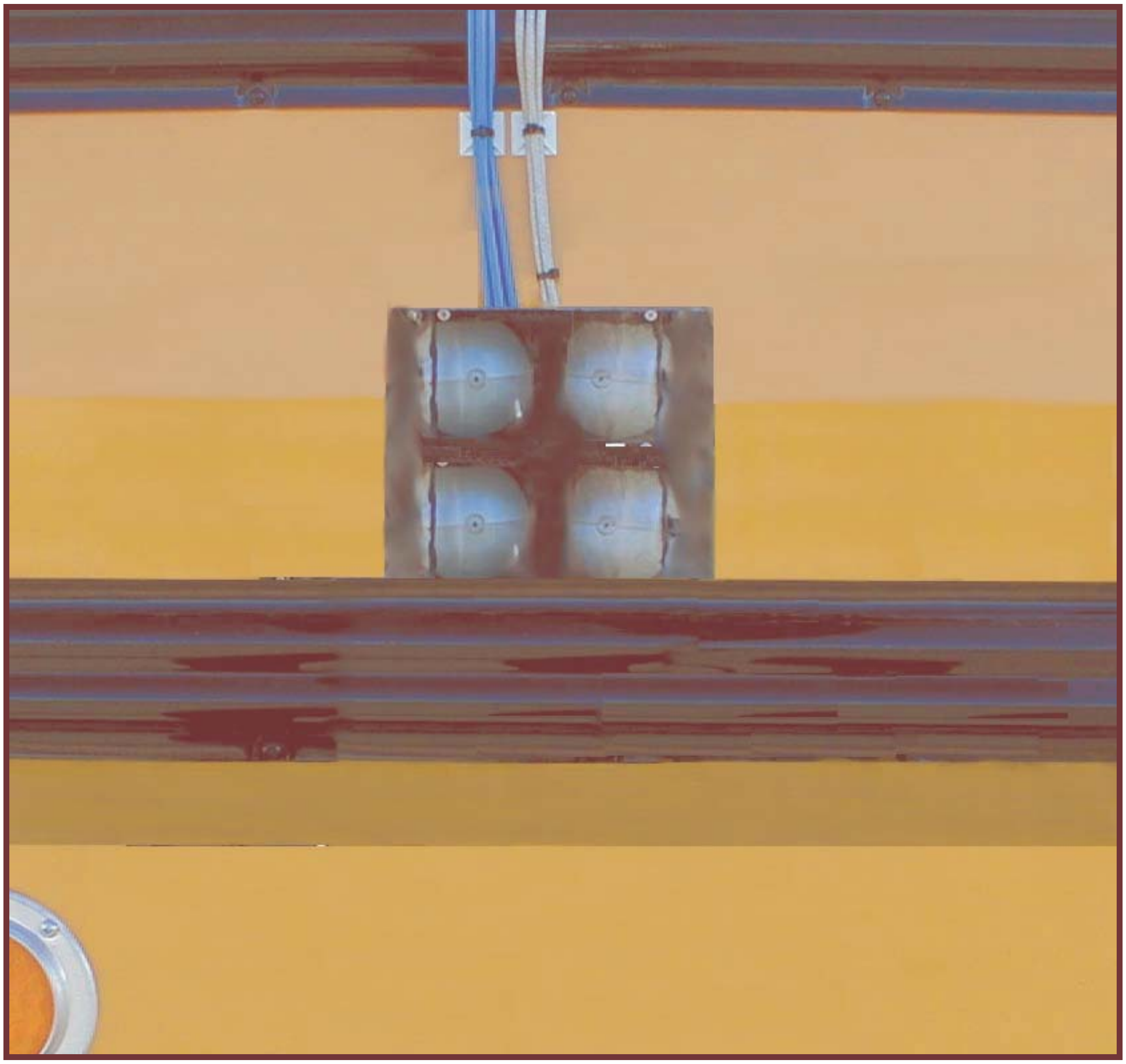

Figure 21. Digitally altered picture showing what the modified violation capture camera configuration, with four cameras, might look like.

In the current version of the prototype, the System Effectiveness for capturing the driver's image (for violations in Passing Lane 2) was similar to that recorded in Red-Light Running systems. That is, Huey and Llaneras (2001b) note that, with Red-Light Running cameras, reliably capturing a driver facial view is less than 20 percent. It is believed that by focusing the camera on Passing Lane 2 and implementing the recommended system design alterations, the System Effectiveness for capturing the driver's face would be improved. However, given the difficulty in recording through glass, the effectiveness is not likely to reach that of the effectiveness for capturing high quality license plate images.

6.1.4 The Prototype System as it Relates to Other Automated Enforcement Systems

6.1.4.1 School Bus Surveillance

The first school bus surveillance system recorded useful information such as time of violation and the speed of the bus. However, the system was not sophisticated enough to produce the favorable recorded images that were attained by the prototype system that was tested in this research. When compared with the system that was implemented in Onslow County, the prototype system has the potential to have a lesser number of non-violation recordings. Recall that the SWC20 begins recording when the stop arm is deployed. This has the potential of introducing many hours of non-violation video. The prototype system, on the other hand, digitally recorded violations only when the violation detection cameras sensed violations.

6.1.4.2 Red-Light Camera

In order to compare the effectiveness of the red-light camera to that of the prototype system's, the speed of the violating vehicle and lane position was revisited. These variables were used because they provide a commonality for comparison. Recall that the prototype's System Effectiveness for Low, Moderate, and High speeds ranged from 41.2 to 57.8 percent and the System Effectiveness for Passing Lane 2, Passing Lane 3, and Passing Lane 4 was 76.9, 8.1, and 2.8 percent, respectively. At 44 percent, the results from Charlotte's first year of red-light automated enforcement use are comparable to the tested prototype system's results for various violating vehicle speeds and for violations that occurred in Lane 2.

6.1.4.3 Automated Speed Enforcement

The Composite Effectiveness of the photo-radar system was also compared to that of the school bus prototype system developed in this project. Recall, the school bus prototype system Composite Effectiveness was 14 percent in Lane 2 and the Composite Effectiveness for the Gatsometer was 9.1 percent. Comparing these values shows that the prototype system has exceeded the effectiveness of a commonly used photo radar system.

6.1.5 Prototype System Proved Robust, with Few Exceptions

One of the findings from the prototype tests was that the system performed quite well across a variety of the conditions. However, as indicated earlier, there were a few exceptions to this.

First, the system was ineffective in darkened conditions. An Infrared Pulse Source was incorporated into the system design, but did not work reliably. There are a few potential solutions that would enable the system to record in very low-light conditions. For example, a more powerful I/R source could be tested, or cameras with night-vision capabilities could be used. However, given that cost is a constraint on the system being developed (e.g., the final cost of the system must not be more than school boards are willing to spend), these solutions do not seem practical. Nonetheless, limited testing could be conducted on improving the effectiveness of the I/R source. Second, as described previously, the system lacked the ability to record quality images from passing lanes other than the lane next to the bus. As suggested, this difficulty could be overcome, but at a substantial hardware cost (e.g., additional cameras dedicated to the outside lanes).

One limitation that has not been raised up until this point was the system's unreliability in accurately determining the offset angle and speed of the violating vehicle. However, this is a software fix that could be made in the next design iteration of the system.

One final point regarding the system testing should be made, and that is, as a deterrent, the prototype system likely worked well enough to serve as a deterrent for violators. Ultimately, the number of reduced violations and crashes will be the most important statistic to assess the effectiveness of the system. In its current state (based on the 75.9 percent and 16.1 percent effectiveness ratings for the license plate and driver face capture, respectively), the system would likely serve as a strong deterrent. However, it is also believed that with the design modifications that have been recommended, system effectiveness for capturing clear license plate images and driver facial images could be improved.

CHAPTER 7: NEXT STEPS

7.1 Areas for Growth

This project has successfully demonstrated a prototype of an automated illegal school bus passing enforcement system. It has cleared technical hurdles to create a system that works well in showing that an inexpensive system can detect violations using non-radiating sensors and capture visual images capable of divulging license plate identification of the offending vehicle and the driver of the vehicle. The data necessary for uniquely identifying the circumstances surrounding the violation has also been included in the capture capabilities of the system. However, there are areas in which the system falls short of the maturity necessary to operationally test the system for its intended purpose. The sections that follow outline the aspects that need further refinement and feasibility assessments.

7.1.1 Prototype Mapping to the Specification

In order to understand the limitations of the prototype system, it is best to compare the prototype system's capabilities to the "ideal" system requirements outlined in the specification document. A checklist that was developed to map the prototype system to the specifications for an idealized operational system can be found in Hanowski, et al (2002).

7.1.2 Functional Growth Implications

In addition to the system refinements suggested previously (based on the results of the Phase I and II tests), perhaps the most significant areas requiring improvement are related to the post-processing and packaging portions of the system. In particular, the prototype system needs refinement in the following areas:

- Packaging of sensors and image capture components for security (vandal and tamper-proof), robustness, and aesthetics will be required in order to perform unaccompanied operational testing.
- Integration of the data and images for use as evidence (i.e., both in a single image frame) will be required to provide an unambiguous, tamper-proof link between them.
- Storage and control of data and images details that fully consider evidence integrity will be required before citations can be executed.

- Definition of the elements and procedures for post-processing of the data and images will be required for full-scale operational testing. Documentation of the responsibilities of each person interacting with the data and procedures for protecting the "chain of evidence" will also be required.
- Controls will need to be provided to the jurisdiction or technician to allow adjustment of the parameters defining a violation (e.g., required conditions of time or distance before a pass is considered a violation). There are several aspects of the law that vary among jurisdictions. Allowing the system to "know" these subtleties will provide the means to filter many of them without the requirement for further administrative or law enforcement review.
- Post-processing tools need to be developed that allow data to be played back and extracted for use in creating citations.
- Day-to-day issues of maintaining the system, calibrating the system, and retrieving the data must be resolved.

7.1.3 Need for Further Feasibility Assessment

To this point, the demonstrations have been concentrated on the technical issues of collecting the data, not on the day-to-day issues of maintaining the system, calibrating the system, and retrieving the data. As the system design evolves, particularly time-consuming or difficult tasks will be exposed that may affect the driver, maintainer, or technician. Documentation of these issues should be captured during functional and operational testing to allow critical assessment and consideration of the need for refinements to procedures or the system design.

7.2 Plan for Future Refinement and Assessments

The following sections outline a plan for the logical extension of this development work. The plans include development of the system to carry violations from detection/image capture to citation/warning delivery. The current project has demonstrated feasibility of the concept; future work needs to extend this to the next logical step, system refinement followed by a limited field operational test. System refinement would involve testing and integrating the design suggestions previously made, which were based on the prototype system test results. Once the next generation system has been developed and tested, a field operational test could be conducted in order to demonstrate the integrity and capabilities of the violation capture components of the system, and provide the assessment of the post-processing procedures required to field a fully functional system.

A limited field test of the system is recommended in two operational environments: (i) an urban area and (ii) a rural area. It is important that these tests include both areas in order to capture the full range of operational environments. Urban environments involve densely, populated areas that include complex traffic movements (motor vehicle, bicycle, pedestrian, etc.), parked vehicles, physical and painted medians separating approaching traffic. In addition to this potential "target" density, it can be anticipated that many opportunities for misses and false alarms would be available. Rural settings, on the other hand, are less visually complex environments and may potentially have higher speeds and less geometric visibility in some cases. Rural operational tests would instrument a portion of a school bus fleet with the automated enforcement system, train bus drivers, conduct functional tests to ensure that components and outputs of the system are functioning as desired, capture data over a period of time (weeks or months), reduce and process the data to assess its reliability and effectiveness, and develop support tools needed to process the data to a level sufficient to support citation development. The scope of this effort is envisioned to be limited to the demonstration of the technical aspects of the violation capture up to the point of being able to integrate data and images to create a citation. However, it is not envisioned that this effort will extend into creation or delivery of warnings or citations. Nevertheless, administrative and legal aspects should be addressed during the process of this field demonstration.

An important consideration in the tasks associated with this effort would be to assess the scope of the problem for the route areas selected. That is, once urban and rural areas have been selected, an assessment as to how many passing violations and crashes occur on a daily/weekly/yearly basis in the area. This information would be used as baseline data for later determining the effectiveness of the system for reducing violations.

7.2.1 Development of the Process Back-End

Getting the collected data to a point at which it could be given to a violator is still not a reality. Procedures and data needs/methods are required to facilitate law enforcement review and citation/warning packaging. Responsibilities for each person/process in the chain of processing must be defined, documented, and tested to ensure that they work as planned. Much can be learned from similar systems (i.e., Red-Light cameras and Automated Speed Enforcement) that are currently being used. However, this application has a unique set of nuances different from those applications that must be addressed. This process will involve preparing definitions of data requirements for the citation/warning documents, developing job descriptions and minimum qualifications for the individuals involved with a given responsibility, and documenting procedures to ensure evidence integrity. The latter two areas will be highly similar to those responsibilities and documentation procedures associated with Red-Light cameras, but the personnel may be only partially dedicated to the task (e.g., bus depot technicians, school safety officers). Thus, the procedures must be made very clear. Integral to the process of developing roles and responsibilities will be a need to include judicial and legislative representatives in the process to ensure that they concur with the allocations of various duties. Unless this can be satisfied before a case is brought to the legal system and the process is determined to be valid and defensible, prosecution of these cases will not be possible and the effort will likely fail.

7.2.2 Define Agency Roles/Responsibilities

The path from the system installer to the maintainer, the bus driver, to the person who retrieves the data, to the person that processes the data, to the person that verifies and delivers the citation is a long one. There are many ways in which duties associated with the process might be defined. One task in the next phase of this project would be to draft a standard procedure with roles outlined for each of the agencies most likely to participate in one of the component tasks for that procedure.

7.2.3 Develop Software Tools for Post-Processing

To this point, our efforts were not concentrated in post-processing (though attempts, with limited success, were made with *PhotoShop*); however, the post-processing tools required to translate raw data and video to citations will need to be developed before a fully functional system can be tested in an operational sense. Ensuring that all of the necessary data items are included and formatted to provide unambiguous indications of the violation details will require some interpretation (and perhaps enhancement) of the data based on known situation factors (GIS info, nuances in the law, etc.). Additionally, a software package that allows the raw (i.e., unmodified evidence) data and images to be enhanced and integrated into the citation will be needed. This system will require image editing tools as well as database tools to provide the linkage to license information and tracking of the progress for a given citation through the adjudication process.

7.2.4 Ensure Legislative/Judicial Integrity

Using legal knowledge gained from the legal review performed under the current project, and local representatives of the judicial and legislative bodies in the Metro DC area, should allow for a review of the plans from those sectors. Such awareness and interaction with parties likely to be called upon to judge or enact legislation related to this type of application will be critical. To allow testing and demonstration of this type of product, these entities, as well as local school and law enforcement officials, will need to be involved and supportive. They also will provide further informal reviews and feedback that may prevent later roadblocks to deployment.

7.2.5 Limited Functional Testing After System Refinement

After the refinement process is complete and a next generation system has been developed, limited functional testing should be conducted. This testing should occur in both urban (e.g., Washington, DC) and rural (e.g., Blacksburg, VA) areas. The purpose of this testing would be to test the effectiveness of the refined system.

7.3 Limited Deployment and Field Testing

7.3.1 Field Multiple Systems

After observing functional tests of the prototype system in various settings, several additional systems could be created and fielded on a limited basis. Unlike the functional tests, these tests would involve deployment without the accompaniment of an observer. In essence, these tests would put the prototype systems into the hands of actual users and observe "from afar" to see what kinds of issues and problems arise from the use/misuse of the system. The data would be handled in the way outlined in the draft procedures for each agency involved in the enforcement process. This effort would ideally include delivery of warnings to drivers and assess feedback from them (perhaps with an invitation to call a telephone interviewer) regarding the violation and the warning/citation format and function.

In concert with the field operational testing, a media campaign could be implemented to educate drivers about school bus passing and put drivers on notice that the automated systems have been installed on area school buses. In addition, an effort to determine the appropriate labeling for buses equipped with the system would also be required prior to the test.

7.3.2 Monitor System and Process Performance

During the limited field-testing, observers would continue to ride in the bus periodically to watch the operation of the system. This would typically be done in situations in which false alarms or disagreements between system and driver indications are noticed during the data processing. Observers would also monitor the tasks associated with post-processing to ensure that draft procedures work smoothly and have minimal levels of overlap or gaps in the steps necessary to obtain and process the violation data. In addition to monitoring the process, researchers could also conduct focus groups and/or interviews with the parties involved in the process, at different functional levels, to get feedback on the adequacy of procedures and the effectiveness of the system in fulfilling its desired role. One group would likely include the bus drivers using the capture systems and another would likely be comprised of the agencies involved in the post-processing and system maintenance.

7.3.3 Recommend Packaging and Marketing Options

After completing the field operational test, an effort would be required to finalize the specifications for the system design and outline the bounds and roles of all parties who interact with the system. Since the current project focused primarily on the detection and recording components of the system, more attention would be required on the later phases of the process that take the data from raw evidence to citations of individuals. In addition, issues arising from the public information campaigns and from the inclusion of outward markings on buses or near jurisdictions using the system would be addressed. Although the general aspect of passing a school bus is illegal, jurisdictional differences add a layer of complexity to the effort, and would require both general and tailored materials to assist in training of system users.

7.4 Closing Remarks

The goal of this project was to determine the feasibility of developing an automated system for recording drivers, and vehicles, which illegally pass school buses. Based on the findings from the technical, administrative, and legal feasibility analyses, a working prototype system was developed. Testing of this system in a variety of real-world conditions indicated that this concept is promising and that valid recordings can be made that clearly show the violating vehicle and driver in the act of committing a violation. The bottom line from this effort is that the concept of an automated enforcement system for this application has been shown to be worthy of further exploration and refinement with the ultimate goal of developing and deploying a fully operational system.

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APPENDIX A: TESTING INFORMATION LETTER TO PARENTS ALONG BUS ROUTE

SCHOOL BUS SAFETY RESEARCH

The Virginia Tech Transportation Institute (VTTI) is conducting a study on school bus safety. In order to accomplish this, we will be testing the system along a typical bus route. This testing will occur the morning of Sunday November 11^{th} and/or Sunday November 18^{th}. We will be conducting the testing when school is not in session and the amount of traffic on the streets will be minimal. The school bus being used in the test will have a sign: "Experimental Vehicle – Testing in Progress."

PLEASE DO NOT BE CONCERNED if you see a school bus on your child's bus route at an unscheduled time. No children will be on the bus. Only VTTI staff will be involved with this study.

Part of the test procedure will require that vehicles pass the stopped school bus with the stop arm out and red lights flashing. If you are driving and encounter this school bus (signed as above) you may safely pass this test vehicle when instructed to do so by VTTI staff.

If you have any questions about this project, feel free to call:

Dr. Rich Hanowski at VTTI; phone: 231-1513.

APPENDIX B: LIST OF THE 255 TESTS THAT WERE ANALYZED IN PHASE I AND PHASE II

The first spread sheet shows the 186 tests and 12 I/R (dark) tests that were conducted on the Smart Road in Phase I. The next five spread sheets shows the 57 tests to that were analyzed on a real bus route in Phase II.

PHASE I: SMART ROAD

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	3	Low	White	Down	Headlights Off	Clear	Light		West					
Oncoming	2	2	Low	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	2	2	Moderate	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Low	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Oncoming	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Oncoming	2	2	High	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Oncoming	4	3	High	White	Down	Daytime Running Lights	Clear	Dusk		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	3	Low	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	2	High	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	4	4	Low	White	Up	Standard Lights	Rain	Light		Not Recorded					
Oncoming	2	2	Moderate	Black	Not Recorded	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	4	3	High	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	3	High	Dk Blue	Up	Headlights Off	Clear	Light		West					
Oncoming	4	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		West					
Oncoming	4	3	Moderate	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	3	Moderate	Dk Blue	Up	Headlights Off	Clear	Light		West					
Oncoming	2	2	Low	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Low	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	3	Moderate	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	3	High	White	Down	Headlights Off	Clear	Light		East					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		South					
Oncoming	4	3	Moderate	White	Down	Headlights Off	Clear	Light		South					
Oncoming	4	3	Low	White	Down	Headlights Off	Clear	Light		North					
Oncoming	4	3	Moderate	Dk Blue	Down	Headlights Off	Clear	Light		North					
Oncoming	4	3	Low	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	4	3	High	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	2	2	Low	White	Up	Standard Lights	Rain	Light		Not Recorded					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Rain	Light		Not Recorded					
Oncoming	4	3	Low	White	Up	Standard Lights	Rain	Light		Not Recorded					
Oncoming	4	3	Moderate	White	Up	Standard Lights	Rain	Light		Not Recorded					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	2	2	Moderate	Black	Up	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	2	2	High	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	2	2	High	Black	Up	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Oncoming	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dark		Not Recorded					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Clear	Dark		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dark		Not Recorded					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	3	Low	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	4	3	Moderate	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	4	4	Moderate	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	4	4	Low	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Oncoming	2	2	High	Dk Blue	Up	Headlights Off	Clear	Light		West					
Oncoming	4	4	High	Dk Blue	Up	Headlights Off	Clear	Light		West					
Oncoming	2	2	High	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	4	Moderate	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	4	High	White	Down	Headlights Off	Clear	Light		West					
Oncoming	2	2	Low	White	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	2	2	Moderate	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	4	High	White	1/2 Down	Headlights Off	Clear	Light		East					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	4 to 3	Low	White	Not Recorded	Headlights Off	Clear	Light		East					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Oncoming	4	4	High	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Oncoming	4	4	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Light		South					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Light		South					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Light		North					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Light		North					
Oncoming	4	4	High	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Light		Not Recorded					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Light		Not Recorded					
Oncoming	2	2	Moderate	Dk Blue	Up	Headlights Off	Clear	Light		West					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Light		North					
Oncoming	2	2	Moderate	White	Down	Headlights Off	Clear	Light		North					
Oncoming	2	2	High	White	Down	Daytime Running Lights	Clear	Dawn		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	2	2	Low	White	Down	Headlights Off	Clear	Light		West					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Light		West					
Oncoming	2	2	Moderate	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	4	Moderate	White	Up	Headlights Off	Clear	Light		West					
Oncoming	2	2	High	White	Down	Headlights Off	Clear	Light		West					
Oncoming	4	2	Low	White	Down	Headlights Off	Clear	Light		East					
Oncoming	2	2	Low	White	Down	Headlights Off	Clear	Light		South					
Oncoming	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Light		South					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Light		South					
Oncoming	2	2	Low	White	Down	Daytime Running Lights	Clear	Dawn		Not Recorded					
Oncoming	2	2	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Light		Not Recorded					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Light		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Not Recorded					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Light		Not Recorded					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Not Recorded					
Oncoming	4	4	Low	White	Up	Headlights Off	Clear	Light		Not Recorded					
Oncoming	4	4 to 3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Not Recorded					
Oncoming	2	2	Low	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Dawn		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Oncoming	4	4	Moderate	White	Down	Daytime Running Lights	Clear	Dawn		Not Recorded					
Oncoming	4	4	Low	White	Up	Standard Lights	Clear	Dark		Not Recorded					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Dark		Not Recorded					
Overtaking	2	2	High	Dk Blue	Up	Headlights Off	Clear	Light		East					
Overtaking	4	2	Low	Dk Blue	Down	Headlights Off (Standard Lights on car stopped in lane 3)	Clear	Dusk		Not Recorded					
Overtaking	4	2	Moderate	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Fog	Light		Not Recorded					
Overtaking	2	2	Low	White	Down	Standard Lights	Fog	Light		Not Recorded					
Overtaking	2	2	Low	White	Down	High Beams	Fog	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Fog	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Down	High Beams	Fog	Dawn		Not Recorded					
Overtaking	2	2	Moderate	Dk Blue	Up	Headlights Off	Clear	Light		East					
Overtaking	4	2	Low	Dk Blue	Up	Headlights Off	Clear	Light		Not Recorded					
Overtaking	4	2	Low	White	Down	Headlights Off	Clear	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	High	White	Down	Headlights Off	Clear	Light		East					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	High	White	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Light		North					
Overtaking	2	2	Low	White	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	Low	White	Up	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	White	Up	Standard Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	White	Down	Headlights Off	Clear	Light		West					
Overtaking	2	2	Moderate	White	Down	Headlights Off	Clear	Light		West					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Light		West					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dusk		Not Recorded					
Overtaking	2	2	High	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Overtaking	4	2	Low	Dk Blue	Down	Headlights Off (Standard Lights on car stopped in lane 4)	Clear	Dusk		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Low	White	Down	Headlights Off	Clear	Light		North					
Overtaking	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Light		North					
Overtaking	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Light		South					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Light		South					
Overtaking	4	2	Low	White	Down	Daytime Running Lights (Standard Lights on car stopped in lane 3)	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	High	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dawn		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Overtaking	2	2	Low	White	Up	Standard Lights	Rain	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Rain	Light		Not Recorded					
Overtaking	2	2	Low	White	Up	High Beams	Rain	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Up	High Beams	Rain	Light		Not Recorded					
Overtaking	2	2	Low	White	Down	Standard Lights	Rain	Light		Not Recorded					
Overtaking	4	2	Low	White	1/2 Down	Headlights Off	Clear	Light		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	White	Down	Standard Lights	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Not Recorded					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Dusk		Not Recorded					
Overtaking	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Late Afternoon		Not Recorded					
Overtaking	2	2	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	White	Down	Daytime Running Lights	Clear	Dawn		Not Recorded					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	Moderate	Black	Down	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	High	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	High	Black	Down	Standard Lights	Cloudy	Light		Not Recorded					

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Dir. of Lighting	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane													
Overtaking	2	2	High	White	Up	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	High	Black	Down	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	Moderate	White	Down	High Beams	Clear	Dawn		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Light		South					
Overtaking	2	2	Moderate	White	Not Recorded	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	Moderate	Black	Not Recorded	Standard Lights	Cloudy	Light		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Not Recorded					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Clear	Dark		Not Recorded					
Overtaking	2	2	Low	White	Up	High Beams	Clear	Dark		Not Recorded					
Overtaking	2	2	Moderate	White	Down	High Beams	Clear	Dark		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Not Recorded					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Not Recorded					
Overtaking	2	2	Low	White	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	Low	Dk Blue	Up	Headlights Off	Clear	Light		East					
Overtaking	2	2	Moderate	White	Down	Headlights Off	Clear	Light		West					
Overtaking	2	2	Moderate	Dk Blue	Up	Headlights Off	Clear	Light		West					

PHASE II: SITE 1- 705 BROCE DRIVE

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Oncoming	2	2	15 mph	Dk Blue	Down	Regular Lights	Clear	Dawn						
Oncoming	2	2	15 mph	Dk Green	Up	Regular Lights	Clear	Dawn						
Oncoming	2	2	10 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	2	2	10 mph	Dk Blue	Down	Off	Clear	Dawn						
Overtaking	2	2	15 mph	Dk Blue	Down	Regular Lights	Clear	Dawn						
Overtaking	2	2	10 mph	Dk Blue	Down	Regular Lights	Clear	Dawn						
Overtaking	2	2	Unknown	Dk Green	Up	Off	Clear	Dawn						

PHASE II: SITE 2- BUCHANAN DRIVE & MCBRYDE DRIVE

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Oncoming	2	2	25 mph	Dk Green	Up	Off	Clear	Dawn						
Oncoming	2	2	10 mph	Dk Green	Down	Off	Clear	Dawn						
Oncoming	2	2	Unknown	White	Up	Regular Lights	Clear	Dawn						
Overtaking	2	2	25 mph	Dk Green	Down	Off	Clear	Dawn						
Overtaking	2	2	10 mph	Dk Blue	Down	Off	Clear	Dawn						

PHASE II: SITE 3- PROGRESS STREET & HUNT CLUB ROAD

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Oncoming	2	2	25 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	2	2	10 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	2	2	Unknown	White	1/2 Down	Off	Clear	Dawn						
Overtaking	2	2	25 mph	Dk Blue	Down	Off	Clear	Dawn						
Overtaking	2	2	10 mph	Dk Blue	Down	Off	Clear	Dawn						
Overtaking	2	2	Unknown	Dk Blue	Down	Off	Clear	Dawn						
Overtaking	2	2	Unknown	Black	Up	Off	Clear	Dawn						
Overtaking	2	2	Unknown	Silver	Up	Off	Clear	Dawn						

PHASE II: SITE 4- PROGRESS STREET & SEMINOLE DRIVE

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect/ Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Oncoming	2	2	25 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	2	2	10 mph	Dk Green	Up	Off	Clear	Dawn						
Overtaking	2	2	25 mph	Dk Blue	Up	Off	Clear	Dawn						
Overtaking	2	2	10 mph	Dk Green	Up	Regular Lights	Clear	Dawn						

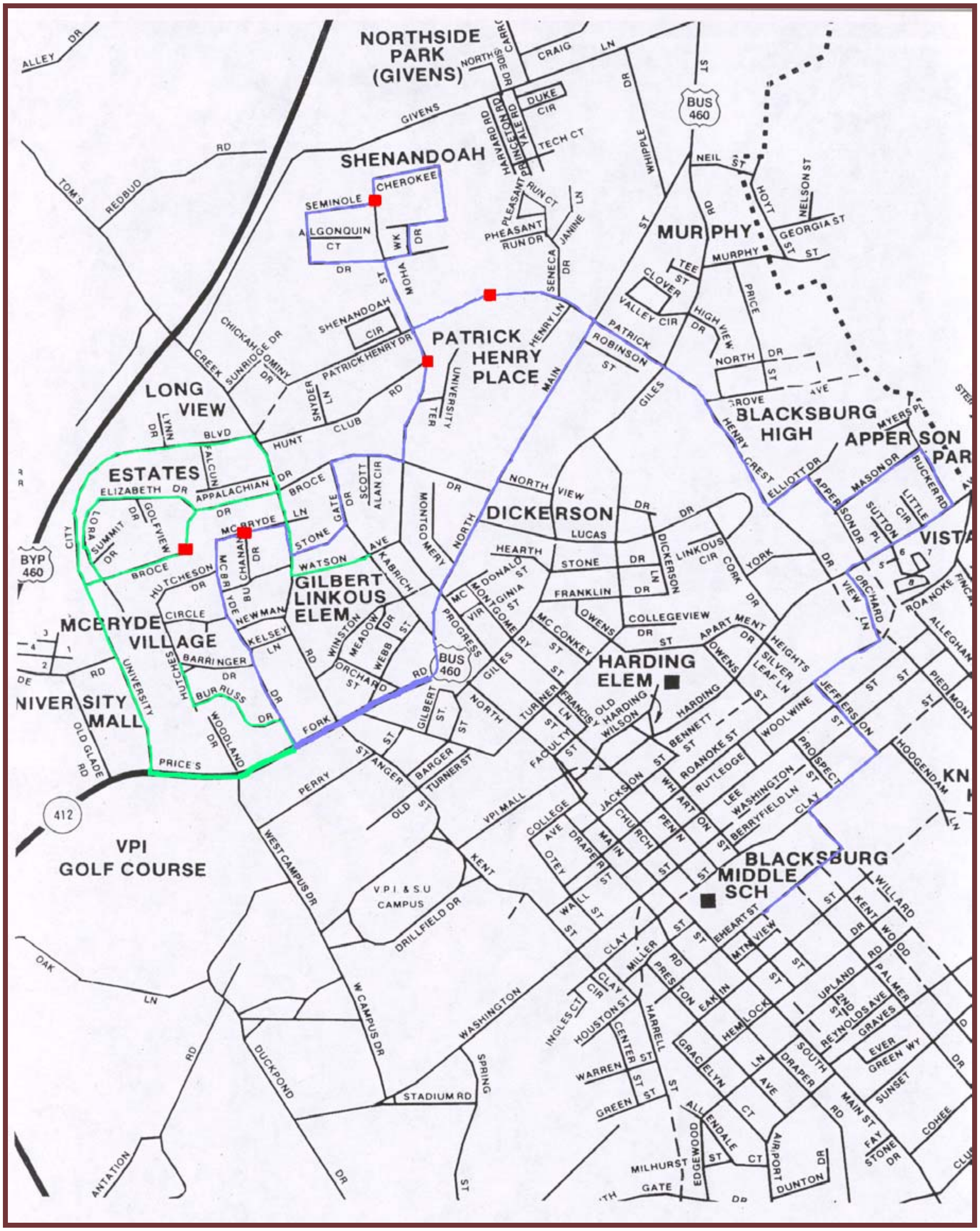
PHASE II: SITE 5- PATRICK HENRY BOULEVARD

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect /Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Oncoming	4	3	35 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	4	3	10 mph	Dk Blue	Down	Off	Clear	Dawn						
Oncoming	4	4	10 mph	Dk Green	Up	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Dk Green	Up	Off	Clear	Dawn						
Oncoming	4	4	Unknown	White	Not Recorded	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Dk Blue	Up	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Lt Blue	Up	Off	Clear	Dawn						
Oncoming	4	3	Unknown	Dk Blue	Up	Off	Clear	Dawn						
Oncoming	4	3	Unknown	Dk Green	Up	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Lt Blue	Up	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Red	Not Recorded	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Red	Not Recorded	Off	Clear	Dawn						
Oncoming	4	3	Unknown	Red	Not Recorded	Off	Clear	Dawn						
Oncoming	4	4	Unknown	Black	Not Recorded	Off	Clear	Dawn						
Oncoming	4	2	Unknown	Dk Blue	Not Recorded	Off	Clear	Dawn						
Overtaking	4	2	35 mph	Dk Blue	Down	Off	Clear	Dawn						
Overtaking	4	2	10mph	Dk Green	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Dk Blue	Not Recorded	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Black	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Gold	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Lt Blue	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Black/Red	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Teal Green	Not Recorded	Off	Clear	Dawn						
Overtaking	4	2	Unknown	White/Black	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Red/White	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Black	Up	Off	Clear	Dawn						

SCENARIO			Speed	Color of Car	Window	Direction of Headlights	Weather	Ambient	Light (klx)	Detect /Record?	Rear Camera?	Front Camera?	Profile Face?	Frontal Face?
Oncoming/ Overtaking	No. Lanes	Passing Lane												
Overtaking	4	2	Unknown	Red	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Silver	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	White	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Beige	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	Dk Green	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	White	Up	Off	Clear	Dawn						
Overtaking	4	2	Unknown	White	Not Recorded	Off	Clear	Dawn						

APPENDIX C: DESCRIPTION AND MAP OF ROUTE

The Blacksburg map below outlines the actual school bus route that was used in the Phase II test. A brief description of each site is also presented.



Site Overview

Site 1: 705 Broce Avenue

This site was located in a residential area. The bus stop was on a two-lane road with a double yellow line that separated opposing lanes of traffic. The site was particularly interesting because it was located at a curve in the road. For Overtaking Passing Scenarios, the overtaking vehicle crested a hill upon approaching the stopped bus. The posted speed limit was 15 mph.

Site 2: Buchanan Drive and McBryde Drive

This site was located near the intersection of two residential roads. The stop site was on a two-lane road with a double yellow line that separated opposing lanes of traffic. For Overtaking Passing Scenarios, the overtaking vehicle rounded a curve (to the right) prior to passing the bus. The posted speed limit was 25 mph.

Site 3: Progress Street and Hunt Club Road

This site was located on a road that accessed several apartment complexes. There were no lane markings on the road, but the road was designed to handle two lanes of traffic and one parking lane. The roadway approach for both Oncoming and overtaking vehicles was straight with a clear line-of-sight. The posted speed limit was 25 mph.

Site 4: Progress Street and Seminole Drive

This site was located near an intersection of two residential, two-lane roads areas. There were no lane markings on the road, but the road was designed for two lanes of traffic. For Overtaking Passing Scenarios, Oncoming vehicles passed the bus at the bottom of a hill. The posted speed limit was 25 mph.

Site 5: Patrick Henry Boulevard

This site was located on a four-lane roadway that had a relatively high traffic density. Each lane was marked, and opposing lanes were marked with a double yellow line. The roadway approach for both Oncoming and overtaking vehicles was straight with a clear line-of-sight. The posted speed limit was 35 mph.

APPENDIX D: INSTRUCTION ON RATING LICENSE PLATE AND PROFILE PICTURES

Image Analysis

For each test, one full frame of the "best" shot of the license plate, profile, and facial image that was in the video was obtained from each of the three cameras, as shown below.

Front Camera

Profile Camera

Frontal Facial Image

In cases where there was no image captured on a particular camera (e.g., the camera "dropped frames" and missed the violation), no picture is analyzed.

After the best frames are presented, a cropped image from each frame, which provides a closer look of the license plate or profile, is shown.

Front Licence Plate – Front Camera

Profile – Middle Camera

Image Enhancement

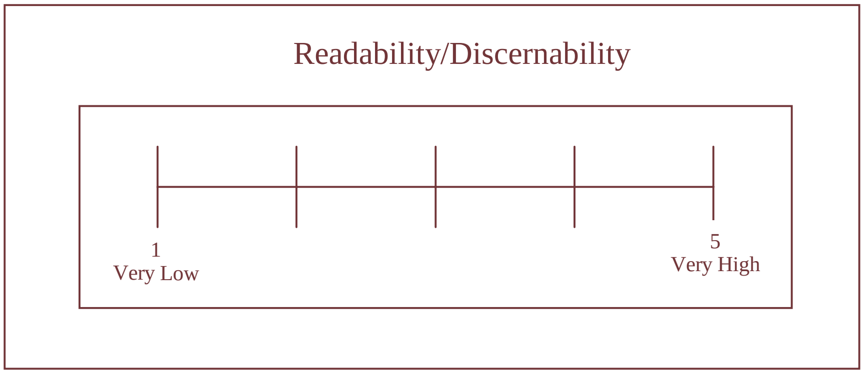
It was determined that some of the images could be enhanced using the various tools in PhotoShop. For images that could be enhanced, a rating is given to the enhanced image.

Front License Plate

Profile

Qualitative Ratings

The rating scale and levels are shown below.



Rating the License Plate

1 – Can see the entire plate, but may not see license due to glare, blurring, etc.

2 – Can read 1-2 letters/numbers of the license plate

3 – Can read 3-4 letters/numbers of the license plate

4 – Can read all letters/numbers*

5 – Can read the entire plate, this includes all letters/numbers and the state

*NOTE: letters/numbers does not refer to the state.

Rating the Driver Facial Image

1 – Can see a facial image, but with very poor resolution (e.g., may not be clear due to glare).

2 – Can see a dark outline of face, with poor resolution.

3 – Can see a blurred facial image.

4 – Can see outline of driver’s face (light image, close-up).

5 – Can see facial image clearly.

Examples of each rating are shown below.

License Plate Rating 1

License Plate Rating 2

License Plate Rating 3

License Plate Rating 4

License Plate Rating 5

Profile Rating 1

Profile Rating of 2

Profile Rating 3

Profile Rating 4

Profile Rating 5

Frontal Facial Rating 1

Frontal Facial Rating 2

Frontal Facial Rating 3

Frontal Facial Rating 4

Frontal Facial Rating 5

Images That Cannot Be Rated

Images (either plate or profile images) that could not be read had one or more of the following conditions present:

1. White lighting at the beginning of the video clip blocks the sight of the vehicle;
2. There are dropped frames on the video clip making it impossible to get an image of the plate/profile;
3. There is not a full image of the plate/profile due to improper triggering of the system; and
4. There is no data on the video (the system did not record a vehicle).

Rating Process

The rating process was conducted in the following order. First, each condition was rated for Readability/Discernability, as shown in the table below.

Qualitative Plate (Un-Enhanced Data)		Qualitative Face (Un-Enhanced Data)		Qualitative Plate (Enhanced Data)		Qualitative Face (Enhanced Data)	
0 Rear Camera	1 Front Camera	Profile Camera	Frontal from Plate Camera	0 Rear Camera	1 Front Camera	Profile Camera	Frontal from Plate Camera

"Raw Data" ratings came from the frames that were captured from each video clip. For example, a license plate image from the rear camera may have been poor and rated a 1, while the front camera was good and rated a 4. As illustrated in the table below, the image from the profile camera was also rated a 4.

Qualitative Plate (Un-Enhanced Data)		Qualitative Face (Un-Enhanced Data)	
0 Rear Camera	1 Front Camera	Profile Camera	Frontal from Plate Camera
1	4	4	4

Recall, the enhanced images were those that were cropped and the readability/discernability improved using Adobe Photoshop. Not all of the images were able to be enhanced. As an example, a particular enhanced image for the front camera may have been improved to a 5. This is illustrated in the table below.

Qualitative Plate (Enhanced Data)		Qualitative Face (Enhanced Data)	
0 Rear Camera	1 Front Camera	Profile Camera	Frontal from Plate Camera
1	5	4	5

The same process is done for the images from each camera. Therefore if all images were ratable, there should be a total of three ratings for the raw data, and up to three rating for the enhanced data (if an enhancement was made).

It should be noted that some of the conditions that were tested involved more than one car (traveling together, following one another, or passing one another). There are frames and cropped images for each car involved. Therefore, though this was considered one test, each car was rated separately for readability/discernability.

VITA

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EDUCATION

2000–2002 Candidate for M.S in Civil in Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

1996–2000 B.S., Civil Engineering, North Carolina Agricultural and Technical State University, Greensboro, North Carolina.

EMPLOYMENT

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