Field Evaluation of Alternative Automated Systems for Reducing Illegal Passing of School Buses
DTNH22-00-07007, Task Order 1

FINAL REPORT

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EXECUTIVE SUMMARY

PROBLEM SCOPE

In 2000, over 43 million students attended grades K-12 in the U.S. Fifty-seven percent of these students were transported to school in public school buses (National Center for Education Statistics, 2002). From 1997-2001, 72 students were killed in school bus loading and unloading zones. Approximately 60% of these fatalities were the result of motorists who failed to stop when the bus was loading or unloading students (School Transport News, 2002).

In the U.S. it is illegal to pass a stopped school bus when the vehicle's stop-arm is extended and the red warning lights are flashing. Yet, each day an estimated 1,000 to 10,000 vehicles illegally pass school buses when they are loading/unloading students (Center for Urban Transportation Research, 1996; Illinois Department of Transportation, 1996; Institute for Transportation Research and Education, 2000), despite the fact that 99% of respondents from a random phone survey rated "passing a school bus that has its red light flashing and the stop-arm in full view" as somewhat or extremely dangerous driving behavior (Boyle, Dienstfrey, & Sothoron, 1998).

To address this problem, the National Highway Transportation Safety Administration (NHTSA) sponsored research aimed at developing an automated system for detecting and recording the license plates and drivers of vehicles who illegally pass stopped school buses. The overall objective of this research was to develop a prototype system that would automatically detect and record vehicles that illegally pass stopped school buses (i.e., the stop-arm of the bus is extended and the warning lights are flashing).

Before the development of an automated enforcement system could begin, it was important to consider comparable systems and assess what technologies were currently being used and what technologies could be applied in the school bus domain. A comparable systems analysis was conducted on three systems: Red-light Running cameras, Railroad Grade-Crossing cameras, and Automated Speed Enforcement cameras. The results of the analyses indicated that each of these systems had demonstrated success in terms of reducing violations and crashes. In the three applications, all were found to substantially reduce traffic violations. Based on this analysis, and the data indicating that a large number of illegal school bus passing maneuvers occur every school day, it seems reasonable for NHTSA to pursue the application of automated enforcement in the school bus domain.

PROJECT OVERVIEW AND OBJECTIVES

There were two parts to this project: (i) an initial development effort and (ii) a refinement effort. Figure E-1 lists all of the project tasks that were conducted. The first part of the project, directed at the initial system research, was co-conducted by WESTAT and VTTI. The second part of the project, directed at system refinement, was conducted by VTTI.

As noted in the project Statement of Work, the overall objective of this research was to develop a prototype system that would automatically detect and record vehicles that illegally pass stopped school buses. 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 an operational field setting.

The objective of the second part of the research was to refine the initial system that had been developed in the first part.

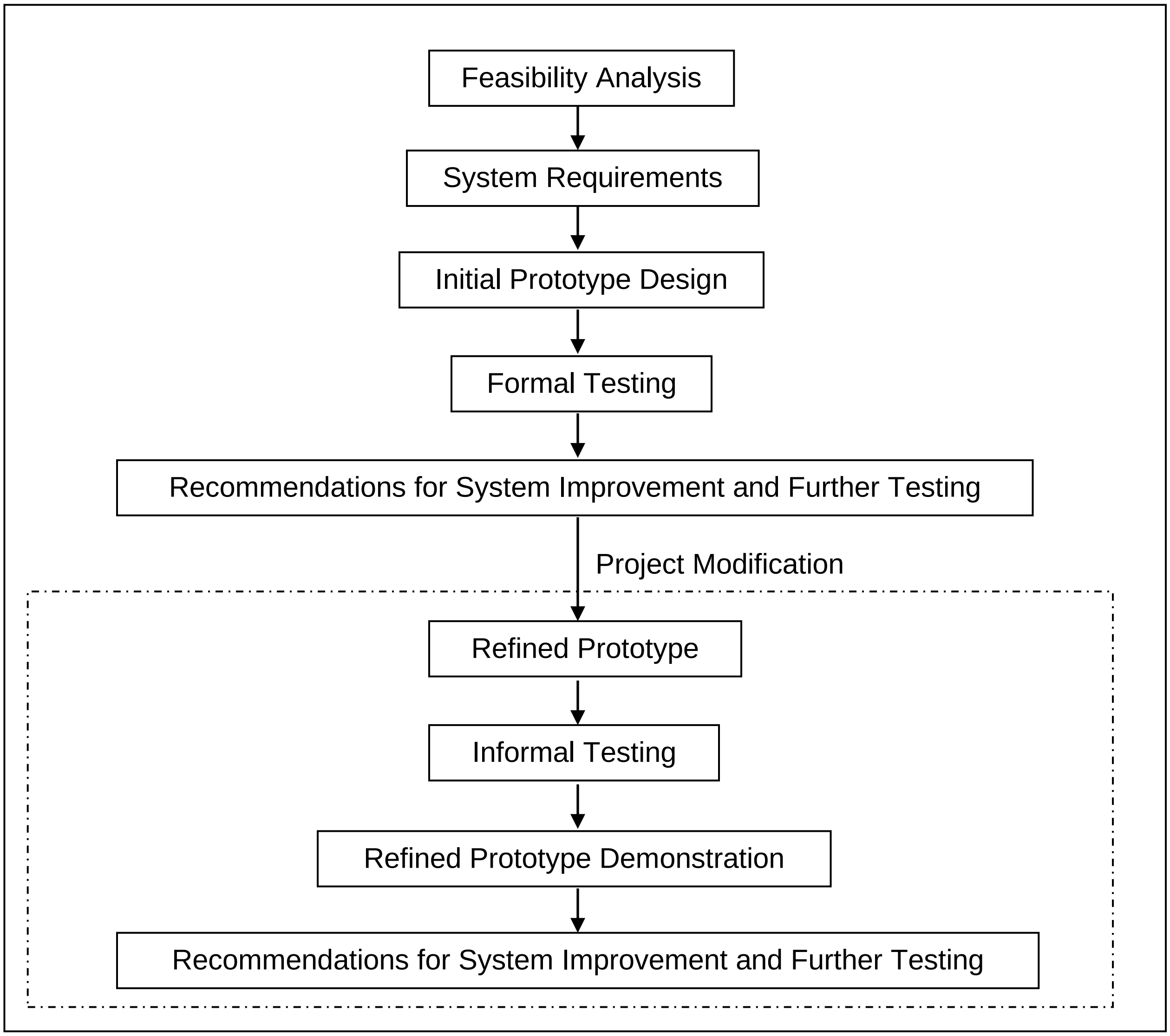

Figure E-1. Outline of the tasks conducted in this project.

FEASIBILITY ANALYSIS

A series of analyses were conducted to assess the technical, administrative, and legal feasibility of automated enforcement systems for this application. Two expert panels and a detailed legal review were conducted to explore each of the three feasibility areas. Results and recommendations from these feasibility analyses provided the groundwork for subsequent tasks of the project, including the design, development, and testing of a prototype system. Highlights of the three feasibility analyses are presented below:

Technical Feasibility Analysis

The technical feasibility expert panel (consisting of instrumentation engineers with experience in design, development, and/or operation of automated enforcement or vehicle instrumentation systems) identified and evaluated various alternative system designs and architectures, weighed advantages and disadvantages of each, and developed recommendations for candidate designs and corresponding system components. In making these determinations, expert panelists relied on a set of functional system specifications developed in the early stages of the project. The product of this analysis led to the development of a specific design concept for the proposed system prototype.

Administrative Feasibility Analysis

An expert panel was also assembled to assess the administrative feasibility of automated systems for capturing vehicles that illegally pass stopped school buses, including issues related to implementation, bus driver education, data processing, the issuance of citations, and system calibration and maintenance. Panelists included law enforcement personnel, researchers, school officials with experience in bus operations and pupil transportation safety, as well as experts in civil and criminal legislation. Experts agreed that school bus passing is an ideal application for automated enforcement technology since the link between the violation and safety is clear and direct, and the issue involves the safety of children.

Legal Feasibility Analysis

A review of federal and state statutes suggests that although legal issues associated with the implementation and administration of an automated school bus enforcement system do exist (evidentiary, due process, privacy issues, etc.), these legal obstacles can be overcome. Although no state currently has specific enabling legislation that explicitly authorizes the use of photo enforcement for capturing school bus passing violations, legislation addressing other existing photo enforcement applications (e.g., red-light enforcement, photo/radar, etc.) does exist and serves to provide guidance for the current application.

INITIAL PROTOTYPE DESIGN

One of the key outputs of the feasibility analyses was a set of general recommended design specifications for an *initial*[1] prototype system. The system that was identified as being the most promising had the following general characteristics:

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[1] It is important to distinguish between the *initial* prototype system that was developed and tested in the early stages of the project and the *refined* prototype system that was developed to address limitations with the *initial* system.

- 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 as well as 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);
- Recording of pertinent non-video violation information.

The initial system is shown in Figures E-2, E-3 and E-4. Views of the license plate and driver (profile angle) were captured by the high-resolution 640 x 480 violation recording cameras (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 (i.e., pixel-by-pixel comparison of images to see if anything in the image has changed).

The system was automatically activated once the bus' amber warning lights were switched on. That is, when the bus' amber warning lights were turned on, the violation detection system became "armed." 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.

Figure E-2. Violation recording cameras positioned in a central location.

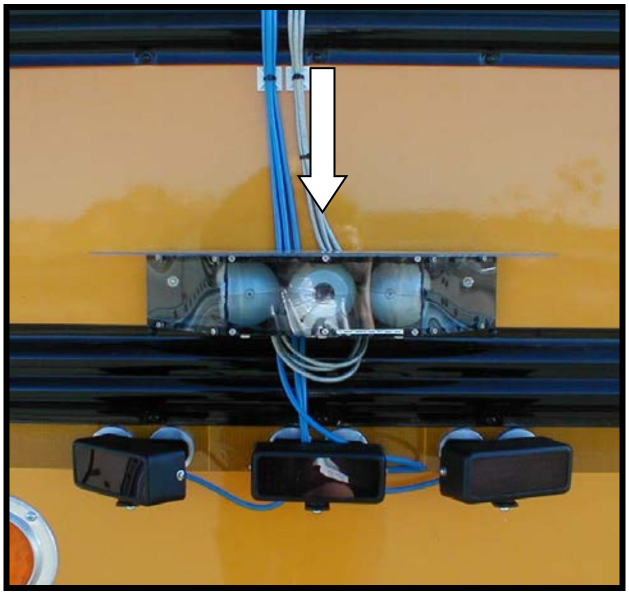

Figure E-3. License plate and profile cameras.

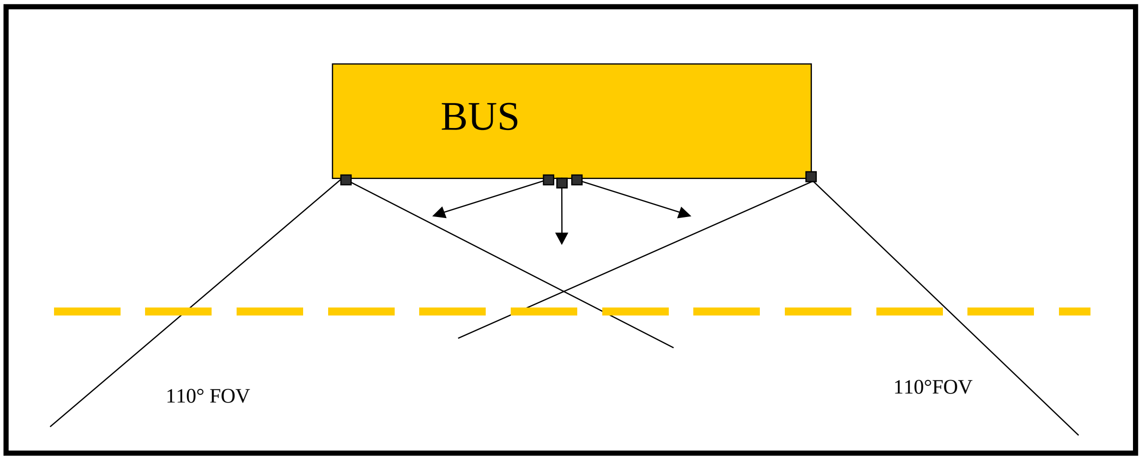

Figure E-4. Schematic of the prototype system; area of coverage is on driver's side.

FORMAL TESTING OF THE INITIAL PROTOTYPE DESIGN

Two formal test phases of the initial prototype system were carried out. The Phase I tests used a closed test-track, while the Phase II tests were conducted on an actual school bus route. The purpose of these formal tests was to determine the operational envelope in which the system would be functional. Three broad "conditions" of operation were identified: (i) Environmental; (ii) Violating Vehicle Characteristics; and (iii) Bus Stop Characteristics (see Table E-1). For each condition, one or more independent variables were identified. It was these variables that were manipulated experimentally for the Phase I test-track (Smart Road) research, as indicated by the "levels" shown in Table E-1.

Conditions were crossed (as feasible), resulting in 108 unique test conditions. For example, weather permitting, 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. Directional Light was tested only in the Light (Ambient Light) and Clear (Weather) conditions. In addition to the levels of independent variables listed in Table E-1, other levels not specified in Table E-1 were also tested as they presented themselves (e.g., Cloudy Weather). Also, a set of system performance questions were raised that were also answered through tests including questions regarding false alarms and multiple vehicle passing configurations.

Table E-1. Conditions involved in formal testing of 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

Summary of the Initial Prototype System Test Results

The prototype system was tested and then evaluated using two primary measures: System Recording Accuracy and System Effectiveness. System Recording Accuracy is a measure of the number of violation recordings divided by the number of opportunities (tests). A total of 186 tests were conducted in Phase I. Of these, a violation recording was made for 177 tests. This resulted in a System Recording Accuracy of 95.2%. That is, in 95.2% of the tests conducted in Phase I, at least one camera recorded the violation. Note that a recording does not imply that the recorded image is of sufficient quality (resolution) to be used, for example, in issuing a ticket.

To look at the quality of the captured recordings, qualitative ratings reflecting readability (of the license plate) or discernment (of the face) were made. These ratings ranged from very low quality (1) to very high quality (5). Qualitative ratings of 4 or 5 were considered “high quality” captures. A measure called System Effectiveness was used and defined as captured images that had a rating of 4 or 5. Overall System Effectiveness for license plates, across all tests, was 51.5%; that is, in 51.5% of the recorded violations, there was judged to be a high quality recording of the license plate. For facial images, Overall System Effectiveness, across all tests, was 11.0%. The results from Phase II were very similar for System Recording Accuracy and System Effectiveness. For example, the System Recording Accuracy for the Phase II tests was 96.5% and the Overall System Effectiveness for license plates and facial images was 58.5% and 9.4%, respectively.

Several key findings were realized when considering the individual conditions that were tested. For example, the system worked best for violating vehicles close to the bus. In the Phase I tests, System Effectiveness as a function of passing lane of the violating vehicle had the following results: Lane 2, lane next to the bus = 75.9%; Lane 3, one lane over from bus = 9.4%; and Lane 4, two lanes over from the bus = 3.7%. Similar results, with regard to lane position, were found for System Effectiveness for the facial image recordings; that is, higher quality facial images were recorded as a function of proximity to the bus.

There were several additional important findings from the Phase I and Phase II tests that helped guide the refined prototype system development work. One such finding was that the system did not work well in low ambient conditions. For example, in the Phase I tests, System Effectiveness ratings for the license plates ranged from 61.7% in the Light condition to 5.3% for the Dusk condition. System Effectiveness ratings for driver facial images ranged from 25.9% in Late Afternoon to 9.0% in Light, to 0% in Dusk. Tests conducted in complete darkness, with an infrared pulse source, found that the system was unable to record any high quality license plate or facial images in darkness. Another important finding was that some of the best quality facial images were unintentionally recorded from the front and rear cameras through the windshield, rather than the profile view of the driver through the side window.

To summarize, the general findings of these tests were that the system showed promise, but was not at a point where it could be included in a field test. This was not surprising as the purpose of the formal testing was to get a better understanding of the operating conditions (i.e., environment, violating vehicle characteristics, school bus characteristics) that a system would function. Based on the results of all tests conducted in Phases I and II, it was determined that the two primary limitations of the initial prototype system were that (i) it did not perform well enough at capturing driver facial images during the day, and (ii) it was not able to capture license plate images at night. These two primary limitations, along with the other information learned from the formal testing, lead to the development of the refined prototype system.

Figure E-5. Video frames of the vehicle/license plate and the driver profile.

Figure E-6. Violating driver's profile.

REFINED PROTOTYPE SYSTEM

Based on the encouraging results of the initial prototype development work, a contract modification was made to allow VTTI to conduct additional research to refine the prototype system. Lessons learned from the initial tests were applied during the refinement stage. This follow-up research involved technology refinement where the limitations of the initial prototype system were addressed in a more sophisticated design that included higher resolution cameras (as compared to the cameras used in the initial system) and a radar triggering device.

The refined prototype system was contained entirely in a single housing (pod). As shown in Figure E-7, the refined system consists of five cameras: two cameras facing forward (one color and one monochrome), two facing to the rear (one color and one monochrome), and one centrally-located wide-angle camera (color). Also, the system is comprised of two high intensity discharge (HID) spotlights and one side-radar unit that is used to trigger the cameras. Due to nighttime imaging limitation of the initial prototype system, HID spotlights were used for the refined prototype system instead of infrared lights. Moreover, due to vehicle detection limitations of the initial system, a side object detection system (SODS) radar unit was used in place of the front and rear cameras used for event triggering in the initial system. The SODS has a vendor-provided accuracy specification of 0.1 ft. As shown in Figure E-8, the pod is located on the left side, near the center of the school bus.

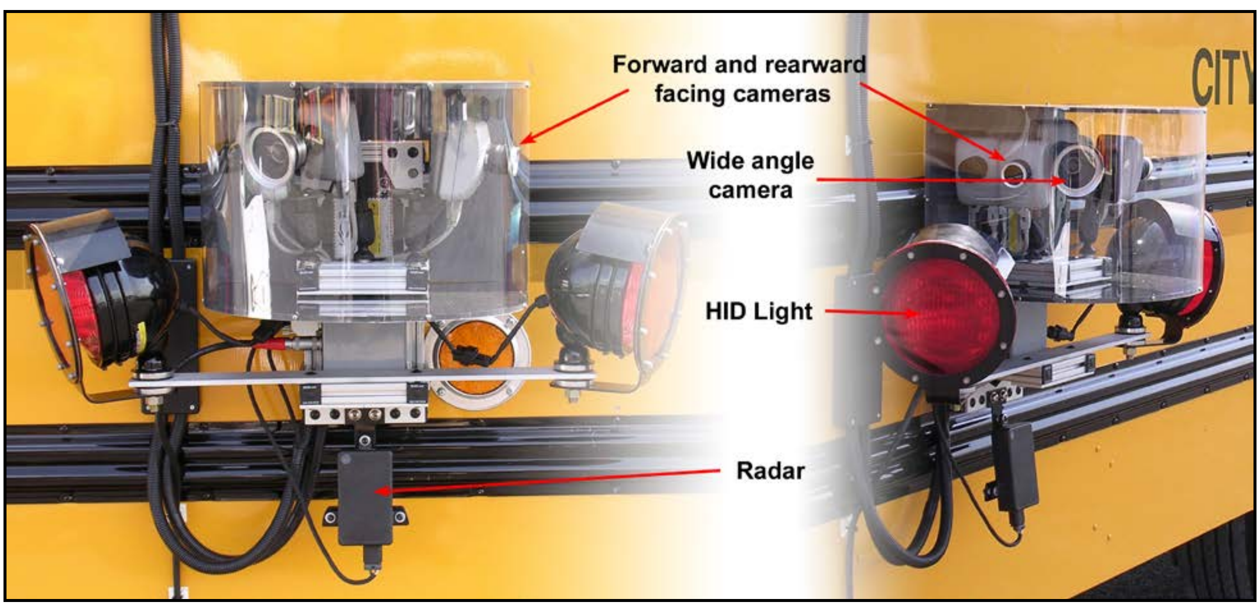

Figure E-7. Prototype system is housed in one pod.

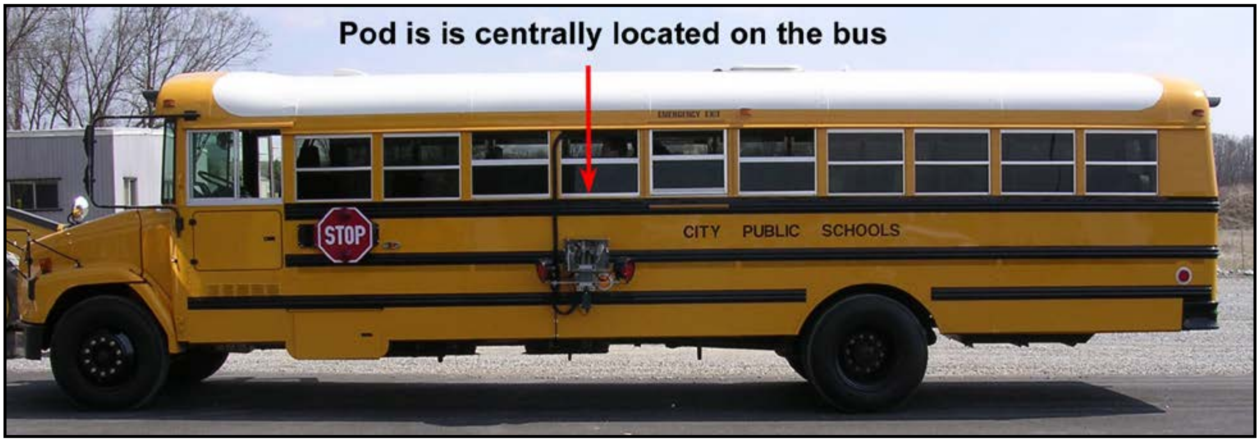

Figure E-8. Prototype system centrally located on bus.

INFORMAL TESTING

Limited experimentation was conducted with the refined prototype system. Information learned from the formal testing with the initial system was applied to the design of the refined system. Most of the experiments with the refined prototype were simple tests to determine whether or not the system functioned in certain conditions. An example of this was an experiment conducted at night to determine if a vehicle passing the bus in the adjacent lane at 15 mph could be captured by the system, and if the vehicle's license plate was legible. Although most tests were carried out at the VTTI, high speed tests were carried out at the Virginia Tech/Montgomery Executive Airport. The tests were conducted to reflect naturalistic conditions; conditions that the system would be subjected to in a field study. A sample of key findings included:

- In daytime tests, legible license plate images and discernable facial images could be acquired at distances up to 20 feet from the system (approximately two lanes from the bus)
- In nighttime tests, legible license plates could be acquired at distances up to 15 feet from the system. Discernable facial images could not be captured at night.
- Sun glare presents problems and deteriorate the legibility of license plates and discernment of facial images. Polarized filters can help with this in the daytime but, if not removed, are problematic for night testing.
- Headlights from passing vehicles can cause interference for the cameras by overdriving the image sensor on the camera. This did not impact the capture of legible license plates, but did have adverse effects on capturing identifiable facial images. Headlights were not a factor in daytime testing, but were problematic during twilight.

Table E-2 summarizes the results of the tests, showing the conditions that the refined prototype system was tested and whether the license plate and driver's face were readable/discernable from the captured image. A sample of the results of the informal tests and the post-processing results is shown in Figure E-9.

Table E-2. Summary of the results from the refined prototype system tests.

Condition	License Plate	Driver's Face
Day-Dry	√	√
Day-Rain	√	√
Dusk (180-675fc)	√	√
Twilight (~5fc)	√	√*
Night	√	**X**
≤ 20 ft/2 lanes (Day)	√	√
≤ 15 ft (Night)	√	**X**
≤ 30 mph	√	√

* Only with post-processing of the image.

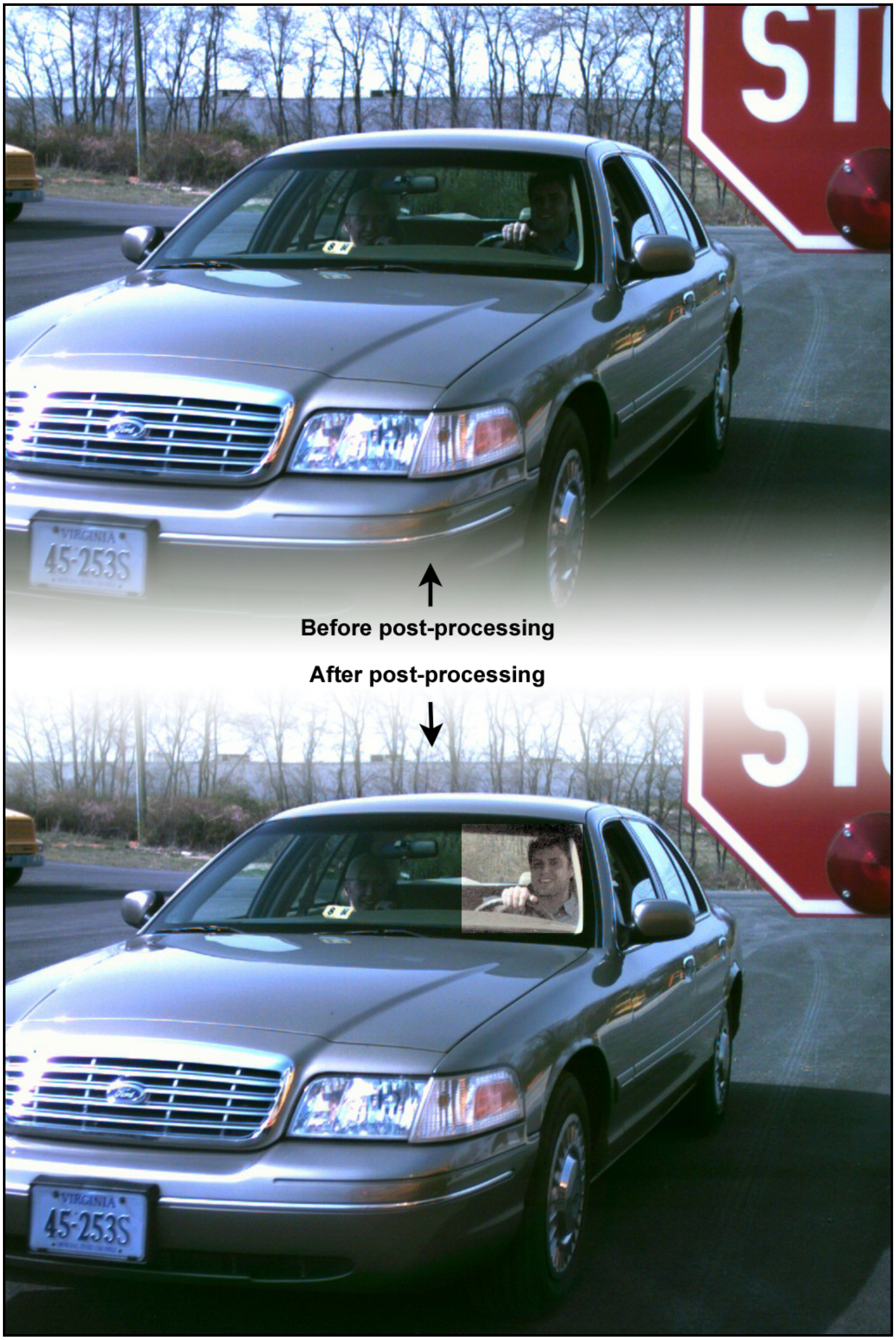

Figure E-9. Before and after post-processing of a color image; vehicle is traveling approximately 15 mph.

Research in the refinement stage also included work to improve the post-processing of images. Future refinements would likely have to undergo additional experimentation before a field study with a deployed system could be conducted.

The refinement stage also included an effort to design a conceptual pod that could be manufactured to hold the system components. A conceptual prototype enclosure was designed by Brooks Stevens Design so that it could be fabricated for production purposes (Figure E-10). This pod, designed to contain the components of the system, could be manufactured to be weather hardened and lockable in order to maintain the safety of the system.

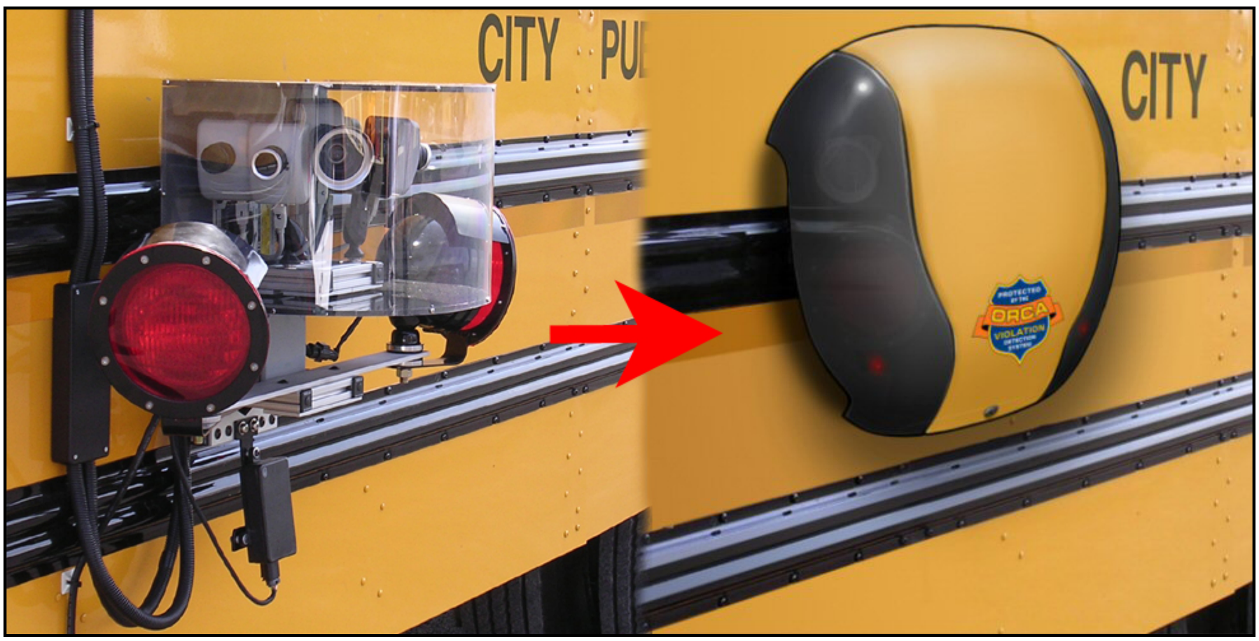

Figure E-10. Existing refined system and conceptual prototype pod.

REFINED PROTOTYPE DEMONSTRATION

A demonstration of the refined prototype system was held to ensure the system's functionality. The purpose of the demonstration was to provide government officials and other interested experts with an overview of the capabilities of the refined prototype system. The demonstration was held at the Turner Fairbank Research Center in McLean, Virginia on April 28, 2004. Officials from organizations such as the National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration (FHWA), school system personnel, and police department personnel were in attendance. The demonstration consisted of a school bus containing the refined system parked along a two-lane road, whereby a driver in a car could pass the bus and be recorded by the system. An example of a resulting image from a mock violation capture is shown in Figure E-11.

Figure E-11. Black and white image taken in rainy weather of a violating vehicle. Violating vehicle is traveling approximately 15 mph.

RECOMMENDATIONS FOR SYSTEM IMPROVEMENT AND FURTHER TESTING

Moving toward a goal of implementation of an automated violation capture system, it is recommended that the next phase of the program be directed at two objectives: further technology development and administrative processing. A deployable system must not only function reliably, but it must also do so under harsh environmental conditions. As such, the next step should include the development of a hardened prototype system that is water-tight and tamper-proof. This hardened prototype system should be streamlined to reduce the footprint of the device. It is recommended that only the two monochrome cameras be used (one facing forward and the other facing to the rear). The reduction in cameras would also reduce the number of computers (from three to one) necessary to operate the system.

In addition, a number of non-technological, administrative-type activities are required as the program moves forward. For example, a protocol for "back-end" processing needs to be developed (i.e., what to do with recorded violations). A clear definition of agency roles and responsibilities is needed, as well as ensuring the legislative and judicial integrity of the program.

At least two additional research phases are needed to fully develop and test the automated school bus violation capture system. The first phase would involve a field study in a real-world environment with an in-service school bus. Upon successful completion of the field study, a more extensive field operational test should be conducted. The experimental design should include several test communities that will equip multiple buses with the revised automated school bus violation capture system for up to one school/academic year. Upon successful completion and expected promising results, the next step would be to implement the automated school bus violation capture system throughout the U.S.

In conclusion, the research presented in this report constitutes the first major effort in assessing the efficacy of the automated school bus violation capture system. Further research, development, and testing is needed to realize the safety benefits associated with this system that automatically detects and records vehicles that illegally pass stopped school buses.

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    - Lt. Glenn Hansen, Howard County, MD Police Department
    - Michael Shellem, U.S. Army Aberdeen Test Center
    - Jerry Singer, WESTAT
- Participants in the Administrative Feasibility Workshop:
    - Eileen Danahy, Montgomery County, MD Public Schools DOT
    - Earl Hardy, NHTSA, Traffic Law Enforcement Division

  - Therese Pelicano, Montgomery County, MD, Division of Consumer Affairs
  - Jeff Smith, Onslow County, North Carolina Schools
  - Jeff Tsai, North Carolina State University, Raleigh, NC, Institute for Transportation Research and Education
  - Diane Wigle, NHTSA
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  - Sgt. James B. Hogue III, Lafourche Parish Sheriff's Office, Thibodaux, LA
  - Susan Karenich, NHTSA

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CHAPTER 1:

INTRODUCTION

PROBLEM SCOPE

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In 2000, over 43 million students attended grades K-12 in the U.S. Fifty-seven percent of these students were transported to school in public school buses (National Center for Education Statistics, 2002). An article on the School Transportation News website (School Transportation News, School Bus Safety, 2001b) indicates that, annually, there are about 20 billion boardings and de-boardings of school buses throughout the U.S. Given that the loading and unloading zone is the most dangerous place around a school bus (School Transportation News, School Bus Safety, 2001a), a significant safety problem for children who are transported by school buses is entering and exiting the vehicle. From 1997-2001, 72 students were killed in school bus loading and unloading zones. Approximately 60% of these fatalities were the result of motorists who failed to stop when the bus was loading or unloading students (School Transport News, 2002).

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).

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 that violate traffic laws. Three such systems are briefly described below: Red-light Running cameras, Railroad Grade-Crossing cameras, and Automated Speed Enforcement cameras.

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%) and crash severity (-27.1%) at these intersections (Harrington, 2001).

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 the vehicle that evades railroad grade-crossing gates. The type of data recorded in 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 light turns 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% after the deployment of three such cameras.

AUTOMATED SPEED ENFORCEMENT CAMERAS

The concept of automatically recording speeding vehicles is not new. Early versions of automated speed enforcement systems, using a stopwatch and a camera, were tested in Massachusetts in 1910 (Lynn, et al, 1992). Modern systems (using radar, etc.) were introduced into the U.S. in the 1970s, with early field trials conducted in Texas and New Jersey (Blackburn and Gilbert, 1995). 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% decline in crashes with the use of photo radar and a 26% reduction in speeding.

SUMMARY OF COMPARABLE SYSTEMS

As described, there have been several successful (in terms of reducing violations and crashes) applications of automated enforcement technology. In the 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.

PROJECT OVERVIEW AND OBJECTIVES

PROJECT OVERVIEW

This research project was conducted in two parts. The un-shaded boxes in Figure 1 list the tasks performed in the first part of the study (pre-contract modification). The shaded boxes in Figure 1 indicate the tasks performed after a contract modification was put in place. The first part of the project is described up until Chapter 6. Chapters 6 and 7 describe the work conducted as part of the contract modification.

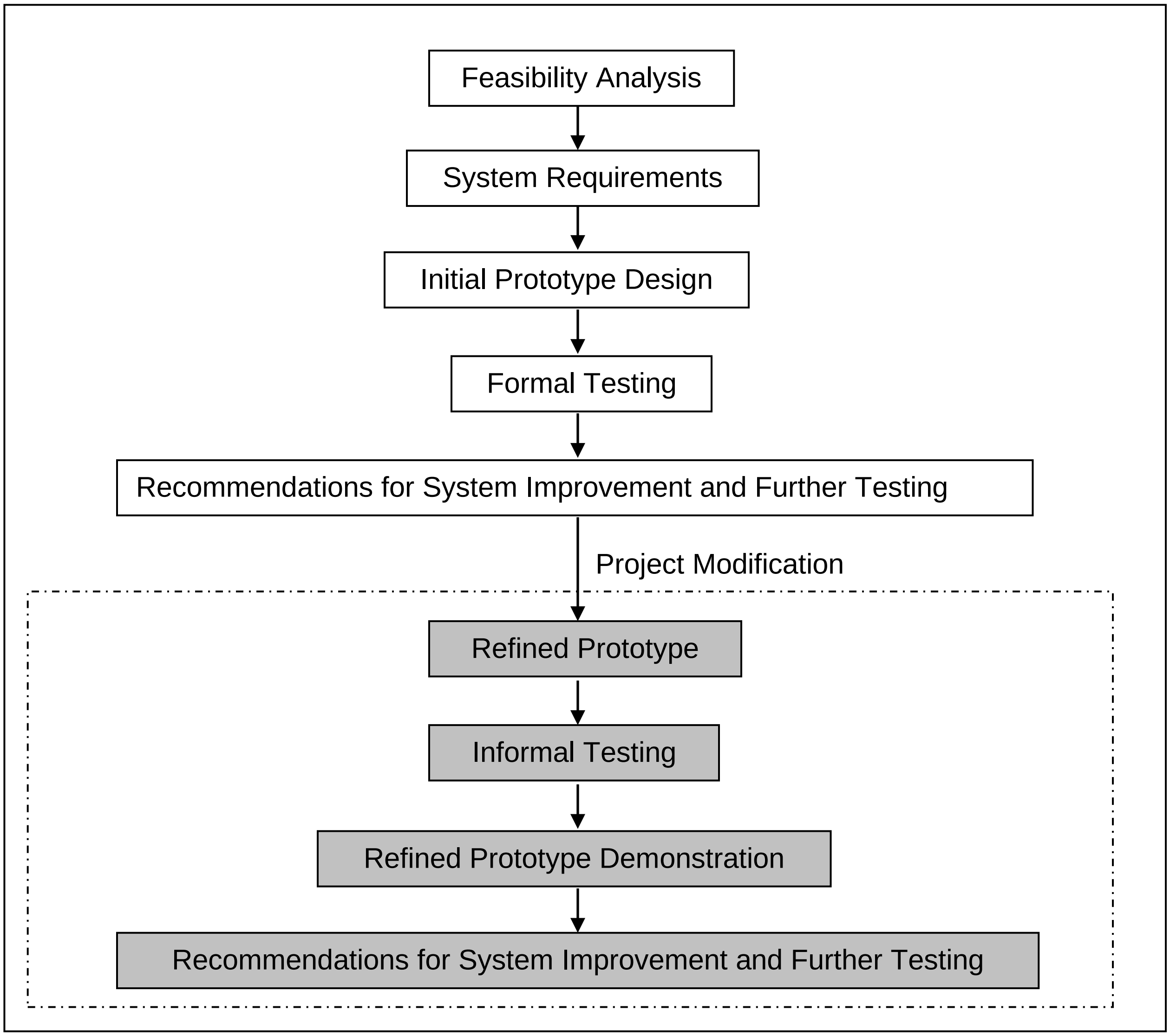

Figure 1. Overview of the tasks conducted during the study; white boxes represent tasks from the first part of the study, while shaded boxes are those from the second part.

PROJECT OBJECTIVES

The overall objective of this research was to develop a prototype system[2] 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:

[2] A description of the terms and definitions relevant to the development of an automated system for reducing the illegal passing of school buses can be found in Appendix A.

1. Determine the feasibility of developing and implementing a prototype system using advanced technology that would automatically document the identity of drivers and the 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 in what has the potential to be a much larger demonstration project. However, before a large demonstration project can occur, the feasibility of developing such a system, and its potential usefulness as determined through limited field testing, must be determined.

The remainder of this report describes the feasibility analyses, the initial and refined prototype development and testing effort, and details the results from the tests. In addition, a discussion of the conclusions that can be drawn from the findings is presented. This discussion further proposes what the future plans might be to go from a prototype system to a finished system that could be deployed and tested in a large demonstration project.

CHAPTER 2:

FEASIBILITY ANALYSIS

OVERVIEW

A series of analyses were conducted to assess the technical, administrative, and legal feasibility of automated enforcement systems for this application. (Only the highlights of these analyses are presented in the body of this report; a more detailed description can be found in Appendix B.) Two expert panels and a detailed legal review were conducted to explore each of the three feasibility areas. In general, results indicated that affordable and reliable systems are technologically feasible and can be implemented successfully, provided that the process is fair and perceived to be safety-driven. Experience with other automated enforcement systems (e.g., red-light enforcement, automated speed enforcement) suggests that legal issues concerning evidentiary, procedural, and policy considerations can be overcome. Due process challenges of photo enforcement of traffic laws are likely to focus on notice issues, specifically the use of signs warning of the presence of automated traffic enforcement devices, and delays in issuing a citation to alleged violators. Privacy concerns are expected to constitute less of an impediment to the implementation of photo enforcement programs than the public perception of photo enforcement devices as a tool of "Big Brother."

TECHNICAL FEASIBILITY ANALYSIS

The technical feasibility expert panel (consisting of instrumentation engineers with experience in design, development, and/or operation of automated enforcement or vehicle instrumentation systems) identified and evaluated various alternative system designs and architectures, weighed advantages and disadvantages of each, and developed recommendations for candidate designs and corresponding system components. In making these determinations, expert panelists relied on a set of functional system specifications developed in the early stages of the project. The product of this analysis led to the development of a specific design concept for the proposed system prototype. While significant challenges exist, experts agreed that low-cost and reliable systems are achievable for this application. Experts also indicated that systems should not rely on interaction or inputs from school bus drivers, and should provide coverage in both directions on the driver's side of the bus as well as yield sufficient information to allow the adjudication of violators. This may include an overall profile of the vehicle as it approaches and commits the violation (with the stop-arm visible). Systems that use a combination of still images and video recordings were perceived to provide the best approach, providing the capability to capture high resolution still-frame images of the license plate as well as lower resolution video of the violation in context. Two basic system configurations were recommended, both employing camera technology to achieve vehicle detection and image capture functions.

ADMINISTRATIVE FEASIBILITY ANALYSIS

An expert panel was also assembled to assess the administrative feasibility of automated systems for capturing vehicles that illegally pass stopped school buses, including issues related to implementation, bus driver education, data-processing and the issuance of citations, and system calibration and maintenance. Panelists included law enforcement personnel, researchers, school officials with experience in bus operations and pupil transportation safety, and experts in civil and criminal legislation. Experts agreed that school bus passing is an ideal application for automated enforcement technology since the link between the violation and safety is clear and direct, and the issue involves the safety of children. The expert panel suggested that successful implementations should be founded on systems that are accurate and reliable, and on a process which is fairly administrated and focused on safety. Systems must be portrayed as public safety devices and not revenue streams, and the system and process should instill public trust. Partnerships between law enforcement, legal, legislative representatives and schools are vital to the success of these systems/programs. These relationships are necessary to ensure enforceable laws and practices as well as to bring public awareness to the problem and solution. Finally, the expert panel indicated that automated systems should not be viewed as replacements for active enforcement by law enforcement personnel, but should be used to supplement these activities. Police officers should still issue citations for illegal school bus passing, much as they do for red-light running and speeding.

LEGAL FEASIBILITY ANALYSIS

A review of federal and state statutes suggests that, although legal issues associated with the implementation and administration of an automated school bus enforcement system do exist (evidentiary issues, due process, privacy, etc.), these legal obstacles can be overcome. Although no state currently has specific enabling legislation that explicitly authorizes the use of photo enforcement for capturing school bus passing violations, legislation addressing other existing photo enforcement applications (e.g., red-light enforcement, photo/radar, etc.) does exist and serves to provide guidance for the current application. In order for automated school bus enforcement to be accepted by the courts as well as the public, the technology must be based upon accepted scientific principles and techniques. The equipment must be reliable and properly maintained, the images collected must be clear, accurate and "tamper proof," the information depicted in images captured by the automated system must establish the elements of the violation, and the authenticity of the images and data must be documented through a carefully recorded chain of custody ensuring the integrity of the evidence. In most states, illegal school bus passing is a criminal offense carrying fines, points, and possible imprisonment. One consideration is the extent to which these sanctions can and will be implemented under automated enforcement. Automated enforcement programs that cite the vehicle owner with a civil infraction rather than a "criminal" moving violation appear technologically, administratively, legally, and politically easier to implement. In many cases, a photograph of the license plate with supporting context information and statutes that create a presumption of owner liability is sufficient to support civil fines, making it generally unnecessary to capture the image of the driver. If criminal penalties are to be sought, automated enforcement systems will need to capture clear frontal photographs of the driver, a significant technological challenge for the target application that involves a moving platform. Thus, it appears likely that school bus passing violations under automated enforcement, by themselves, will be processed as civil rather than criminal offenses due to the anticipated difficulty in capturing adequate driver facial images needed to provide positive identification of the driver. A stepped system may also be feasible, allowing tradeoffs between criminal and civil penalties. For example, some states with red-light running systems designed to capture both driver facial views and vehicle license plates attempt to first identify the driver and, if possible, seek criminal sanctions. If positive identification of the driver is not possible, they resort to civil sanctions based on the license plate data. It may also be possible to structure laws that presume the owner is the driver and then to seek criminal sanctions unless proven otherwise.

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:

INITIAL PROTOTYPE SYSTEM SPECIFICATIONS

INITIAL SYSTEM OVERVIEW

One of the key outputs of the feasibility analyses was a set of general recommended design specifications for an *initial*[3] prototype system. 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 Figure 2 and in the schematics in Figures 3 and 4, 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.

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[3] It is important to distinguish between the *initial* prototype system that was developed and tested in the early stages of the project and the *refined* prototype system that was developed later in the project to address limitations with the *initial* system.

Figure 2. School bus used in project.

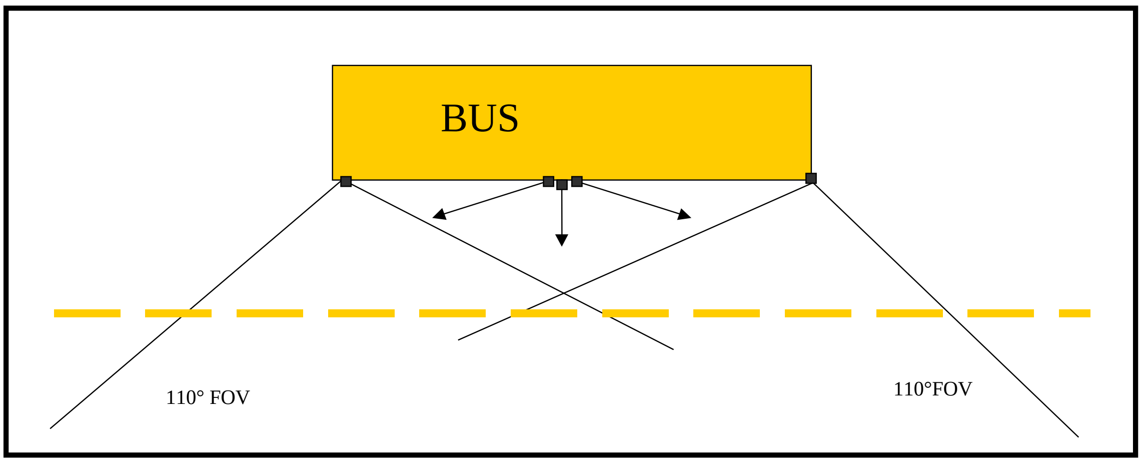


Figure 3. Schematic of the prototype system; area of coverage is on the driver's side.

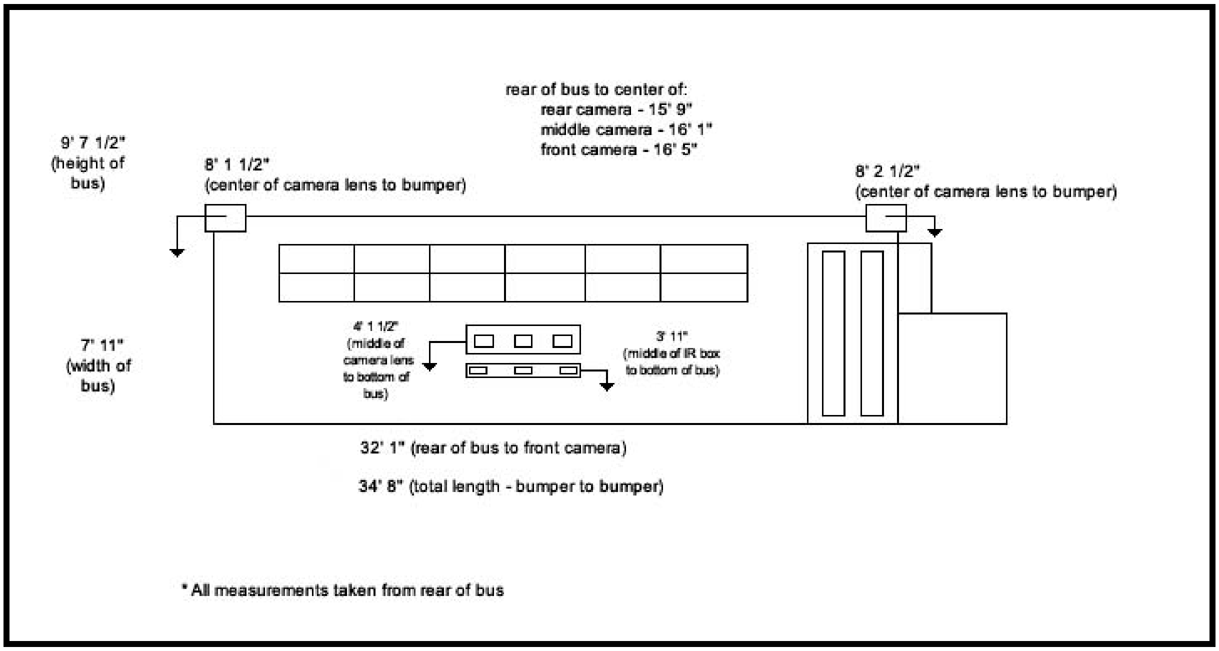


Figure 4. Schematic (side-view) outlining school bus and system components.

COMPUTER OVERVIEW

The five system cameras were controlled by a computer positioned on the front seat of the bus (Figure 5). This computer actually consisted of three separate computers: one master computer; one computer for the license plate cameras; and one computer for the driver profile camera.

Figure 5. Computer positioned on a seat at the front of the bus.

Each of the three computers held identical components. Each computer was a 1GHz Pentium III, and all had 256M of RAM and a 40GB 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 400MB 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: (i) 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, and (ii) the computers required a minimum of a 1 GHz Pentium III processor in order to function with the FireWire equipment.

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 (also described later) were collected, the master computer was used to download it onto a floppy disk.

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 were collected, it was downloaded onto a zip disk.

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 were collected, it was downloaded onto a zip disk.

COMPUTER INTEGRATION

Figure 6 shows a system block diagram of how 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 which stored the data. Once the data was collected, it was downloaded to portable memory (floppy and zip disks) for laboratory analysis.

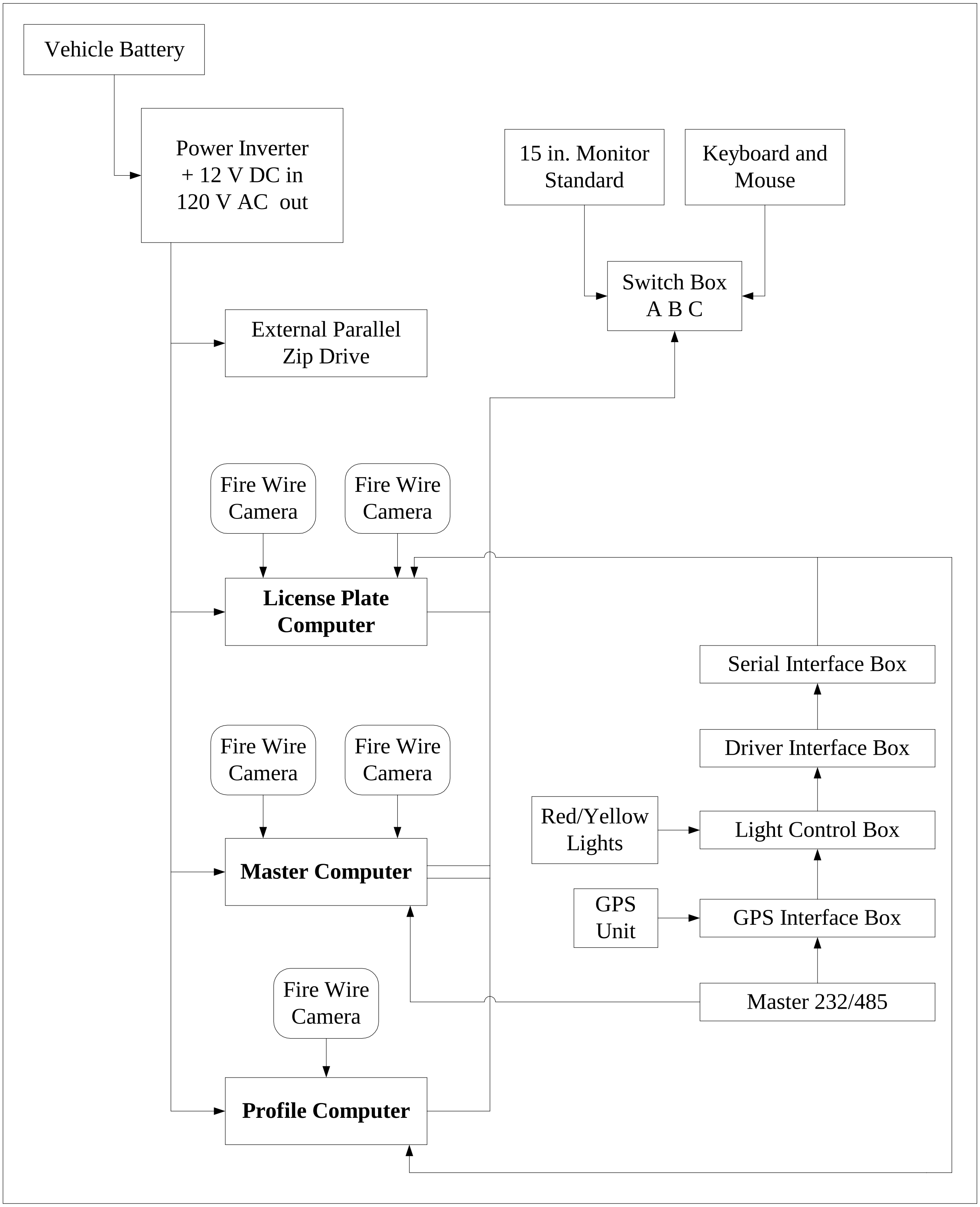


Figure 6. **System block diagram of the initial system.**

CONTROL BOXES

SERIAL INTERFACE BOX

Figure 7 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 7. Four control boxes used in the prototype system.

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.

LIGHT CONTROL BOX

The light control box was connected to the red and yellow lights on the bus, which signaled the loading and unloading of school bus passengers. The computers were running the entire time the school bus was en 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.

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 makes it possible to track 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.

DRIVER INTERFACE BOX

The driver interface box (Figure 8) 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 8. Driver interface box.

SYSTEM CAMERAS

VIOLATION DETECTION CAMERAS

The violation detection cameras served to trigger the three violation-recording cameras that recorded the license plate (x 2) and driver profile (x 1). Figure 9 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 1 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 began. 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 9. Violation detection cameras on front and rear of school bus.

Table 1. 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

VIOLATION-RECORDING CAMERAS

As shown in Figures 10 and 11, the three cameras that were used in the recording of the license plate and driver profiles were located in a central location on the exterior of the bus (driver's side). A schematic of these cameras is shown in Figure 12. 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 2 and 3 show the field-of-view for a 12 mm lens and an 8 mm lens, respectively, from 5 feet to 30 feet.

Figure 10. Violation-recording cameras positioned in a central location.

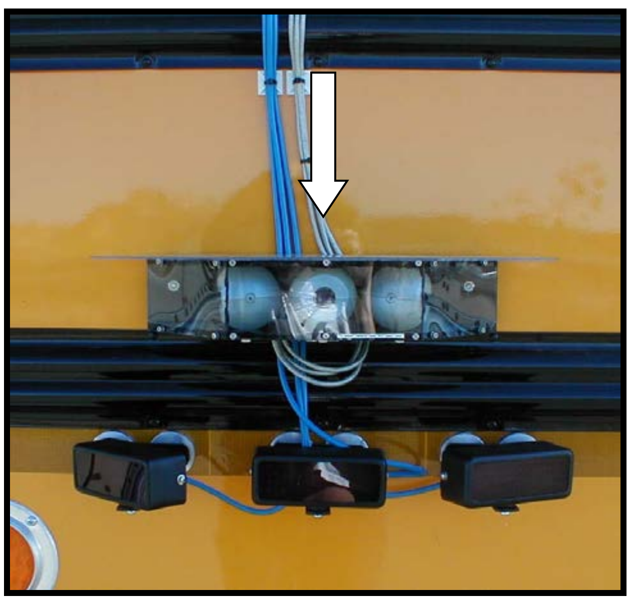


Figure 11. License plate and profile cameras.

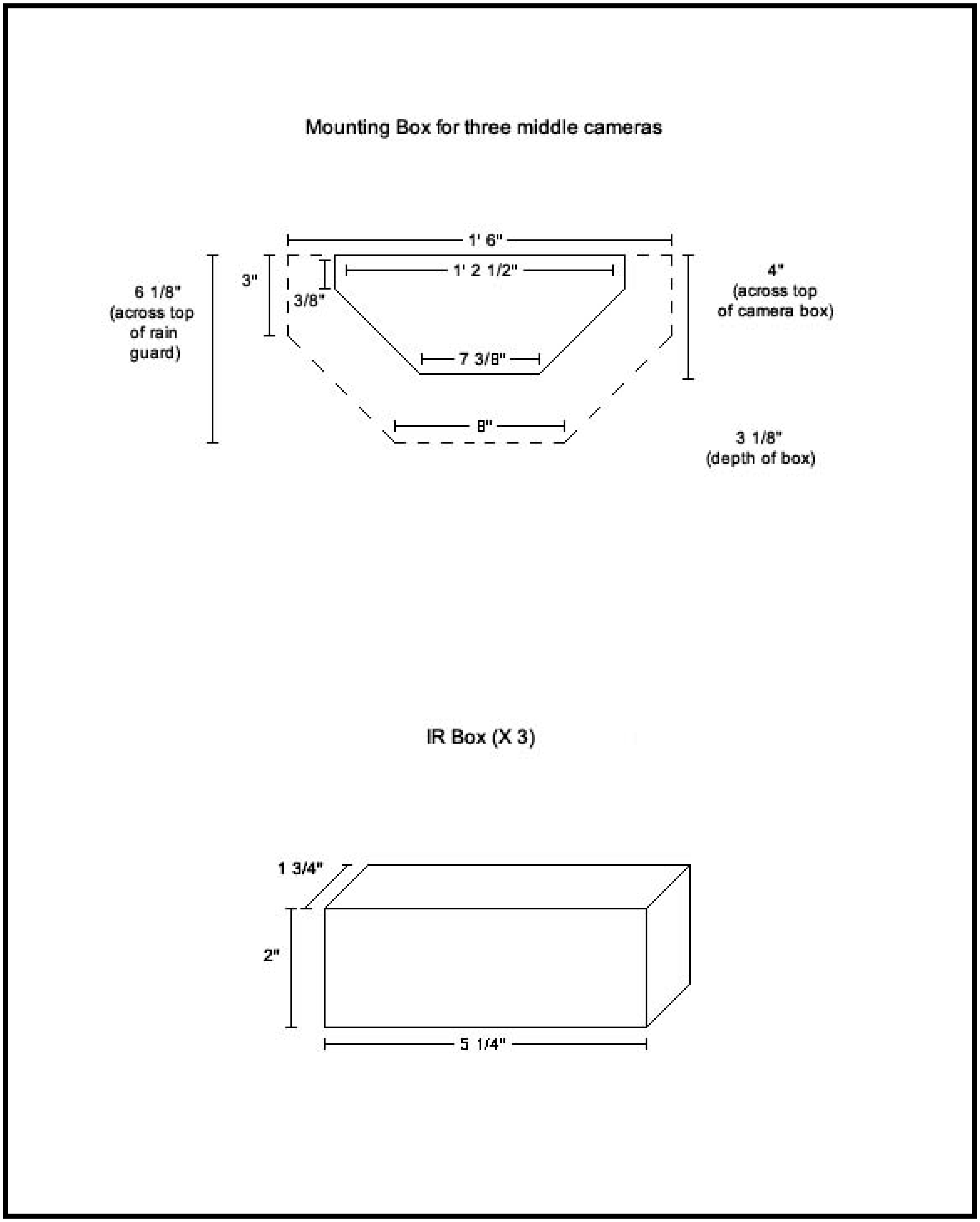


Figure 12. Schematic for the violation recording (middle) cameras and I/R boxes.

Table 2. 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 3. 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

CAMERA ADJUSTMENTS

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 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 maximum viewing of the license plate (license plate was in the center of the video image).

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 that seemed reasonable was selected 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 currently more automobiles than pickup trucks on the road, the optimal approach would be to set the camera for automobiles.

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 13). 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: weight was 11.5 ounces; power was 12 volts DC; current draw was 900 milliamps per unit; range was 40 feet; emission angle was 45 degree horizontal; and light emitted was 880 nanometer wavelength.

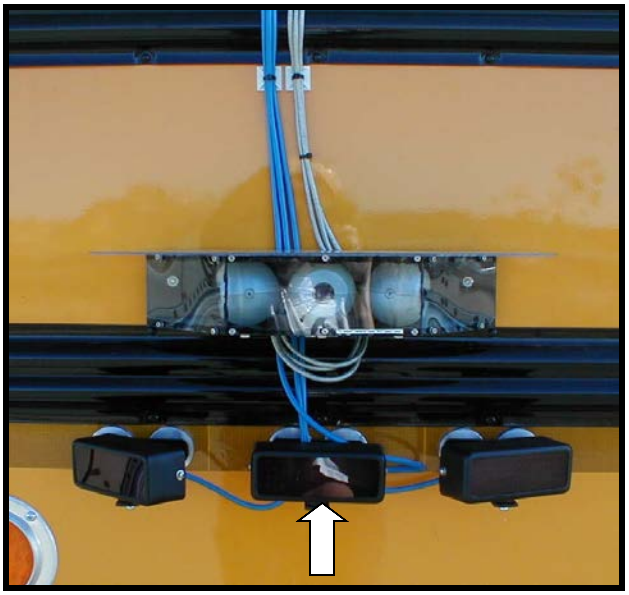


Figure 13. Three infrared pulse sources mounted on side of bus.

CHAPTER 4:

METHODOLOGY FOR TESTING THE INITIAL PROTOTYPE SYSTEM

PURPOSE OF TESTS

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 (i.e., the *refined* system, described later in this report)**. The main purpose of developing the initial system was to investigate issues and answer questions that would support future system development work.

PROOF-OF-CONCEPT FIELD TEST OVERVIEW

The initial 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. As previously noted, the results of the test were used to document what system refinements were needed to further develop the system.

System effectiveness was determined through staged or "mock" violations and non-violations ("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, the lights were flashing, and a vehicle passed the bus. Experimental or shill 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 system 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 initial prototype system. The bus is shown in Figure 14.

Figure 14. VTTI's prototype system for reducing the illegal passing of a school bus 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 system 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 was not a human factors experiment, per se. 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, then 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 was 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.

SAFETY PRECAUTIONS

System testing took place in two phases. Phase I occurred on the Smart Road and Phase II occurred at sites on an actual school bus route. The Smart Road is a 2.2 mile, closed test track at VTTI that was built using actual roadway specifications (Figure 15). 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 15. 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. Those safety precautions are listed below:

1. Local police were notified of the testing 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 of notification sent to parents is presented in Appendix C).
3. To provide advance notice to drivers, researchers served as "flagmen" on the side of the road at the front and rear of the testing area holding "Stop/Slow" signs.
4. "Experimental vehicle" signs were posted on the school bus as well as on the experimental vehicles. Signs were also placed on the school bus stating, "EXPERIMENTAL VEHICLE, TESTING IN PROGRESS." Signs were important to inform the public of the testing taking place and so that they would also be aware that actual violations were not taking place.
5. The bus was operated in compliance with normal school bus operations. To ensure this, a licensed, experienced school bus driver from Montgomery County, Virginia 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 while other traffic was on the road. To the greatest extent possible, care was taken to wait for traffic to clear before a trial began to help minimize the general driving public interacting with the experimental vehicles.
9. Test site locations were selected so that there was sufficient line-of-sight for all drivers (general public) to clearly see the bus, as well as oncoming traffic.
10. The school bus used in the testing was licensed to operate in the Commonwealth of Virginia and carried required insurance.

PHASE I: EXPERIMENTAL TEST CONDITIONS

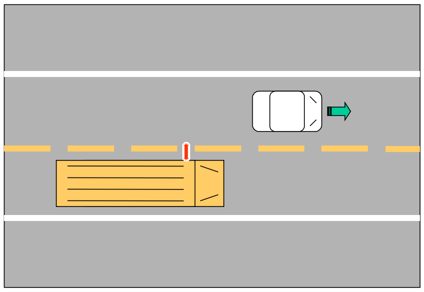
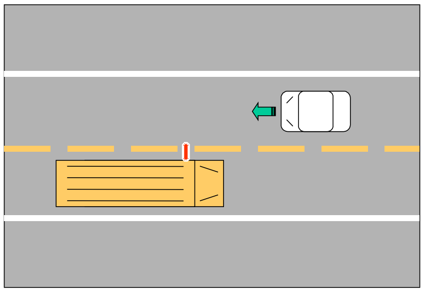
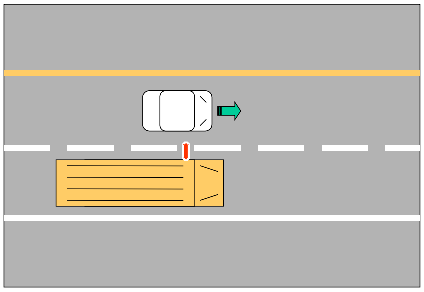
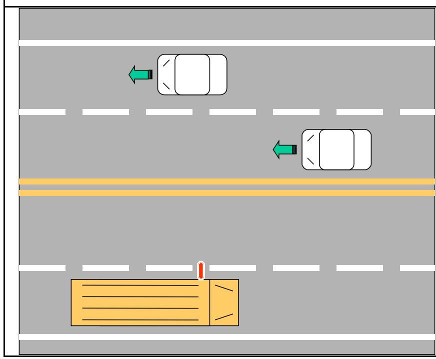
To define the range that the system would typically operate in, three broad "conditions" of operation were identified: Environmental; Violating Vehicle Characteristics; and Bus Stop Characteristics (see Table 4). For each condition, one or more independent variables were identified. These variables were manipulated experimentally for the Phase I Smart Road test, as indicated by the "levels" shown in Table 4. Weather permitting (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 4.

Table 4. Conditions involved in testing the prototype system.

Condition	Independent Variable	Level
ENVIRONMENT	Ambient Light	4. Light 5. Dawn 6. Dusk
	Weather	3. Clear 4. Rain
	Directional Light (Light Ambient Level and Clear Weather Only)	5. North 6. South 7. East 8. West
VIOLATING VEHICLE CHARACTERISTICS	Speed of Violating Vehicle	4. Low (10 mph) 5. Moderate (20 mph) 6. High (40 mph)
BUS STOP CHARACTERISTICS	Characteristic Scenarios	5. Overtaking; 2-way traffic, 2 lanes 6. Oncoming; 2-way traffic, 2 lanes 7. Overtaking; 1-way traffic, 2 lanes 8. Oncoming; 2-way traffic, 4 lanes

The Characteristic Scenarios shown in Table 4 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 5.

Table 5. 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 5, 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 (such as Cloudy Weather). These are not represented in Table 4 but were also tested. Tests were conducted with both light and dark colored vehicles, with multiple (passing) vehicles, in dark ambient conditions.

In addition to the 108 conditions described in Table 4, 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 initial 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 test:
  - 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 vehicles following each other 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 a pickup truck, there was less of a problem in capturing that 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 pickup trucks. Because of this, the profile camera was set 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 initial 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: different makes, models, and colors; with headlights on, off, and with high-beams; and with driver and passenger windows opened and closed.

The complete listing of test conditions is presented in Appendix D. 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 the test (measured in Lux).

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 E). 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 to 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 4 were included in the Phase II test (see Appendix D for a list of conditions). As shown in Table 4, the Characteristic Scenarios tested for this study included two-lane and four-lane roads. Both roadway types were included in Phase II testing. Five different stop sites were included in the test. Because the majority of violations occur on two-lane roads (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.

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

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

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

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

With the Phase I and Phase II tests combined, the system was tested in a total of 255 typical conditions.

STEPS IN PROCESSING THE TEST DATA

For both the Phase I and Phase II tests, there were two steps in the testing process. First, mock violations occurred where a vehicle illegally passed the school bus. Second, video and other data were recorded from the test and were then reviewed 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, selecting a single frame in which the license plate was most visible, selecting a single frame in which the driver's profile or front facial image was most visible, and selecting the "tag" information that contained non-video data relevant to the violation such as date, time, etc. Referencing 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 *Adobe PhotoShop* (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 16 provides an example of video frames showing the vehicle and license plate, while Figure 17 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 6.

Figure 16. Video frames of the vehicle, license plate and the driver profile.

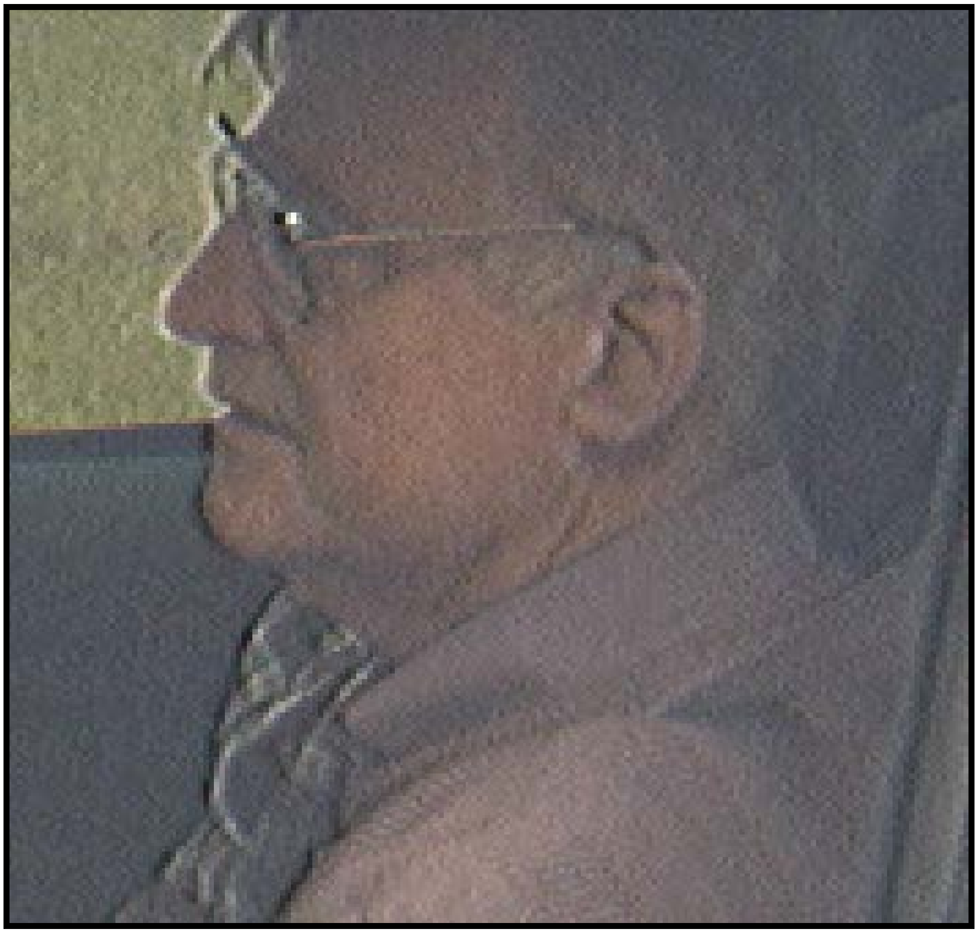


Figure 17. Violating driver's profile.

Table 6. 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)[4] 3 = Valid Trigger
3	Trigger Type	1 = Rear to Front (Overtaking) 2 = Front to Rear (On-coming) 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.

[4] 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 resulted in an "invalid trigger."

OVERVIEW OF THE MEASURES OF EFFECTIVENESS

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." When reading the license plate, usable hits were those where the license plate was not only detected, but could be clearly read (Readability/Discernment rating of 4 or 5, as shown in Figure 18). Similarly, usable hits for driver facial identification were detections in which the driver's face could be clearly identified (Readability/Discernment rating of 4 or 5). The scale values used in assessing Readability/Discernment are listed after the figure. Appendix F includes the protocol used to determine System Effectiveness and provides examples of images (both license plate and profile) rated from Very Low to Very High on the Readability/Discernment scale.

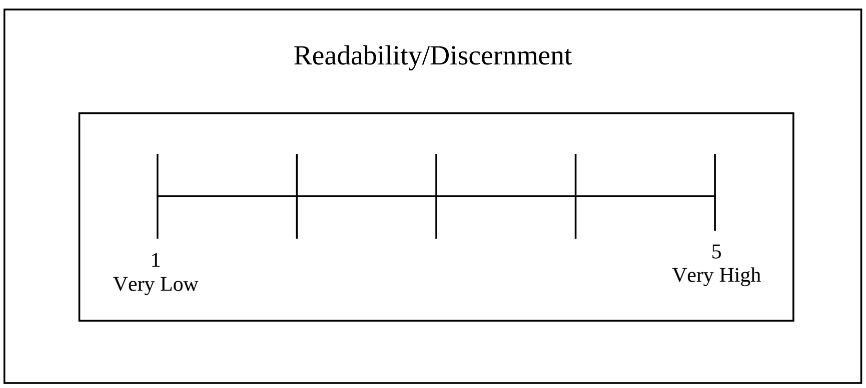


Figure 18. Five-point qualitative scale used to assess Readability/Discernment of each post-processed file.

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 as well as the state of issue).

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

RATING THE DRIVER'S FACIAL IMAGE

1 – Can see a facial image, but with very poor resolution (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 5:

INITIAL PROTOTYPE SYSTEM TEST RESULTS AND DISCUSSION

OVERVIEW

This chapter presents the results from the initial prototype testing. The findings from Phase I that were conducted on the Smart Road will be presented, then the results from the Phase II actual route tests will be presented. For each test phase, System Recording Accuracy, Readability/Discernment of the recording, and System Effectiveness are discussed for the variables manipulated in the tests.

PHASE I: SMART ROAD TESTS

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

RESULTS

System Recording Accuracy

A total of 186 tests were conducted in Phase I. Of these tests, 165[5] were used in the analysis. Twenty-one of the tests conducted involved multiple vehicles (two vehicles per test), resulting in more that one captured image (with a corresponding qualitative rating) for some of the conditions.

Note that the multiple vehicle tests involved vehicles passing the bus at the same time (one vehicle following a lead vehicle), orthogonally (one vehicle passing in one lane while, at the same time, a second vehicle is passing while moving from one lane to another), and simultaneously (one vehicle in Lane 2 and one vehicle in Lane 3). The result of these tests was 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.

[5] 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.

The System Recording Accuracy is a measure of the number of violation recordings divided by the number of opportunities (note that this does not imply a legible license plate or discernable facial image was captured; the results from System Effectiveness are described later). Across the 186 tests, the System Recording Accuracy was 95.2%, with a violation recording (recording of the license plate or face) 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% (n = 177)
- Front Camera- 68.4% (n = 177)
- Profile Camera- 83.1% (n = 177)

Though the recording accuracy for the cameras was fairly high (at least one camera recorded the violation in 95.2% of the tests), the system did not record all violations. There are several reasons to explain why a violation was not recorded. First, the video recording was not full motion. 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 shot was not always captured. Second, 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 from the front camera, was that a lens with a relatively wide field-of-view was used on the front camera. The intent was 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. Therefore, the front camera did not always capture an image of the license plate, thus reducing the recording accuracy for the front camera. Recording the stop-arm is an important feature associated with the system, however this 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%; 97 recordings of the driver's frontal face were made over the 177 tests where the violation was recorded. It should be noted that no attempt was made to capture a shot 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) higher up at the driver's front windshield area. In the tests reported here, the rear camera was directed lower to capture the vehicle's license plate, and the front camera was directed to capture the stop-arm and license plate.

Qualitative Ratings

Qualitative ratings to reflect readability/discernment 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 assessed 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[6]).

It should be noted that an attempt was made to enhance a subset of the images using *Adobe PhotoShop*. If it was believed that an image could be enhanced, an attempt was made to do so. In fact, an attempt was made to enhance 166 images. However, the attempt at enhancement did not always improve the qualitative rating of the image. That is, the enhancement never made the image less readable/discernable, but it did not always make it any better either. Of these attempted enhancements, noticeable improvements in the image quality were made to only 16 images (9.6%); 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. When the enhancement was

[6] 167 of the 177 tests where a violation was recorded had a captured license plate.

successful, the quality of the image improved, on average, by 20%). This finding suggests that the process of image enhancement should be examined further.

System Effectiveness

System Effectiveness is defined as captured images that had qualitative readability/discernment ratings of 4 or 5 (i.e., a high quality image was recorded). Looking at both the un-enhanced 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%. Although this value is lower than expected, it seems valid given the design of the system. 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: Lane 2, lane next to bus = 75.9%; Lane 3, one lane over from bus = 9.4%; and Lane 4, two lanes over from bus = 3.7%. 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. This finding suggests that when a refined system is developed, the focus will be on Lane 2.

Of the 177 tests that had valid recordings, 164 had ratable driver facial images, either profile or frontal shots. 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%. 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: Lane 2, lane next to bus = 17.3%; Lane 3, one lane over from bus = 0.0%; and Lane 4, two lanes over from bus = 0.0%. 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.

INDEPENDENT VARIABLES TESTED

A number of scenarios were tested to determine the operational envelope of the system. A number of conditions were included to determine the operational boundaries; that is, under what conditions would the system work and not work. Each of the independent variables are described in turn.

Passing Lane Scenario

Three Passing Lanes Scenarios were investigated: Lane 2, the lane next to the bus; Lane 3, one lane over from the bus; and Lane 4, two lanes over from the bus. Table 7 shows the results of the tests with regards to System Recording Accuracy and System Effectiveness for both capturing license plate and facial images. As shown in Table 7, based on the System Effectiveness results from the license plate and driver facial image recordings, the system was found to be relatively effective in 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 out.

Table 7. Test results for the Passing Lane of the violating vehicle.

	Passing Scenario	2- Lane Next to Bus	3- One Lane From Bus	4- Two Lanes from Bus
All Tests	# Tests	117	35	34
	# Tests With Plate or Face Captured by at Least One Camera	111	34	32
	System Recording Accuracy	94.9%	97.1%	94.1%
License Plates	# Tests With Ratable Plate Images	108	32	27
	# Plate Images Rated 4 or 5	82	3	1
	System Effectiveness For Capturing Clear Plate Image	75.9%	9.4%	3.7%
Driver's Face	# Tests With Ratable Face Images	104	31	29
	#Face Images Rated 4 or 5	18	0	0
	System Effectiveness For Capturing Clear Face Image	17.3%	0%	0%

Violation Passing Scenario

Two Violation Passing Scenarios were investigated: Oncoming and Overtaking. The results from the tests focusing on the Violation Passing Scenario are shown in Table 8. As with the breakdown of effectiveness ratings for the license plate recordings, the impact of lane position on capturing a high quality image is clear.

Table 8. Test results for the Violation Passing Scenario.

	Violation Passing Scenario	2- Oncoming	3- Oncoming	4- Oncoming	2-Overtaking
All Tests	# Tests	107			79
	# Tests With Plate or Face Captured by at Least One Camera	102			75
	System Recording Accuracy	95.3%			94.9%
License Plates	# Tests With Ratable Plate Images	33	32	27	75
	# Plate Images Rated 4 or 5	24	3	1	58
	System Effectiveness For Capturing Clear Plate Image	72.7%	9.4%	3.7%	77.3%
Driver's Face	# Tests With Ratable Face Images	33	31	29	71
	#Face Images Rated 4 or 5	10	0	0	8
	System Effectiveness For Capturing Clear Face Image	30.3%	0%	0%	11.3%

SPEED OF VIOLATING VEHICLE

Three speeds for the violating vehicle were investigated: Low Speed (10 mph), Moderate Speed (20 mph), and High Speed (40 mph). Table 9 shows the results of the tests for speed as a function of lane position. As noted in the previous analyses, for all speeds and for both license plate and driver facial images, the system performed best in Lane 2.

Table 9. Test results for the Speed of Violating Vehicle Scenario.

	Speed of Violating Vehicle by Lane Position	Low Speed			Moderate Speed			High Speed		
		2	3	4	2	3	4	2	3	4
All Tests	# Tests	87			62			37		
	# Tests With Plate or Face Captured by at Least One Camera	84			57			36		
	System Recording Accuracy	96.6%			91.9%			97.3%		
License Plates	# Tests With Ratable Plate Images	51	17	12	36	9	8	21	6	7
	# Plate Images Rated 4 or 5	39	3	1	29	0	0	14	0	0
	System Effectiveness For Capturing Clear Plate Image	76.5%	17.6%	8.3%	80.6%	0%	0%	66.7%	0%	0%
Driver's Face	# Tests With Ratable Face Images	50	16	13	35	9	8	19	6	8
	#Face Images Rated 4 or 5	9	0	0	7	0	0	2	0	0
	System Effectiveness For Capturing Clear Face Image	18%	0%	0%	20%	0%	0%	10.5%	0%	0%

AMBIENT CONDITIONS

For this study, "Dawn" was defined as the time prior to, and shortly after, sunrise[7] (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. Five Ambient Conditions were investigated: Dawn; Light, Late Afternoon, Dusk, and Dark. Table 10 shows the average values of the light readings for Phase I.

Table 10. 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. Table 11 shows the findings for the tests of the Ambient Conditions as a function of lane of the passing vehicle. As with the previous variables, the violating vehicle's lane position impacted the effectiveness of capturing a high quality license plate and driver facial image.

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

Table 11. Test results for the Ambient Condition Scenario.

	Ambient Condition By Lane Position	Dawn			Light			Late Afternoon			Dusk		
		2	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**
All Tests	# Tests	23			107			35			21		
	# Tests With Plate or Face Captured by at Least One Camera	20			101			35			21		
	System Recording Accuracy	87%			94.4%			100%			100%		
License Plates	# Tests With Ratable Plate Images	16	2	2	56	21	17	22	6	6	14	3	2
	# Plate Images Rated 4 or 5	9	0	0	54	3	1	18	0	0	1	0	0
	System Effectiveness For Capturing Clear Plate Image	56.3%	0%	0%	96.4%	14.3%	5.9%	81.8%	0%	0%	7.1%	0%	0%
Driver's Face	# Tests With Ratable Face Images	15	2	2	57	23	20	18	4	5	14	2	2
	#Face Images Rated 4 or 5	2	0	0	9	0	0	7	0	0	0	0	0
	System Effectiveness For Capturing Clear Face Image	13.3%	0%	0%	15.8%	0%	0%	38.9%	0%	0%	0%	0%	0%

WEATHER CONDITIONS

Four Weather Conditions were investigated: Clear, Fog, Cloudy, and Rain. Table 12 shows the findings for the tests of the Weather Conditions as a function of lane of the passing vehicle. Once again, an important consideration for capturing a clear image of the license plate or face was the lane of the passing vehicle. That is, Lane 2, the lane immediately adjacent to the bus, resulted in the most usable recordings.

Table 12. Test results for the Weather Condition Scenario.

	Weather Condition By Lane Position	Clear			Fog			Cloudy			Rain		
		2	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**
All Tests	# Tests	150			12			14			10		
	# Tests With Plate or Face Captured by at Least One Camera	144			12			11			10		
	System Recording Accuracy	96%			100%			78.6%			100%		
License Plates	# Tests With Ratable Plate Images	84	30	25	6	N/A	1	11	N/A	N/A	7	2	1
	# Plate Images Rated 4 or 5	58	2	1	6	N/A	0	11	N/A	N/A	7	1	0
	System Effectiveness For Capturing Clear Plate Image	69%	6.7%	4%	100%	N/A	0%	100%	N/A	N/A	100%	50%	0%
Driver's Face	# Tests With Ratable Face Images	78	27	26	8	2	2	11	N/A	N/A	7	2	1
	#Face Images Rated 4 or 5	16	0	0	2	0	0	0	N/A	N/A	0	0	0
	System Effectiveness For Capturing Clear Face Image	20.5%	0%	0%	25%	0%	0%	0%	N/A	N/A	0%	0%	0%

DIRECTION OF LIGHT CONDITIONS

The Directional Light variable was examined to determine the impact of various sunlight angles on the cameras. 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 19). As shown in the (a) portion of Figure 19, 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. The East and West Conditions refer to the camera in partial sunlight. NOTE: This condition was only tested for the Light Ambient Condition in Clear Weather.

Table 13 shows the findings for the tests of the Direction of Light Conditions as a function of lane of the passing vehicle. Across all conditions, System Effectives for capturing the license plates was high in Lane 2, but low in lanes further out from the bus. System Effectives for capturing driver facial images was low, across all conditions, but when highly rated images were recorded, it was done so in Lane 2.

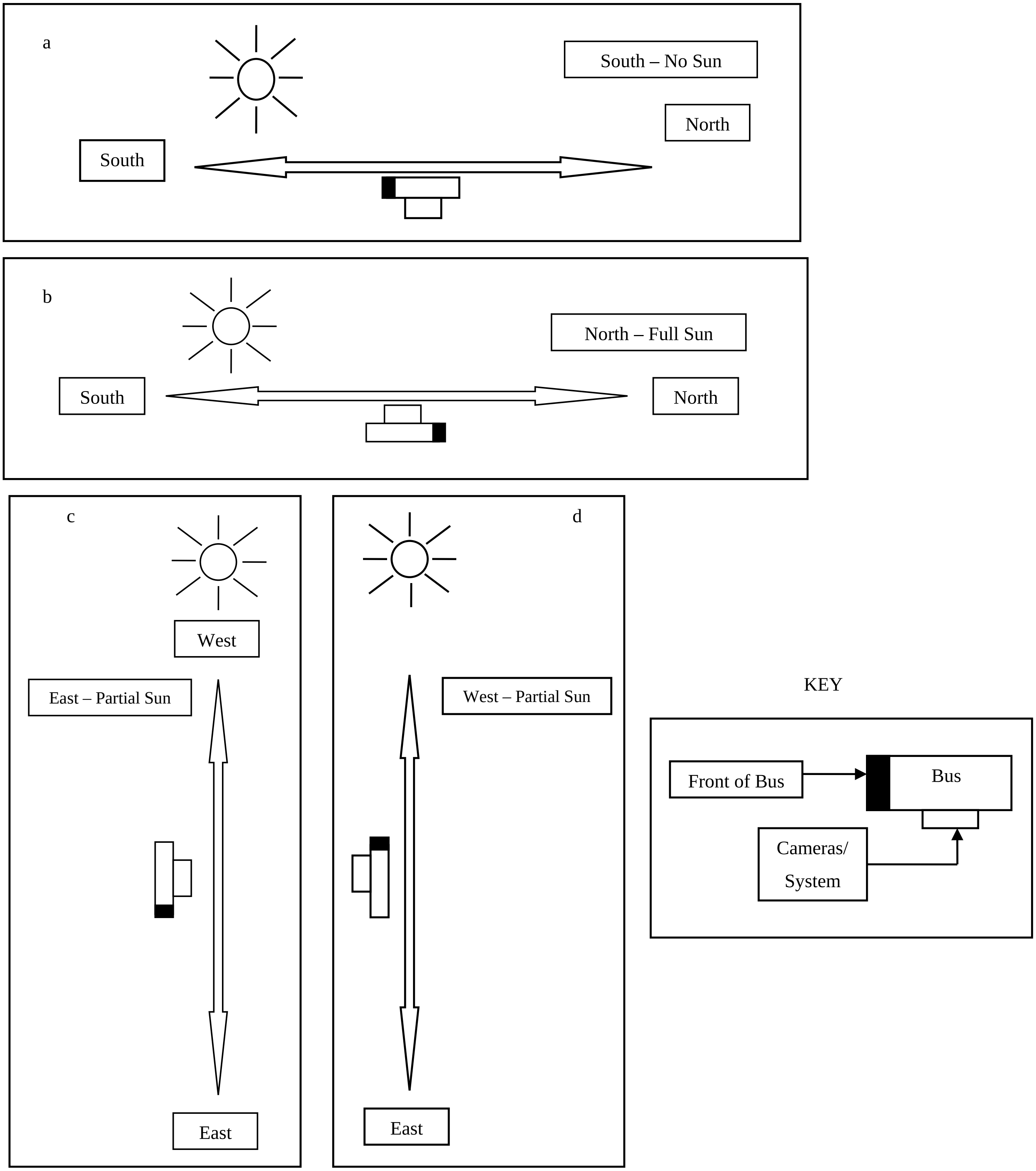


Figure 19. Illustration of Direction of Light conditions: a. South, b. North, c. East, d. West.

Table 13. Test results for the Direction of Light Conditions.

	Direction of Light Condition By Lane Position	North			South			East			West			Not Recorded		
		2	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**
All Tests	# Tests	9			10			18			23			126		
	# Tests With Plate or Face Captured by at Least One Camera	9			9			16			23			120		
	System Recording Accuracy	100%			90%			88.9%			100%			95.2%		
License Plates	# Tests With Ratable Plate Images	5	2	2	4	2	3	10	4	2	11	6	4	78	18	16
	# Plate Images Rated 4 or 5	5	0	0	4	0	0	9	0	0	11	0	0	53	3	1
	System Effectiveness For Capturing Clear Plate Image	100%	0%	0%	100%	0%	0%	90%	0%	0%	100%	0%	0%	67.9%	16.7%	6.3%
Driver's Face	# Tests With Ratable Face Images	5	2	2	4	2	3	9	4	2	11	6	6	75	17	16
	#Face Images Rated 4 or 5	0	0	0	1	0	0	1	0	0	6	0	0	10	0	0
	System Effectiveness For Capturing Clear Face Image	0%	0%	0%	25%	0%	0%	11.1	0%	0%	54.5%	0%	0%	13.3%	0%	0%

HEADLIGHT CONDITION SCENARIO

Four Headlight Scenarios were investigated: Headlights-Off, Standard Lights, Daytime Running Lights, and High Beams. The findings for the tests of the Headlight Condition scenarios as a function of lane of the passing vehicle are shown in Table 14. For license plate recordings System Effectiveness was high in Lane 2, but less effective in Lanes 3 or 4. For driver facial recordings, the System Effectiveness was low across all three Headlight Conditions but, in comparing across conditions, was relatively more effective in the Lane 2 tests.

Table 14. Test results for the Headlight Condition Scenario.

	Headlight Condition By Lane Position	Headlights-Off			Standard Lights			Daytime Running Lights			High Beams		
		2	3	4	2	3	4	2	3	4	2	3	4
All Tests	# Tests	98			57			23			8		
	# Tests With Plate or Face Captured by at Least One Camera	94			53			22			8		
	System Recording Accuracy	95.9%			93%			95.7%			100%		
License Plates	# Tests With Ratable Plate Images	53	20	16	37	8	8	10	4	3	8	N/A	N/A
	# Plate Images Rated 4 or 5	41	2	1	28	1	0	7	0	0	6	N/A	N/A
	System Effectiveness For Capturing Clear Plate Image	77.4%	10%	6.3%	75.7%	12.5%	0%	70%	0%	0%	75%	N/A	N/A
Driver's Face	# Tests With Ratable Face Images	48	18	18	36	8	7	12	5	4	8	N/A	N/A
	#Face Images Rated 4 or 5	11	0	0	4	0	0	2	0	0	1	N/A	N/A
	System Effectiveness For Capturing Clear Face Image	22.9%	0%	0%	11.1%	0%	0%	16.7%	0%	0%	12.5%	N/A	N/A

DRIVER/PASSENGER WINDOW POSITION STATUS

Tests were conducted with the driver and passenger windows 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 passenger window, while the position status of the driver's 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 non-tinted glass had on the profile recordings. Table 15 shows the results of the tests. Consistent with the other findings, it was the lane position rather the primary variable of interest (Window Position Status, in this case) which had a greater impact on the capturing of clear license plate and facial images.

Table 15. Test results for the Window Status Position Scenario.

	Window Position By Lane Position	Window-Up			Window-Down			Window Half-Down			Not Recorded		
		2	3	4	2	3	4	2	3	4	2	3	4
All Tests	# Tests	31			149			2			4		
	# Tests With Plate or Face Captured by at Least One Camera	29			144			2			2		
	System Recording Accuracy	93.5%			96.6%			100%			50%		
License Plates	# Tests With Ratable Plate Images	21	4	4	85	27	22	1	N/A	1	1	1	N/A
	# Plate Images Rated 4 or 5	21	1	0	60	2	1	0	N/A	0	1	0	N/A
	System Effectiveness For Capturing Clear Plate Image	100%	25%	0%	70.6%	7.4%	4.5%	0%	N/A	0%	100%	0%	N/A
Driver's Face	# Tests With Ratable Face Images	21	4	4	81	26	24	1	N/A	1	1	1	N/A
	#Face Images Rated 4 or 5	3	0	0	15	0	0	0	N/A	0	0	0	N/A
	System Effectiveness For Capturing Clear Face Image	14.3%	0%	0%	18.5%	0%	0%	0%	N/A	0%	0%	0%	N/A

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 flooding 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.

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 were 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. A thorough understanding of these conditions is necessary for developing recommendations for a refined system. 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%). This very high accuracy clearly demonstrates the system's reliability in identifying and recording violating vehicles. Note that false alarms, where the system triggered without the presence of a vehicle did occur and is a problematic issue associated with the image subtraction triggering technique. The triggering approach was a high priority issue that was addressed in Phase II.

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%) for capturing license plates in the lane immediately adjacent to the bus, and was 100.0% 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 the camera 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. 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, high quality facial images were found for the lane next to the bus for the Oncoming scenario (30.3%) and for the West Directional Light (partial sun) condition (54.5%). 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. Though unintentional, 54.8% of the front and rear camera violation recordings contained a frontal image of the driver's face. This is a key finding in that the design approach for a refined system should be to focus on the front windshield rather than attempting to capture the driver's profile.

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. Improvements to the image quality can be made to the violation capture data later in the lab. The use of post-processing software for image enhancement should be considered further in the refinement stage.

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. The variable conditions that were manipulated had relatively little impact on the effectiveness of the system. However, there were two exceptions to this: (i) tests that occurred in lanes other than the lane directly adjacent to the bus, and

(ii) 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. Nonetheless, a refined system should be designed to capture quality images in low-light conditions.

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 actual 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.

GENERAL RESULTS

System Recording Accuracy

A total of 55 tests were conducted in Phase II. Of these tests, 45[8] 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 [45 tests – 7 multi-vehicle tests + (8+3+8)], with recordings that had ratable images, were analyzed. Considering all 57 tests, the System Recording Accuracy for Phase II was 96.5%. A violation recording was made by at least one camera for 55 of the 57 (96.5%) vehicles that illegally passed the school bus.

For the 55 tests where there was a recording, the System Recording Accuracy, as a function of the three cameras, was as follows:

- Rear Camera- 90.9% (n = 55)

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

- Front Camera- 72.7% (n = 55)
- Profile Camera- 94.5% (n = 55)

Although the recording accuracy for the cameras was fairly high (M = 96.5%), 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 triggered when non-vehicles (e.g., pedestrians) passed by (this resulted in false alarms rather than missed recordings).

Qualitative Ratings

Qualitative ratings of the images in terms of readability/discernment were made for all of the recorded images. These subjective 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[9]).

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

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[9] 53 of the 57 tests where a violation was recorded had a captured license plate.

System Effectiveness

System Effectiveness was defined earlier as captured images that had a qualitative readability/discernment 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%. Looking at the System Effectiveness as a function of the violating vehicle passing lane, the ratings were: Lane 2, lane next to bus = 79.5%; Lane 3, one lane over from bus = 0.0%; and Lane 4, two lanes over from bus = 0.0%. 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 face 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%. 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: Lane 2, lane next to bus = 12.8%; Lane 3, one lane over from bus = 0.0%; and Lane 4, two lanes over from bus = 0.0%.

PASSING LANE SCENARIO

Three Passing Lanes were investigated in Phase II: Passing Lane 2, lane next to the bus; Passing Lane 3, one lane over from the bus; and Passing Lane 4, two lanes over from the bus. The results of the tests are shown in Table 16. As in the controlled tests, the on-road tests showed that the system worked most effectively in Lane 2.

Table 16. Test results for the Passing Lane of the violating vehicle.

	Passing Scenario	2- Lane Next to Bus	3- One Lane From Bus	4- Two Lanes from Bus
All Tests	# Tests	43	5	9
	# Tests With Plate or Face Captured by at Least One Camera	41	5	9
	System Recording Accuracy	95.3%	100%	100%
License Plates	# Tests With Ratable Plate Images	39	5	9
	# Plate Images Rated 4 or 5	31	0	0
	System Effectiveness For Capturing Clear Plate Image	79.5%	0%	0%
Driver's Face	# Tests With Ratable Face Images	39	5	9
	#Face Images Rated 4 or 5	5	0	0
	System Effectiveness For Capturing Clear Face Image	12.8%	0%	0%

VIOLATION PASSING SCENARIO

Two violation passing scenarios were investigated: Oncoming and Overtaking. The results from the tests are shown in Table 17. Regardless of the Violation Passing Scenario, the system was only able to capture clear images in Lane 2.

Table 17. Test results for the Violation Passing Scenario of the violating vehicle.

	Violation Passing Scenario	2- Oncoming	3- Oncoming	4- Oncoming	2-Overtaking
All Tests	# Tests	27			30
	# Tests With Plate or Face Captured by at Least One Camera	26			29
	System Recording Accuracy	96.3%			96.7%
License Plates	# Tests With Ratable Plate Images	10	5	9	29
	# Plate Images Rated 4 or 5	7	0	0	24
	System Effectiveness For Capturing Clear Plate Image	70%	0%	0%	82.8%
Driver's Face	# Tests With Ratable Face Images	11	5	9	28
	#Face Images Rated 4 or 5	4	0	0	1
	System Effectiveness For Capturing Clear Face Image	36.4%	0%	0%	3.6%

SPEED OF VIOLATING VEHICLE

Three speed conditions for the violating vehicle were investigated: Low Speed (10 mph), Moderate Speed (posted speed ranging from 15-35 mph), and Unknown Speed[10]. Table 18 shows the results of the tests. Once again, it was the Lane Position of the violating vehicle that had the greatest impact on the effectiveness of capturing clear images.

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

Table 18. Test results for the Speed of Violating Vehicle Scenario.

	Speed of Violating Vehicle by Lane Position	Low Speed			Moderate Speed			Unknown		
		2	3	4	2	3	4	2	3	4
All Tests	# Tests	12			11			34		
	# Tests With Plate or Face Captured by at Least One Camera	11			10			34		
	System Recording Accuracy	91.7%			90.9%			100%		
License Plates	# Tests With Ratable Plate Images	8	1	1	8	1	N/A	23	3	8
	# Plate Images Rated 4 or 5	8	0	0	6	0	N/A	17	0	0
	System Effectiveness For Capturing Clear Plate Image	100%	0%	0%	75%	0%	N/A	73.9%	0%	0%
Driver's Face	# Tests With Ratable Face Images	9	1	1	8	1	N/A	22	3	8
	#Face Images Rated 4 or 5	2	0	0	1	0	N/A	2	0	0
	System Effectiveness For Capturing Clear Face Image	22.2%	0%	0%	12.5%	0%	N/A	9.1%	0%	0%

HEADLIGHT SCENARIO

Two Headlight Scenarios were investigated in the Phase II tests: Headlights-Off and Standard Lights. Table 19 shows the results of these tests. In both Headlight Scenarios, the system was most effective in capturing clear images in Lane 2, and was completely ineffective in Lanes 3 or 4.

Table 19. Test results for the Headlight Scenario.

	Speed of Violating Vehicle by Lane Position	**Headlights Off**			**Standard Lights**		
		2	**3**	**4**	**2**	**3**	**4**
All Tests	# Tests	51			6		
	# Tests With Plate or Face Captured by at Least One Camera	49			6		
	System Recording Accuracy	96.1%			100%		
License Plates	# Tests With Ratable Plate Images	34	5	9	5	N/A	N/A
	# Plate Images Rated 4 or 5	26	0	0	5	N/A	N/A
	System Effectiveness For Capturing Clear Plate Image	76.5%	0%	0%	100%	N/A	N/A
Driver's Face	# Tests With Ratable Face Images	33	5	9	6	N/A	N/A
	#Face Images Rated 4 or 5	4	0	0	1	N/A	N/A
	System Effectiveness For Capturing Clear Face Image	12.1%	0%	0%	16.7%	N/A	N/A

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 passenger window, while the position status of the driver's window was of interest in the Overtaking tests. Including this variable in the testing could potentially provide information on how effective the system was at capturing profile images through glass.

Four Window Positions were investigated in Phase II: Window-Up, Window-Down, Window-Half-Down, and Not Recorded (inadvertent). The test results are shown in Table 20 and highlight how the system was ineffective at capturing usable images outside of Lane 2.

Table 20. Test results for the Window Status Position Scenario.

	Window Position By Lane Position	Window-Up			Window-Down			Window Half-Down			Not Recorded		
		2	3	4	2	3	4	2	3	4	2	3	4
All Tests	# Tests	30			17			1			9		
	# Tests With Plate or Face Captured by at Least One Camera	28			17			1			9		
	System Recording Accuracy	93.3%			100%			100%			100%		
License Plates	# Tests With Ratable Plate Images	20	2	5	14	2	N/A	1	N/A	N/A	4	1	4
	# Plate Images Rated 4 or 5	15	0	0	13	0	N/A	1	N/A	N/A	2	0	0
	System Effectiveness For Capturing Clear Plate Image	75%	0%	0%	92.9%	0%	N/A	100%	N/A	N/A	50%	0%	0%
Driver's Face	# Tests With Ratable Face Images	20	2	5	14	2	N/A	1	N/A	N/A	4	1	4
	#Face Images Rated 4 or 5	1	0	0	4	0	N/A	0	N/A	N/A	0	0	0
	System Effectiveness For Capturing Clear Face Image	5%	0%	0%	28.6%	0%	N/A	0%	N/A	N/A	0%	0%	0%

PHASE II SUMMARY

From the 55 tests that were conducted in Phase II, 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. The system recorded a violation in 55 of the 57 tests conducted (96.5%). 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%). Recall that this same measure in Phase I was a very similar 75.9%. 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% (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).

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% 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% for the Low speed condition, 28.6 percent when the window of the violating vehicle was down, and 36.4% for the Oncoming scenario.

INITIAL PROTOTYPE TEST CONCLUSIONS AND IMPLICATIONS FOR THE DESIGN OF A REFINED PROTOTYPE SYSTEM

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, an initial 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 formal testing was to gather data that could be used to support design recommendations and changes for a refined system (i.e., the next generation of the system). The primary findings from the initial prototype testing and the implications for a refined prototype system are described below.

System Recording Accuracy

There were 243 violation tests conducted in the study. Of these, 232 resulted in a valid recording of the violating vehicle resulting in a System Recording Accuracy of 95.5%. Although this is a very high percentage, the *Results* section listed instances where the system failed to respond, or responded inappropriately. As such, the refinement research should consider alternative methods of recording (triggering) violations to improve the recording accuracy.

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% for violating vehicles in Passing Lane 2. When looking at the outside passing lanes, the System Effectiveness was much less. If the recording of vehicles in multiple lanes becomes a necessary specification requirement, then either multiple cameras may be needed or, perhaps more simply, a wider angle lens than was used for the initial prototype system. It would be expected that having multiple cameras would substantially increase the cost[11] and complexity of the system. As described in the next chapter, the option determined to be most feasible was to test different lenses to optimize field-of-view, and to also focus on the lane immediately adjacent to the bus because from a practical standpoint, most school bus routes are on two-lane roads (Institute for Transportation Research and Education, 2000).

With regard to the relatively poor quality license plate images that were recorded in Passing Lane 2 (23.1% were rated <4), one of the problems encountered was difficulty with the system in low-light conditions. As described in the next chapter, this was an important issue that had to be resolved for the refined prototype system. In addition, the work described in the next chapter also describes a software solution to improve image quality through post-processing image enhancement.

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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 $200,000 (Huey and Llaneras, 2001a).

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

Looking at the effectiveness of the initial prototype system in capturing usable driver facial images, the overall effectiveness was 10.6% across all tests. However, when only Passing Lane 2 tests were considered, the effectiveness was 16.1%. Interestingly, the percentage of usable images from the frontal view was 13.4%, as compared to 10.2 % 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.

These results suggest that 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 described in the next chapter, the refined prototype system was designed to capture the frontal view of the driver. This is a better design solution because: it provides better identification and a frontal image seems to be the preferred view for identifying a violating driver as indicated in the legal feasibility analysis; the system would be more effective for capturing images of both automobiles and pickup truck drivers, as the height of the driver in the cab of the vehicle would be less of an issue; and tinted glass windows would be less of an issue (although tinted glass windows were not thoroughly tested in this study, it is recognized as being potentially problematic for capturing a profile image).

In the initial prototype design, 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. Huey and Llaneras (2001b) note that, with Red-Light Running cameras, reliably capturing a driver facial view is less than 20%. 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. These hypotheses were tested with the development of the refined system (described in Chapter 6).

Prototype System Proved Robust, with Few Exceptions

One of the findings from the initial prototype tests was that the system performed quite well across a variety of conditions. However, as indicated earlier, there were a few exceptions to this. First, the system was ineffective in darkened conditions. As described in the next chapter, this problem was addressed in the development of the refined system. Second, the capture of facial images was not a consistent high quality. Though the initial system worked about as well as a red-light running system for capturing facial images, the research team believed that this could be improved upon. This too is described in the next chapter. Third, the system lacked the ability to record quality images from passing lanes other than the lane next to the bus. (This issue was discussed with the government sponsor before the refined system was developed and the decision was made to focus on the lane next to the bus.)

One final point regarding the system testing should be made, and that is, the initial prototype system may have 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, albeit initial, state (based on the 75.9% and 16.1% effectiveness ratings for the license plate and driver face capture, respectively), the system may serve as a deterrent. However, based on what was learned in this initial development phase, the research team conducted follow-up work to improve the design.

NEXT STEPS

OVERVIEW

After the completion of the initial prototype system development and testing, the NHTSA Task Order Manager requested that WESTAT provide an assessment of what steps need to be taken to further the program. The remainder of this chapter includes WESTAT's assessment. Note that this assessment was conducted *prior* to the decision to modify the project and conduct additional research aimed at refining the system. The system refinement work, described in the next chapter, was only directed at refining the technology (and was conducted after WESTAT's assessment of the initial system was conducted). As such, much of WESTAT's assessment is, even after that refinement work has been completed, still relevant.

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 can capture visual images capable of divulging license plate identification of the offending vehicle as well as the driver of the vehicle. The data necessary for uniquely identifying the circumstances surrounding the violation have 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.

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 was developed to map the prototype system to the specifications for an idealized operational system. This checklist is contained in Appendix G.

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.

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.

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 operational field test. (The system refinement work is described in the next chapter).

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.

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.

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 *Adobe 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 link to licensing information and tracking of the progress for a given citation through the adjudication process.

Ensure Legislative/Judicial Integrity

Using legal knowledge gained from the legal review performed under the current project, as well as, local representatives of the judicial and legislative bodies in the Metro Washington, 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 will also need to provide further informal reviews and feedback that later may prevent roadblocks to deployment.

CHAPTER 6:

PROTOTYPE SYSTEM REFINEMENT AND TESTING

INTRODUCTION

Based on the encouraging results of the initial prototype development work, a contract modification was made to allow for additional work to be conducted to refine the prototype system. Figure 20 provides an outline of how the project was carried out for the initial prototype design work and for the refined design work (after the project modification). As described in the previous chapter, the feasibility analysis and system requirements lead to the development of an initial prototype system. As detailed in previous chapters, this initial system underwent a formal testing process that included tests on a control test track and on an actual bus route. To learn about the important variables that would impact the system's design, including variables related to the environment, violating vehicle characteristics, and bus stop characteristics, a carefully planned testing methodology was carried out. The encouraging results of the initial development work lead NHTSA to provide a modest amount of additional funding to refine the prototype. Therefore, the information learned from the formal, thorough evaluation of the initial system was used to develop a refined system. As part of the refined system design process, informal tests (as compared to formal tests) were conducted. Even with additional funding, project funds were not sufficient to allow formal testing of the refined system. However, minimal testing was conducted to generate an assessment of the refined system. As will be described in the remainder of this report, the performance of the refined system was far superior to the initial system in all test conditions.

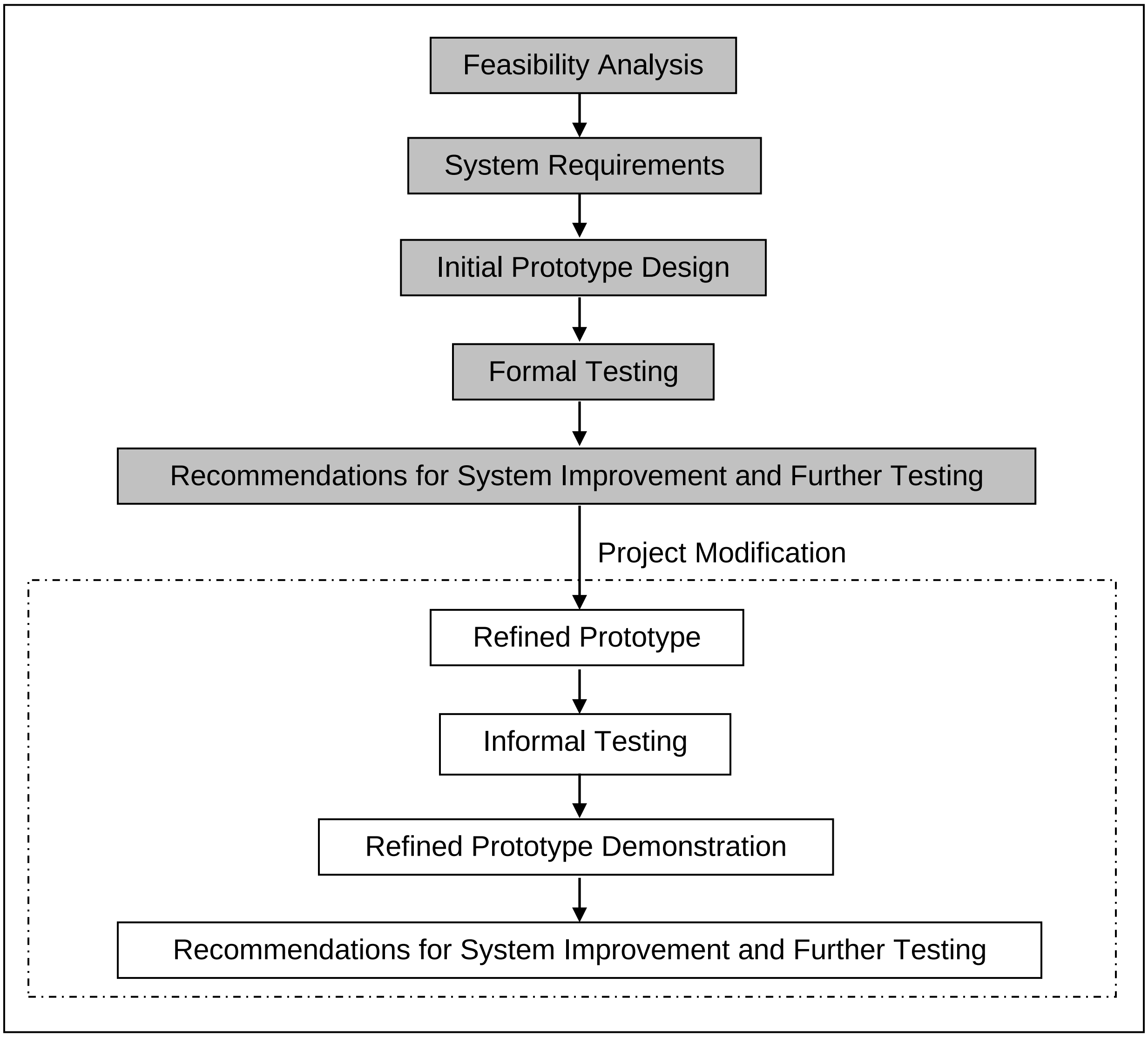

Figure 20. Flow chart including the main phases of the project, before and after the project modification.

As described in the previous chapter, the initial prototype system worked sufficiently in many of the test situations, however the project sponsored concluded that there were two areas in particular in which the refined system needed to excel. The two primary improvements that were identified were:

- Ability to capture high quality license plate images during both day and night conditions
- Improvement upon the capture of facial images.

These two issues were identified in the initial development work and were areas that the research team believed could be improved upon in a refined prototype system. The remainder of this chapter describes the research that was conducted to refine the system and to achieve these system improvements. The sections that follow describe the refined prototype system, outline the method used to test the system, present the results from the testing, describe the results from an effort to design a conceptual pod that could be manufactured to hold the system components, report the results of a system demonstration held for government personnel, and highlight the recommended steps that could be taken to further develop and test the system.

REFINED PROTOTYPE SYSTEM

HARDWARE OVERVIEW

Informal testing was necessary to make design decisions that were then implemented into the refined system. In describing the refined prototype system, the implementation of these design decisions is highlighted.

Unlike the initial system, the refined prototype system was contained entirely in a single housing (pod). As shown in Figure 21, the refined system consists of five cameras: two cameras facing forward; two facing to the rear; and one centrally-located wide-angle camera. Also, the refined system uses two High Intensity Discharge (HID) spotlights and one side-radar unit that is used to trigger the cameras. Due to nighttime imaging limitation of the initial prototype system, HID spotlights were used for the refined prototype system instead of Infrared lights. Moreover, due to vehicle detection limitations from the initial system, a SODS unit was used for event triggering; this solution replaces the high-mounted trigger cameras used in the initial system. As shown in Figure 22, the pod is located on the left side, near the center of the school bus.

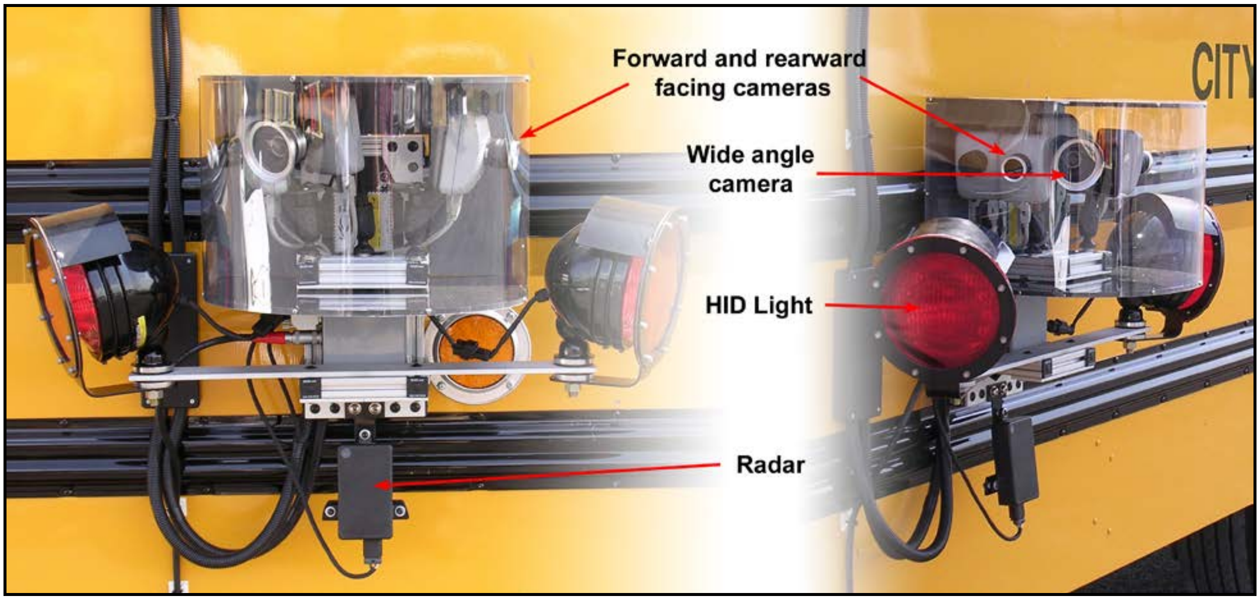

Figure 21. Prototype system is housed in one pod.

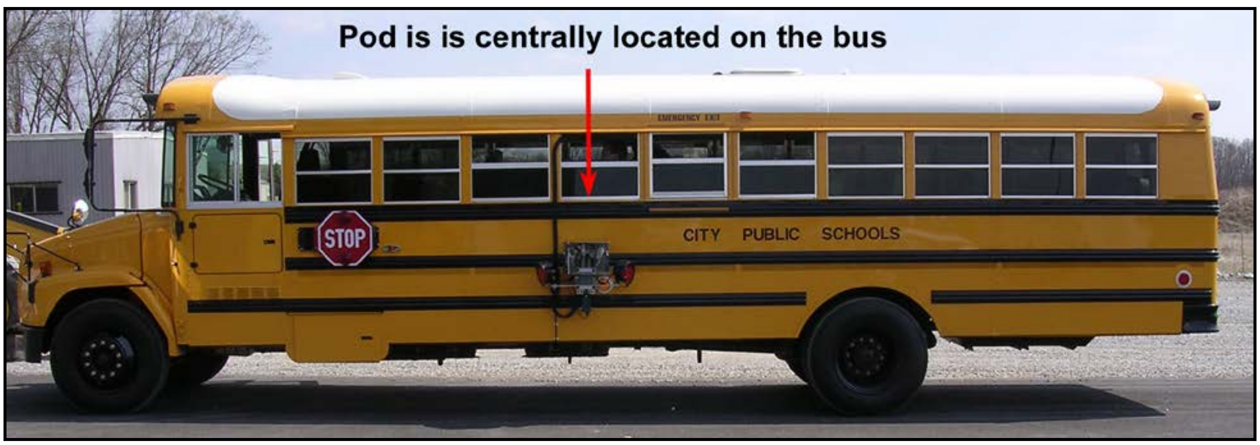

Figure 22. Prototype system centrally located on bus.

A feature of the refined system is that the cameras are positioned to record, in a single image, the driver's face and the vehicle's license plate. It was believed after tests with the initial design, that having the license plate and driver's face together in a single image would provide unambiguous evidence of a violation. A limitation of the initial system was that the cameras used did not have an appropriate vantage point, field-of-view, focal distance, or resolution to capture usable images of both the violating vehicle driver and the license plate together in a single image. The refined single-pod design and placement of cameras makes the system capable of capturing the necessary images of violators coming from both forward and rear directions. The refined design is also expected to be easier to implement in the “real-world,” as compared to the initial system, since the one-unit design could be more easily installed and maintained.

The refined system also includes a network of three computers used to capture images, a main software interface, and a bus driver trigger-notification display (Figure 23). The driver trigger-notification display indicates to the bus driver when the system is in operation, when the radar is triggered, and when the system is capturing a violating driver. When the radar is triggered, an audible warning sound for the bus driver accompanies a visual LED indicator.

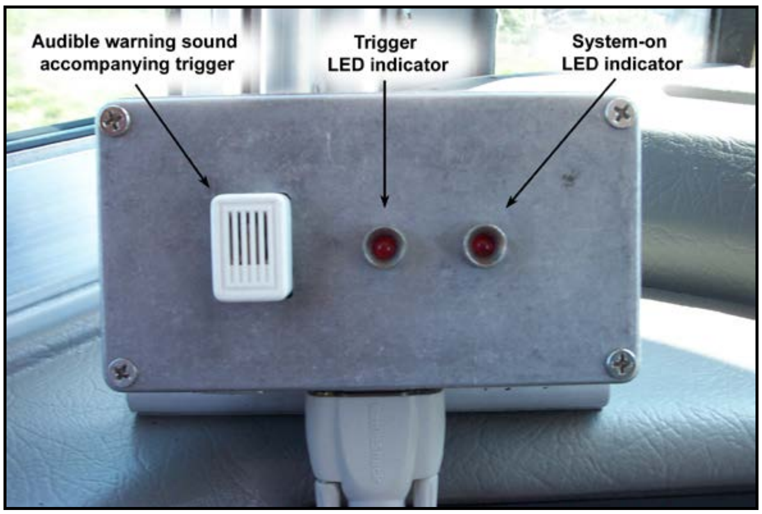

Figure 23. Prototype driver trigger-notification box.

SOFTWARE OVERVIEW

The main system interface was designed to provide diagnostic system information to a designer/researcher for purposes of calibration and maintenance. During actual system use, the bus driver would not see this interface screen (Figure 24).

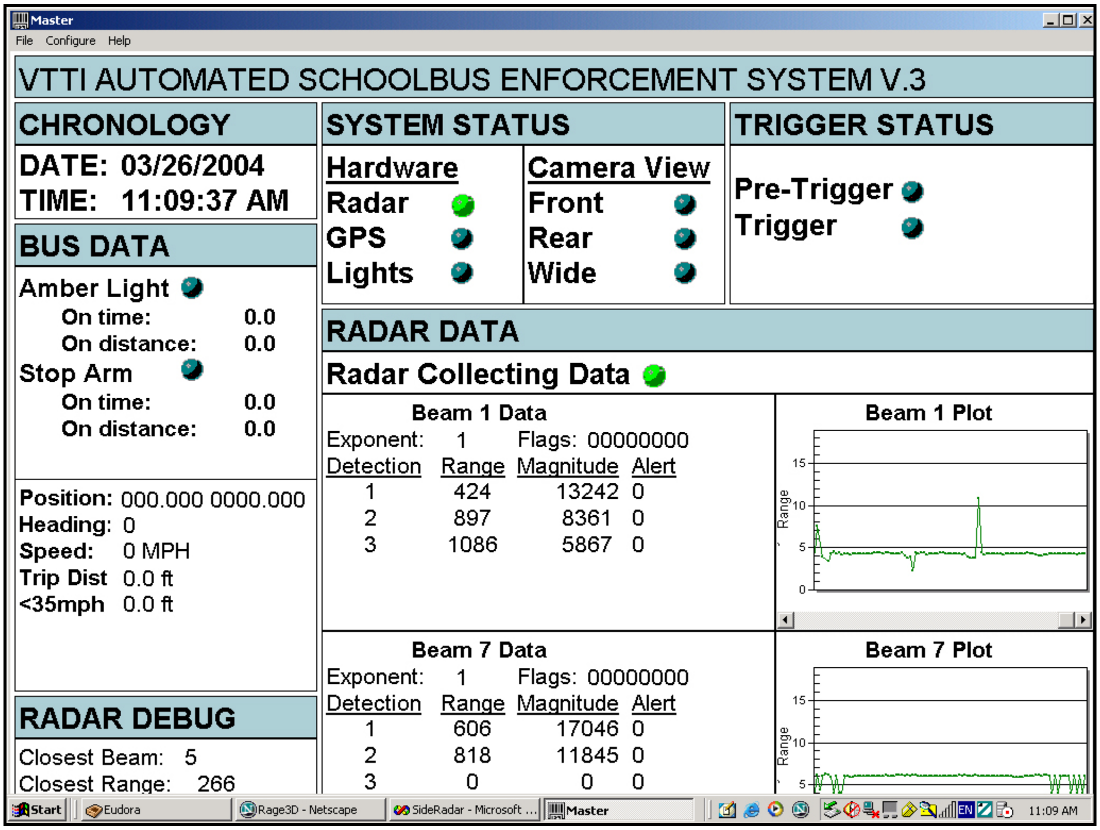

Figure 24. Main software user interface. This was developed for researchers and is not a screen that is seen by the bus driver.

As shown in Figure 24, there are six information areas on the main interface screen. Each of these six areas is described below.

Chronology

This area indicates the current date and time.

System Status

System Status is segmented into Hardware and Camera View. For the Hardware section, a status indicator is lit when the system senses a signal from the radar, GPS unit, and HID lights. For the Camera View section, the status light indicates if a signal is being received from the front camera, rear camera, and wide-angle camera.

Trigger Status

A status light illuminates if the Pre-trigger signal is received. The Pre-trigger signal refers to the bus driver's operation and whether or not he complied with the stopping regulations (e.g., driver triggers amber warning lights at least 300 feet or 10 seconds prior to stopping). The Pre-trigger signal illuminates if the radar detects a vehicle passing and the cameras are turned on.

Bus Data

There is an upper and lower area in the Bus Data section. The upper area includes status information on the Amber Light and Stop-Arm. For the Amber Light, a light illuminates on the screen when the amber lights are switched on. The On time measure is the running time (seconds) from when the bus driver switches the amber lights on until they are switched off. The On distance measure is the distance the bus travels (ft) from when the amber lights are switched on until they are switched off.

Information about the Stop-Arm status is also presented. A light illuminates when the amber lights are switched on. The On time measures are the running time (seconds) from when the bus driver activates the stop-arm until it is de-activated. The On distance measure is the distance the bus travels (ft) from when the bus driver activates the stop-arm until it is de-activated.

The lower area pf the Bus Data section provides information about the bus' position and heading (determined from the GPS unit). The speed information refers to the speed of the bus prior to switching on the amber lights. The trip distance is the distance that the bus has gone without stopping and the <35 mph measure indicates how many feet that were traveled on a given trip when the bus was traveling less than 35 mph.

Radar Data

The radar data provides a number of information items including an illumination signal indicating that the Radar is collecting data. Data and plots for the two outside beams are presented (Beam 1 and 7). Several information items are presented to help the designer troubleshoot problems with the radar unit.

Radar Debug

The Radar Debug area provides technical information about the performance of the radar unit that can be used by the designer to troubleshoot.

CAPTURING A VIOLATING VEHICLE

A typical violation scenario would occur in the following manner: the bus would slow down and the driver would activate the amber warning lights and, when stopped, the stop-arm would be extended. Although the bus driver would not see the interface, activation of the amber warning lights would also activate the system. The system would catalog the activation of the amber lights and the stop-arm. Should a violating vehicle approach the bus, and assuming that the driver followed the correct pre-stop procedures (e.g., trigger the amber warning lights at least 300 feet or 10 seconds prior to the stop) the Pre-trigger status indicator would illuminate. As the violating vehicle passes the bus, the radar would detect the passing, activate the cameras and record the event. The bus driver would be alerted to the passing via the trigger notification box.

Data captured from the system is stored on a computer and can be accessed by a “Violation Data Viewer” (Figure 25). Events are stored by day and time of capture and this information is accessed by selecting the day on a calendar and the capture time of interest through the “Violation Data Viewer” program. Specific images and a video clip of the violation can be saved and archived after the event of interest is selected and loaded. Note that this screen is not displayed to the bus driver, but rather is used by personnel reviewing and validating violations.

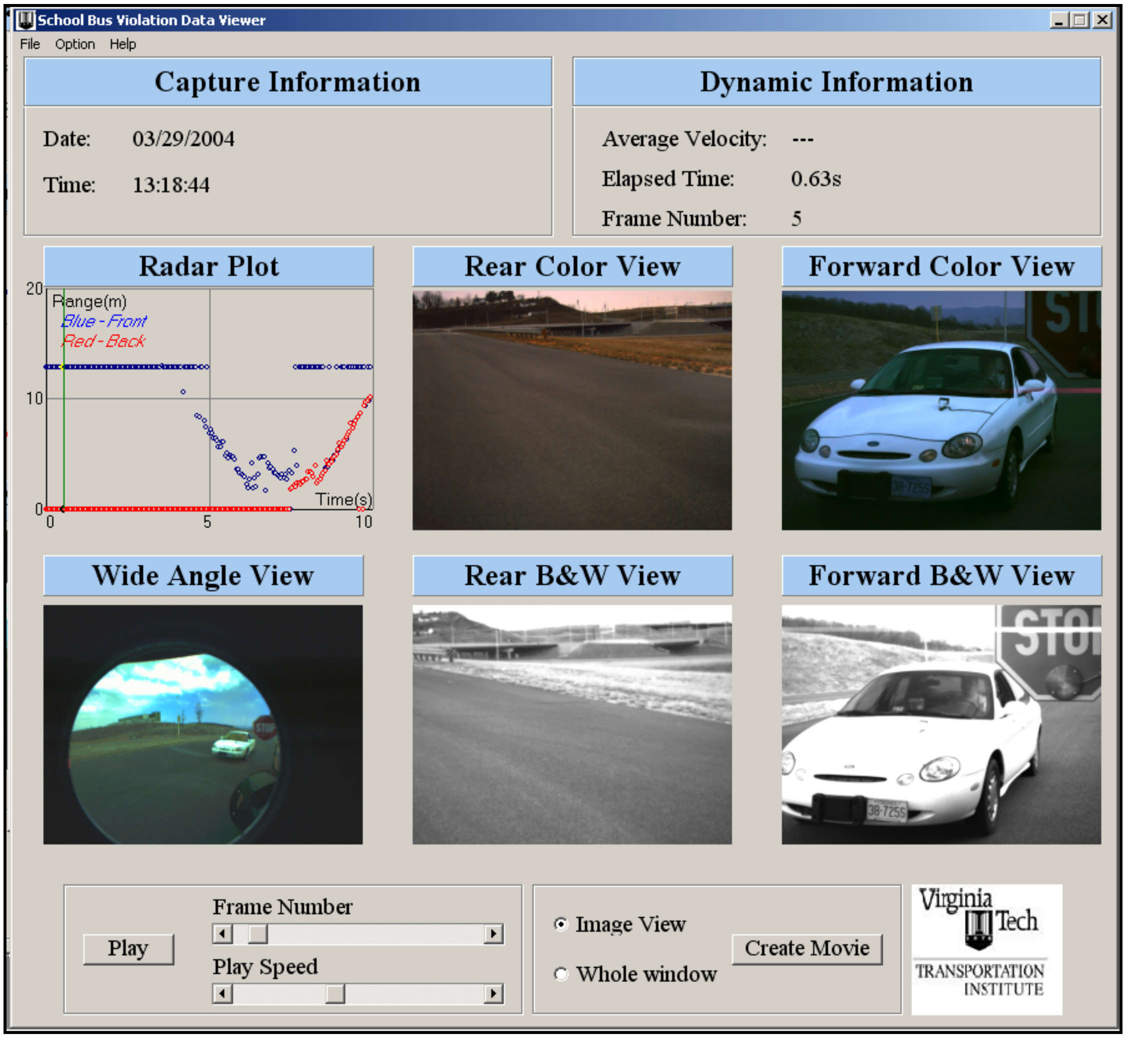

Figure 25. "Violation data viewer" software interface. This interface is for the personnel involved in reviewing the violation captures.

RADAR DESCRIPTION

One of the problems encountered with the previous prototype system was that detection and recording were occasionally missed. To alleviate this problem, and to keep a single pod design, a SODS was used. The SODS used was a radar unit (P/N H314114) made by Raytheon (Figure 26). Mounted below the camera housing as shown previously in Figure 21, this radar unit is designed to detect objects within a specified range. The radar unit has seven detection areas, or beams. The outside beams (Beam 1 and Beam 7) were used to detect moving objects as they passed by the bus. The total azimuth span for both beams was approximately 130 degrees. The detection distance for the SODS beams is approximately 20 meters (Figure 27). Note that this is further out than the required sensor coverage area of 10 feet fore and aft of the bus. If this radar approach is used as the trigger mechanism for future system iterations, it is recommended that either the beams be "gated" via software to reflect the required sensor coverage and not trigger for vehicles that are outside of this area, or a radar device be developed for this particular application.

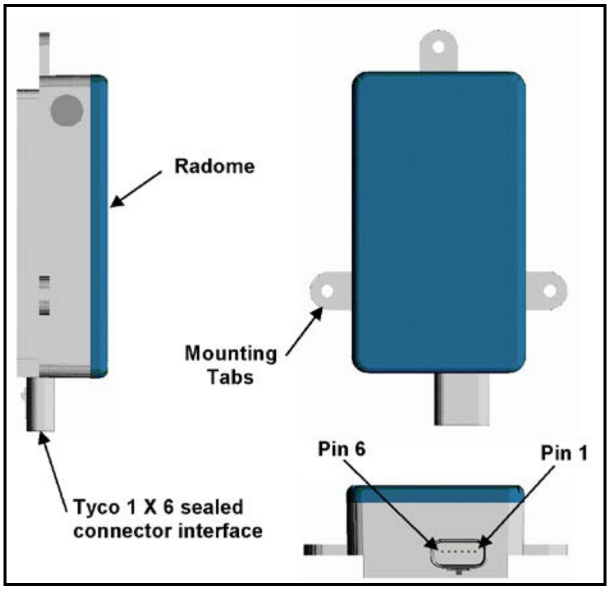

Figure 26. Side-object detection radar by Raytheon.

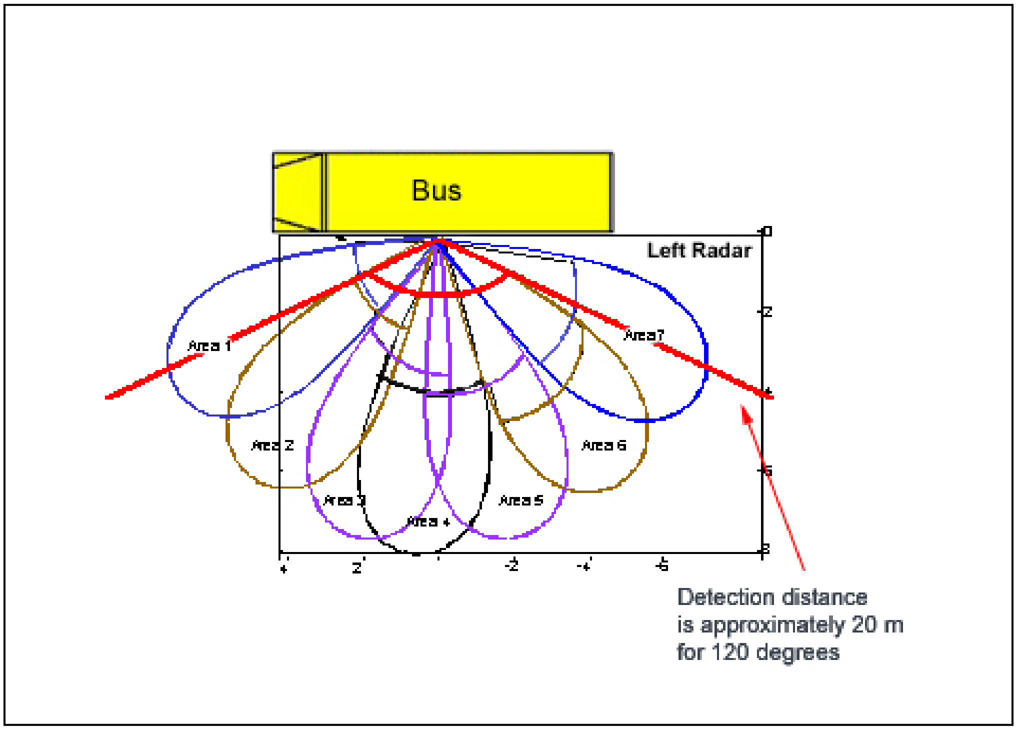

Figure 27. Approximate beam patter of the radar unit used in the refined system.

The initial system, using two cameras (mounted near the top corners of the bus) for detection, had a less-than-optimal level of reliability. Additionally, having cameras on top of the bus meant that it was not possible to house the system in a single pod. The refined design has the radar situated near the other hardware, making it much easier to install and maintain. The radar system used was not independently tested for accuracy, however the vendor specifications indicate that they system is accurate to within 0.1 ft. No other system specific testing was conducted (e.g., for false positive, misses, etc) with the SODS.

CAMERA DETAILS

After reviewing the captured images from the initial system, NHTSA indicated that higher-resolution (and higher cost) cameras should be used. Additionally, it was determined that the system should be capable of capturing usable images when a violating vehicle was passing the bus at speeds up to 30 mph. Therefore, in addition to high resolution, the cameras had to have high shutter speeds.

The cameras used for the refined system were PixelLink color (PL-A662) and monochrome (PL-A660). The pod contained two cameras, one color and one monochrome, with similar vantage points facing forward, and two cameras facing to the rear. The cameras were digital high resolution (1.3 megapixels) that were software programmable (meaning that variable shutter speed, exposure time and capture resolution could be varied). Figure 28 shows the camera view from the forward-facing cameras. Figure 29 shows the view obtained from the rear-facing cameras. The color cameras and monochrome cameras were placed side by side in the pod and acquired images from similar vantage points.

Figure 28. Color and monochrome views from forward-facing cameras (12 mm lense); vehicle is traveling approximately 15 mph.

Figure 29. Color and monochrome views from rear-facing cameras (16mm lens); vehicle is traveling approximately 15 mph.

Field-of-view

Having the appropriate field-of-view was essential for capturing a single, clear image of both the driver's face and the license plate. The placement and focus of the cameras was chosen to maximize images taken of a violating vehicle in the lane immediately adjacent to the bus which was a recommendation made based on the results of testing the initial system. Figure 30 shows the field-of-view of the cameras. Lenses (Computar 12 and 16 mm C-Mount lenses) were chosen that would yield distinguishable face and plate images. The lens focus and field-of-view for the cameras allowed the capture of a clear image of the license plate and the driver's face in a single frame. Lens polarization filters were used during bright ambient light conditions to reduce glare so that a driver's face could be identified and not washed out by reflections on the windshield.

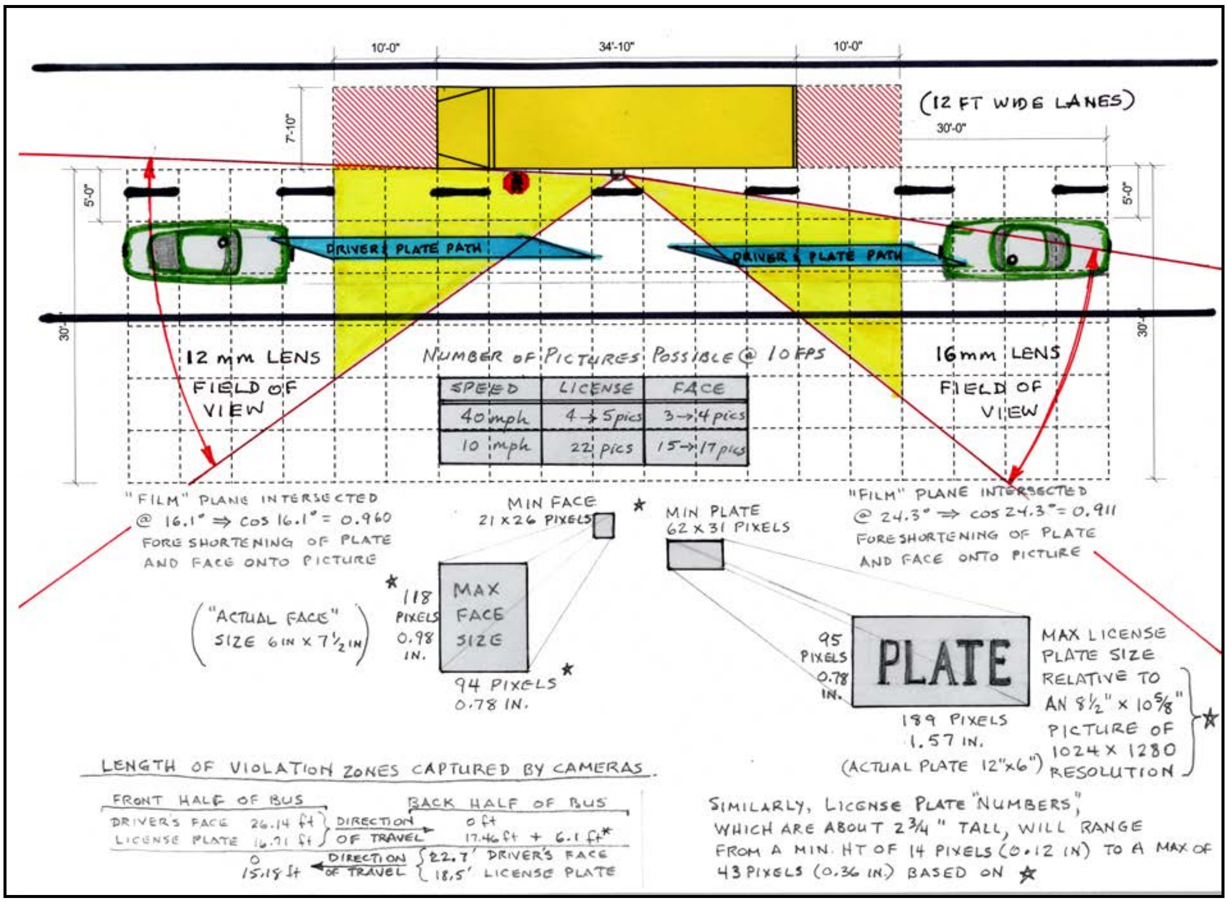

Figure 30. Field-of-view drawing for the forward and rear-facing cameras.

Wide-Angle Lens

The placement of two forward-facing and two rear-facing cameras captured images in two directions. One centrally located wide-angle camera was tested to capture a wide-angle view of a violating vehicle as it passed from the field-of-view of one set of cameras to field-of-view of the other set. The rationale behind this was to provide a view of the vehicle passing by the length of the bus. Testing indicated that the wide-angle viewpoint served to capture an overall passing view. However, the resulting video did not provide a distinguishable image of the license plate or of the face of the driver due to the use of a wide-angle "fisheye" lens. Although the wide-angle camera provided an overview of the scene, it did not provide any facial information or detailed license plate information. Figure 31 shows the view taken from the wide-angle camera.

Figure 31. Wide-angle camera view.

Nighttime Imaging

As noted in the Introduction to this chapter, the original system was not able to collect discernable images at night. To address this limitation, two HID spotlights were added to the refined system. However, as will be shown in the Results section, due to low light levels, capturing clear images of a driver's face was still not possible at night. Only the license plate could be captured at night which was a major improvement over the initial prototype.

Through informal testing, it was determined that the placement of the HID lights had to be such that the beam was directed at the same angle as the cameras. This ensured that the reflection from the license plate could be captured by the camera. Results from tests showed that if the light was not in line with the camera, the license plate was not readable. Figure 32 shows images acquired at night. Only the license plate and the vehicle's headlights were viewable at night and the license plate was legible without image post-processing. A red filter was placed in front of the HID light to reduce glare to oncoming drivers.

Figure 32. Color and black and white nighttime images (no polarization filter); vehicle is traveling approximately 15 mph.

Lens Filters

Cameras were tested with and without polarization filters. Without polarization filters, the driver's face could not be adequately captured due to reflected glare from the front windshield of the car. A polarization filter, which increases imaging through transparent mediums and is used in photography to reduce reflected glare, sufficiently reduced glare on the front windshield of the passing vehicle allowing the camera to capture the driver's face. There are several types of polarization filters used to reduce glare; the filters used in this study were high-performance circular polarization filters.

Using a polarization filter did not degrade imaging performance for most conditions; the exception to this was during darkness. Image capture at twilight and at night was degraded by the polarization filter by a factor of approximately two. This meant the exposure time of the camera had to be approximately two times greater to overcome the filter and to produce an image similar to one taken without a filter. Although darker, most images of the license plate in the lane adjacent to the bus were legible with use of the filter.

IMAGE POST-PROCESSING

Post-processing of images refers to improving the quality of the captured images using an image enhancement software program. *Adobe PhotoShop* was used for the initial prototype testing and *JASC Paint Shop Pro 8* was used for the refined prototype testing. In some cases, post-processing of a captured image was necessary to extract a high-quality usable image. Images of the license plate, from limited experimentation conducted, did not require post-processing (in either day or night conditions) for legibility. However, in some cases, post-processing was necessary to enhance the image of a driver's face to make it identifiable. Figure 33 shows an example of "before" and "after" images of a driver's face. Post-processing dramatically improved the facial image by lightening the image and modifying the contrast. As shown in Figure 34, only limited benefit from image post-processing was noticed for license plate images. There are two primary reasons for this. First, the license plates are not obscured by glass, as the driver's face is. Second, the ambient lighting at the license plate is similar to the ambient lighting at the camera, and not in a darkened cab like the driver's face.

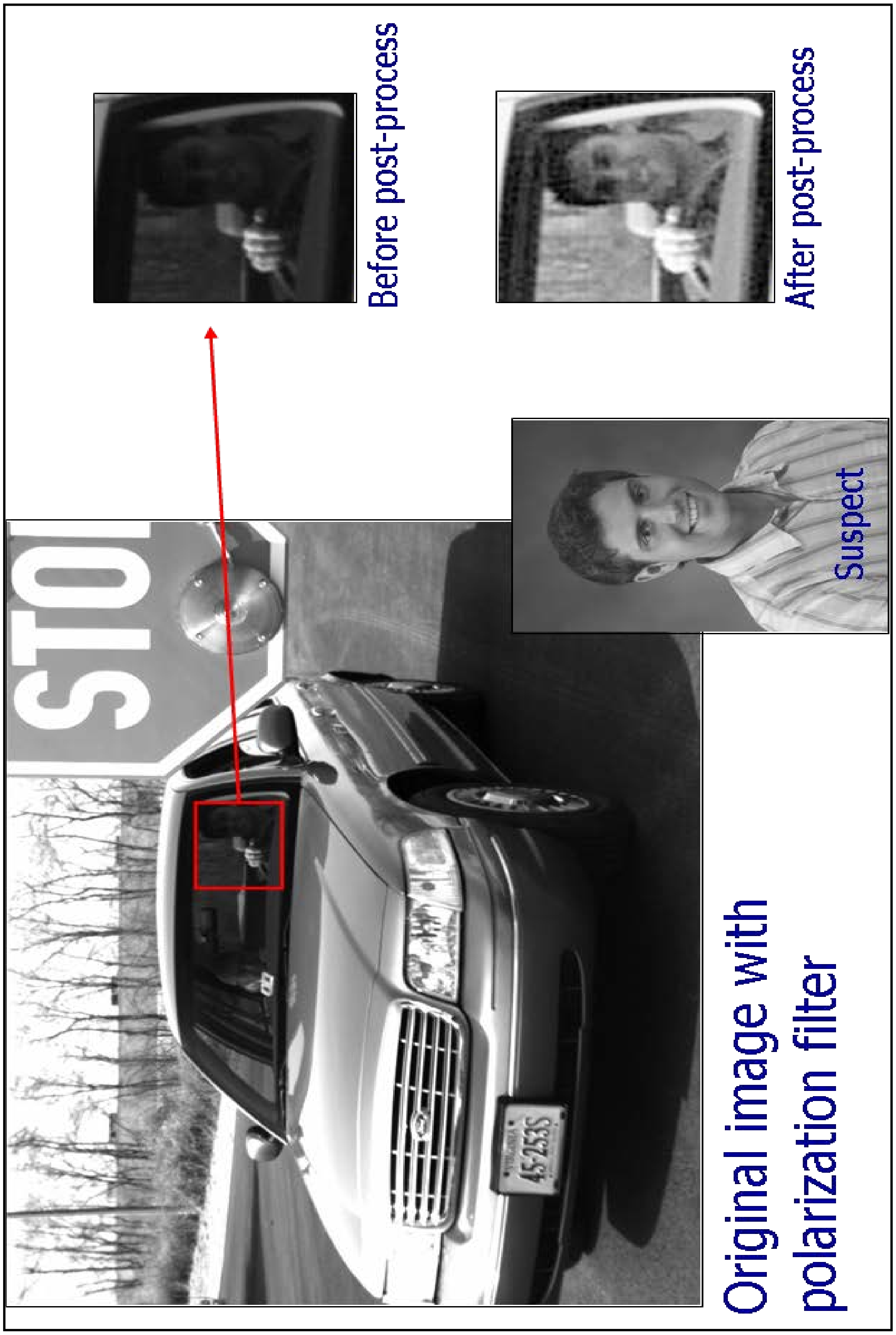

Figure 33. Post-processing of daytime black and white image.

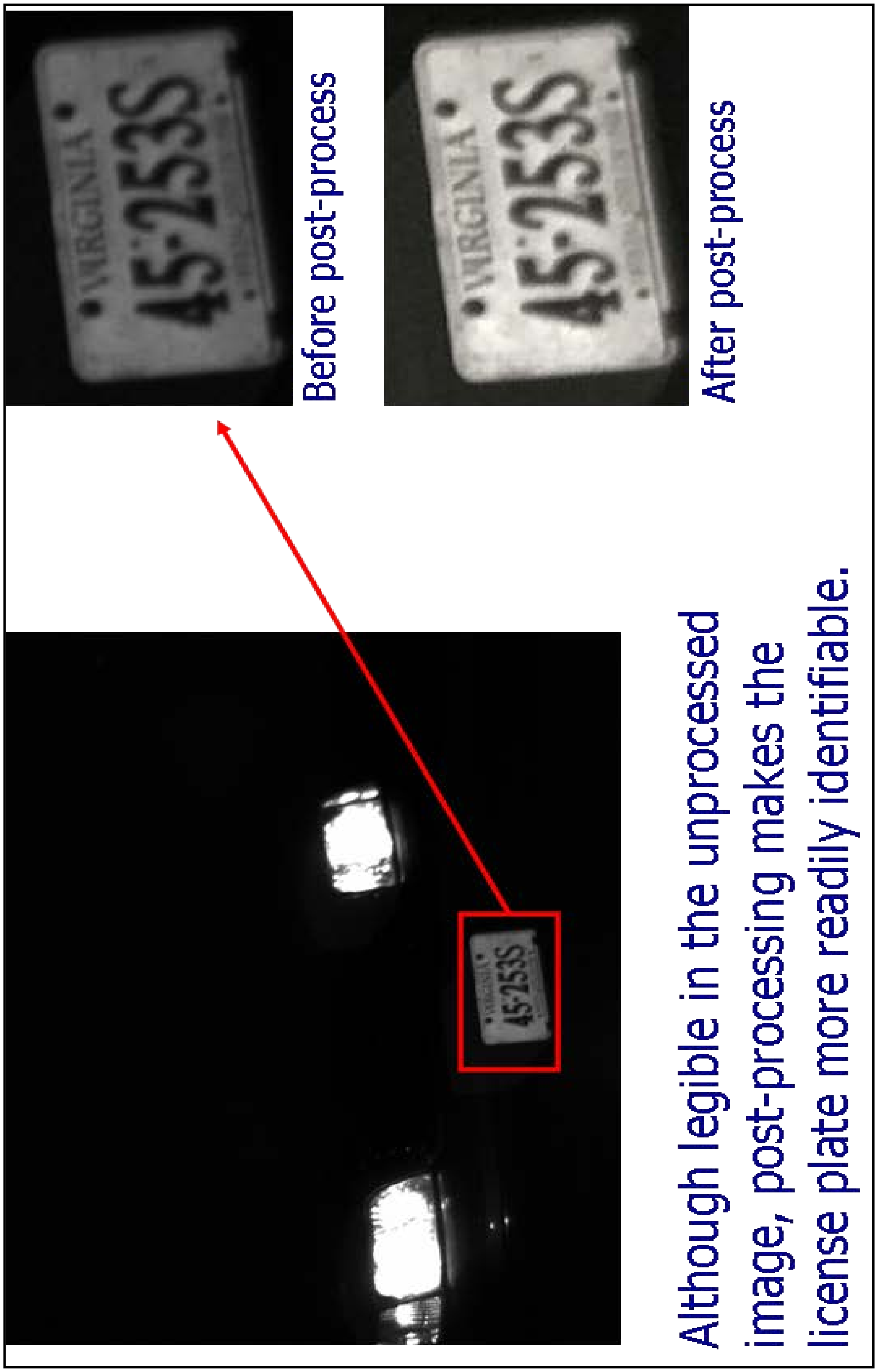

Figure 34. Post-processing of a nighttime image (without polarization filter).

INFORMAL TESTING METHODOLOGY

Limited experimentation was conducted for the refined prototype system. Although the original system developed included a formal experimental design, experiments conducted on the refined prototype system were of an informal nature and some results were subjective and based upon researcher opinion. Most of the experiments on the refined prototype were simple tests to determine whether or not the system functioned in certain conditions. That is, quick tests were conducted to make design decisions. An example of this is an experiment conducted at night to determine if a vehicle passing the bus in the immediately adjacent lane at 15 mph could be captured by the system, and to determine if the vehicle's license plate was legible. Although the majority of the testing was carried out at the VTTI, the high speed tests were carried out at the Virginia Tech/Montgomery Executive Airport. The tests were conducted to reflect naturalistic conditions, that is, the tests were carried out in conditions that the system would be subjected to in a field study. Future refinements would likely have to undergo additional experimentation before a field study with a deployed system could be tested.

Radar Testing Methodology

Although technically more capable than a camera-based approach to trigger violation events, the radar constraints for this application were unclear. Below is a list of issues and questions that were raised and tested to determine the feasibility of using radar for this application:

- Trigger speed: What were the upper and lower speed thresholds of a passing violating vehicle in order for the radar to trigger a violation? Violating vehicle speed was tested in increments of 5mph up to 40mph. Beyond 40mph, vehicle speed was increased to 55mph and 65mph. Due to the limitations of the experimental environment and the test vehicle, speeds beyond 65mph were not possible.
- Trigger distance: At what distance from the bus (e.g. how many lanes over from the bus) will the radar detect an object?
- Multiple road surfaces: How will the radar perform on various road surfaces such as asphalt and gravel?
- Inclement weather: How will the radar perform in rain?

Camera Testing Methodology

Although the cameras used in the refined system provided much higher quality images, an appropriate field-of-view, and faster shutter speeds as compared to the original system, it was necessary to determine the limits of these high-resolution cameras and whether the design could capture the necessary information. Several research issues and questions were investigated to determine the camera's limitations.

- <u>Image distance:</u> How far out from the side of the bus (how many lanes over) can the violating vehicle be before the system can no longer capture an identifiable image of the driver's face and the license plate?
- <u>Maximum speed for image acquisition</u>: What is the vehicle speed threshold in order to capture a distinguishable image that is readable and not blurry? This was captured for 5mph speed increments up to 40mph. Beyond 40mph, speeds of 55mph and 65mph were tested as well.
- <u>Lighting:</u> At what ambient light level would the cameras still be able to capture images of the vehicle's license plate and the driver's face? Ambient light level consisted of daytime (greater than 70 fc, 753.2 lux), twilight (between 5 fc, 53.8 lux and 70 fc, 753.2 lux), and nighttime (less than 4.5 fc, 48.42 lux).
- <u>Vehicle size</u>: With a narrow field-of-view in the lane immediately adjacent to the bus, can the cameras capture images of both the driver's face and the license plate for large vehicles?
- <u>Inclement weather:</u> How will the cameras perform in rain?

Post-processing Methodology

Although it may be possible to incorporate image post-processing into the violation viewing software, an off-the-shelf post processing application was used in the current study. The software program used was *Jasc Paint Shop Pro 8*. There are numerous off-the-shelf programs designed to post-process photographic images and the *Jasc* program is only one example. Although the *Jasc* program was found to be easy to use and produced quality enhancements, *Adobe Photoshop 7* was also tested and yielded filtered images of a similar quality. Also noteworthy is that each program required a similar set of functions to achieve these comparable results. The next section outlines the steps involved in post-processing an image using the *Jasc* software.

The time necessary to process an image depended upon the quality of the original image and was typically varied for many of the images. Images requiring a small amount of refinement tended take approximately 5 to 10 minutes. Images requiring extensive refinement tended to take much longer to post process (sometimes greater than 20 minutes).

Process Steps

- Import/open the selected image into the program.
- Enlarge the portion of the image containing the driver of the vehicle. This can be done by either using a "magnifying glass" tool or the "zoom-in" command.
- Select an area of the windshield. Either the "rectangular" selection tool or the "magic wand" set to 50% tolerance can be used to select an area around the driver.
- Adjust the key tone levels. The brightness and contrast of the selected area could be adjusted using the automatic control, or manually by increasing the brightness and contrast to appropriate levels. A tool to adjust the key tone levels involves moving arrows along the bottom of a histogram continuum (Figure 35). This action lightens or darkens the image, or increases or decreases the image contrast levels. For color images, a similar tool can be used to adjust the color level, or each individual color channel (red, green, or blue) in the image.

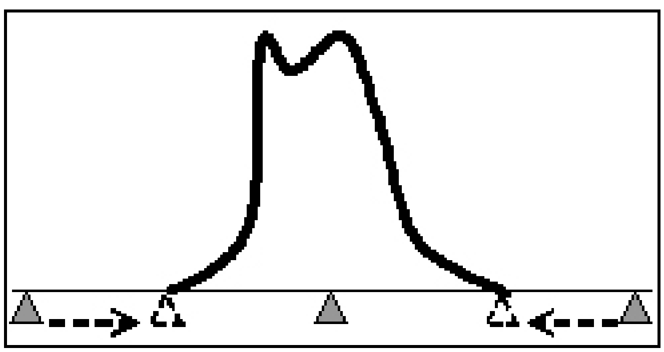

Figure 35. Example of adjusting image key tone levels by moving arrows along histogram.

Color and contrast levels may vary from image to image depending upon ambient light conditions. Therefore, each image presents a different contrast range or color gamut to adjust. Adjusting the input levels reduces the overall gamut, enabling the image to have a wider and more visually distinguishable contrast range. Since some images already have a very wide contrast range, increasing the range may not give the desired result. By selecting a smaller part of the image, such as the driver's face, the contrast range is much narrower, and increasing the range brings out features of the image not previously seen. The result of this adjustment was shown previously in Figures 33 and

34. The pre-processed image in Figure 33 shows an unidentifiable face; post-processing increases the contrast range which enables the driver's face to become identifiable.

If necessary, the sharpness of the image can be increased by using the "adjust sharpness" tool. In *Jasc*, this tool has several settings. One added enhancement is a "texture preserving edge smooth" tool which can help reduce the noise while still preserving the image.

For color images, it was necessary to adjust the color level by selecting the color adjustment tool with either "automatic adjustment" or manual adjustment and selecting RGB values separately. Whereas black and white images only required adjustment of brightness and contrast levels, color images required the overall adjustment of brightness, contrast, and color gamut, along with the adjustment of brightness and contrast for each of the color channels (red, green, and blue).

Before and after post-processed images can be seen in Figures 36 and 37. Figure 36 shows a color image of the drivers face before and after post-processing. Before it is post-processed, the driver's face is unidentifiable, whereas after image post-processing, it is much more identifiable. Figure 37 shows a black and white image of the driver's face before and after post-processing. Since there is no color and only brightness and contrast are adjusted, the image is much cleaner after post-processing. For both cases, it was necessary to have polarization filters on the cameras to acquire a usable face image for post-processing.

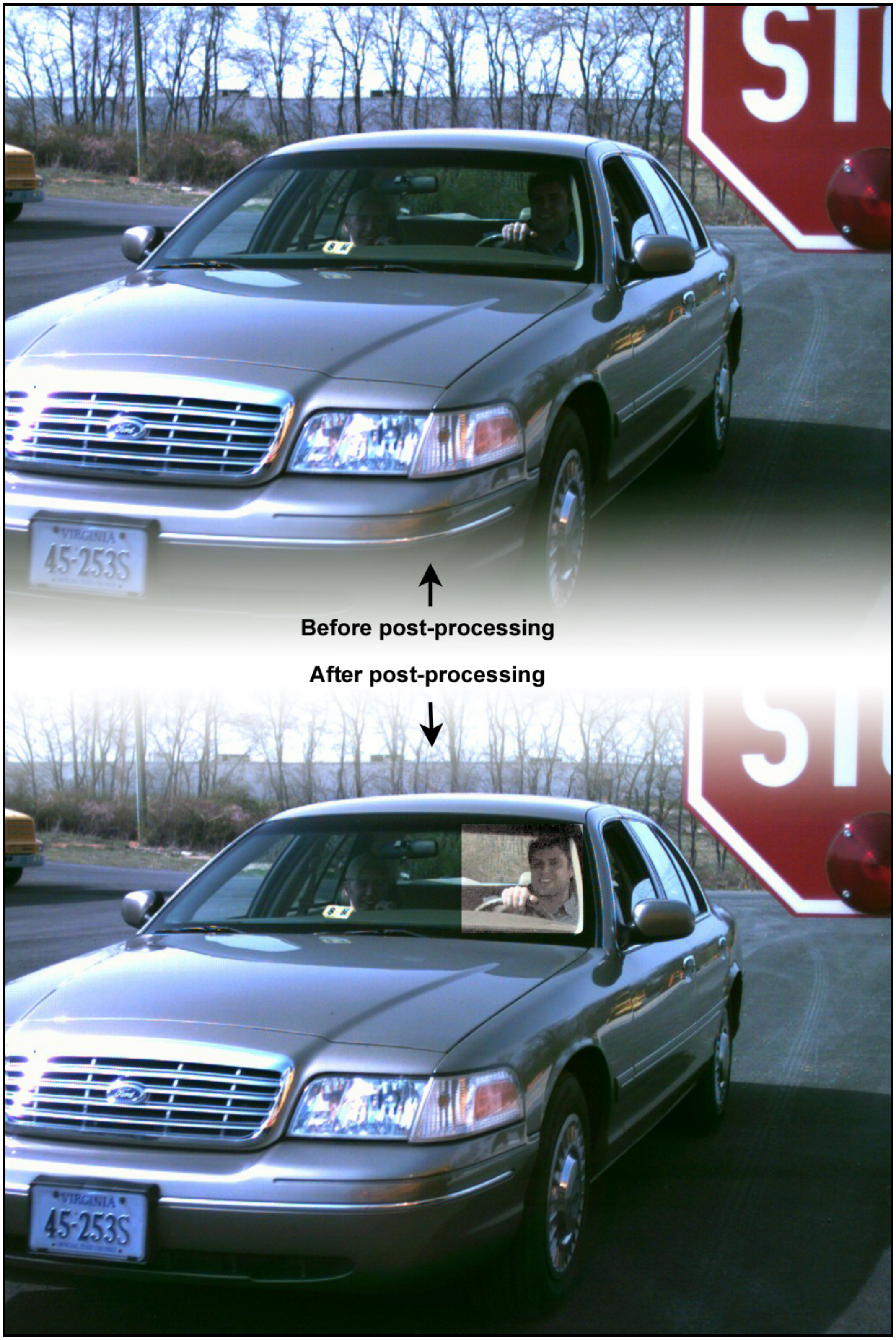

Figure 36. Before and after post processing of a color image; vehicle is traveling approximately 15 mph.

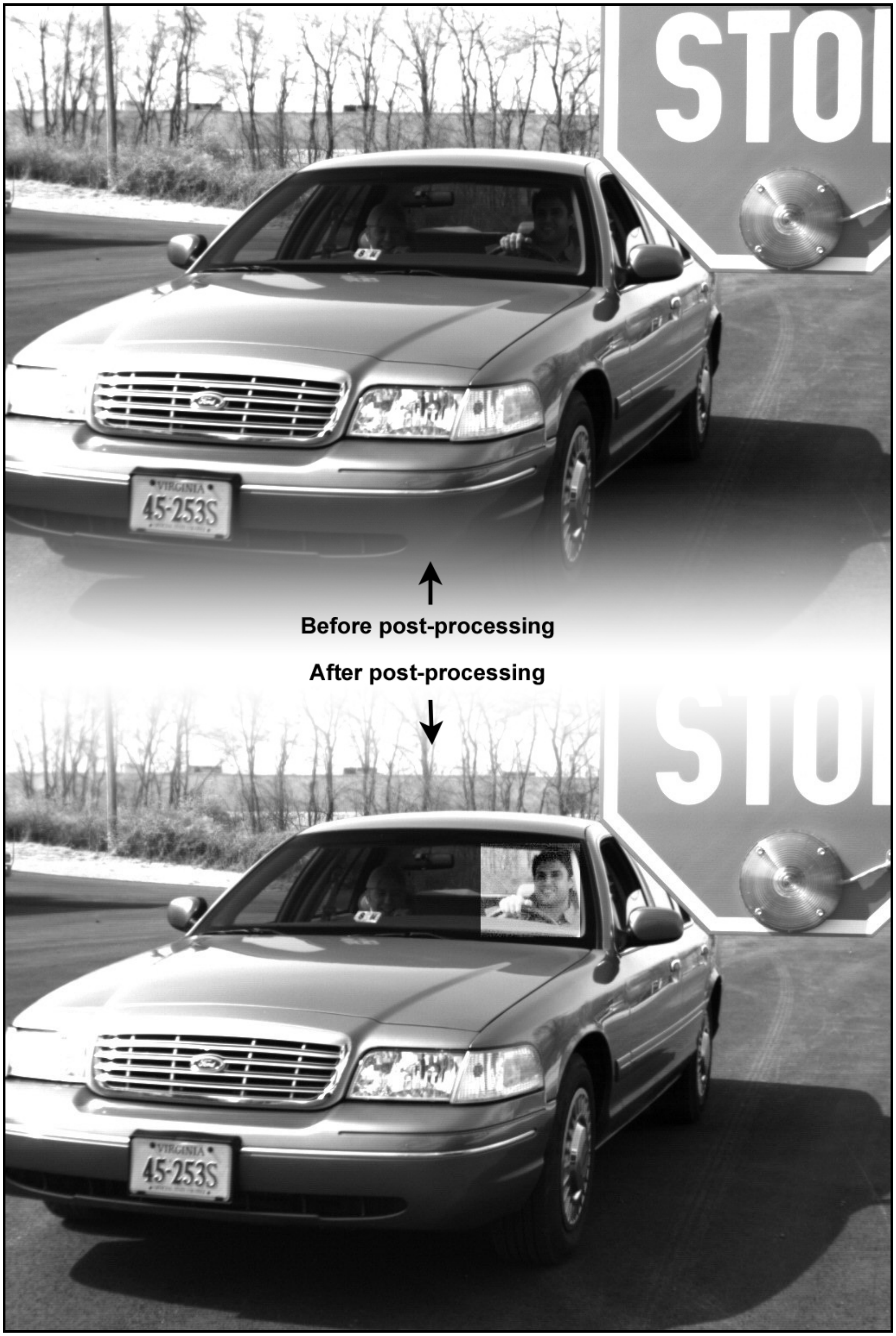

Figure 37. Before and after post-processing of a black and white image; vehicle is traveling approximately 15 mph.

RESULTS AND DISCUSSION

The results from the refined system testing are presented in three sections. First, the radar test results are presented. Second, camera tests including license plate and facial image quality results are presented for both daytime and nighttime conditions. Third, other interesting findings and conclusions are discussed.

RADAR RESULTS

Researchers examined the effectiveness of the radar in multiple conditions. Conditions that were tested included trigger speeds, trigger distances, multiple road surfaces, and weather.

The focus of the first examination was finding the range of speeds with which a violating vehicle would trigger the radar. During daylight hours, a vehicle was driven alongside the bus in the adjacent lane at speeds ranging from 5 mph to 65 mph. Speed increments were 5 mph up to 40 mph and tests with speeds $\leq$ 40 mph were conducted in a VTTI lot. Beyond 40 mph, speeds of 55 mph and 65 were tested and these tests were conducted on a runway at the Virginia Tech/Montgomery Executive Airport. The vehicle initiated these speeds beginning from behind the bus and passing by (Overtaking) and beginning from in front of the bus and passing by (Oncoming). The radar triggered as expected for every speed tested, from both Overtaking and Oncoming directions.

The focus of the second examination was to determine distances perpendicular to the bus in which the radar would trigger (e.g. how many lanes over from the bus would the radar trigger). A vehicle was driven alongside the bus in the adjacent lane, second lane, and third lane from both directions (Figure 38). To keep the speeds consistent throughout testing, using a reasonable and safe passing speed, vehicle speed was kept at 15 mph. The radar triggered reliably for each lane, when the violating vehicle was traveling from both Overtaking and Oncoming directions.

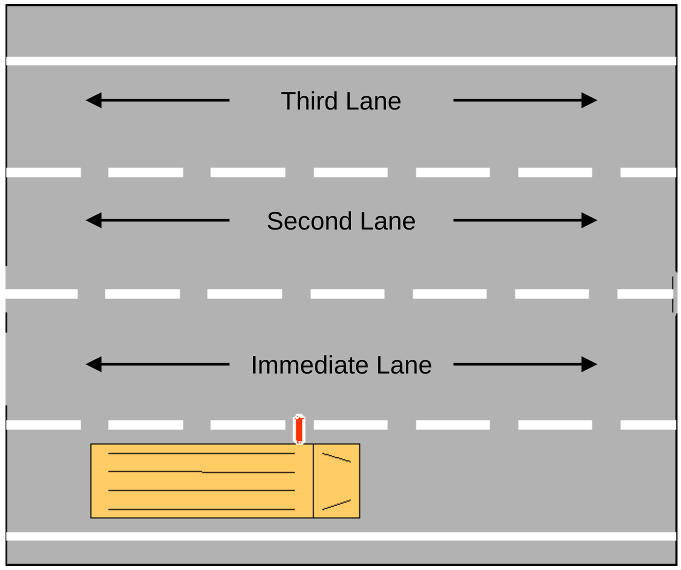

Figure 38. Radar triggered as vehicles passed by in the immediately adjacent, second, and third lane from the bus.

The third condition tested was different road surfaces. Testing began on an asphalt road surface. An oncoming vehicle was driven past the bus, in the immediately adjacent lane, at 10 miles per hour. After expected radar triggers were obtained and plots were recorded, testing on a gravel road surface was then conducted in the same manner. Results showed that the radar tracking in the asphalt condition (Figure 39) was cleaner (less interference) than the gravel condition (Figure 40). The figures show a violating vehicle driving past a parked school bus from front to rear. The vertical axis is distance to the target and the horizontal axis is time. The blue line shows the vehicle approaching the bus (and radar) from the oncoming direction, and the pink line shows the vehicle departing (on the other side of the radar). The radar had 7 beams that covered approximately 180 degrees. Beam 1 (in blue) faced towards the front of the bus and Beam 7 faced towards the back of the bus. In the figures below, the blue line shows the radar capturing is the approaching front bumper of the violating vehicle and the pink line is the receding rear bumper. The slope of the lines represents the speed of the vehicle as it passed. The noisy area in the middle of the plots represents the radar capturing the side of the vehicle as it passed by the sensor. The curve in Figure 39 shows the system working well on asphalt. However, in Figure 40, a test of the radar on gravel, it appears that the radar was picking up the rough gravel surface.

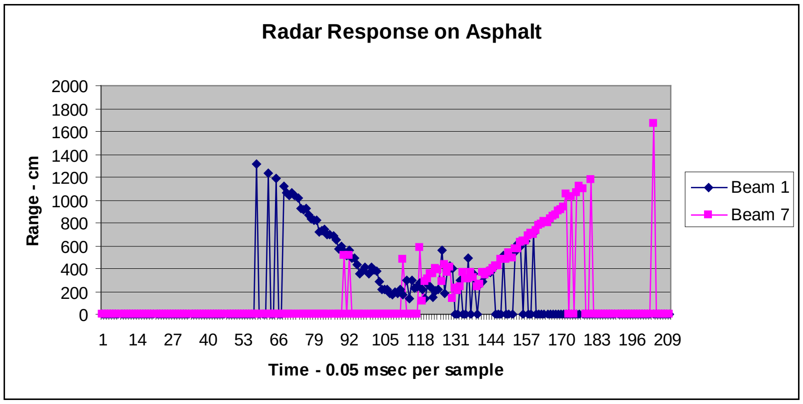

Figure 39. Radar view across asphalt lot – note symmetrical response in both beams (Beam 1 is to the front of the bus and Beam 7 is to the rear). Radar ~ 2 feet from ground and perpendicular to the ground.

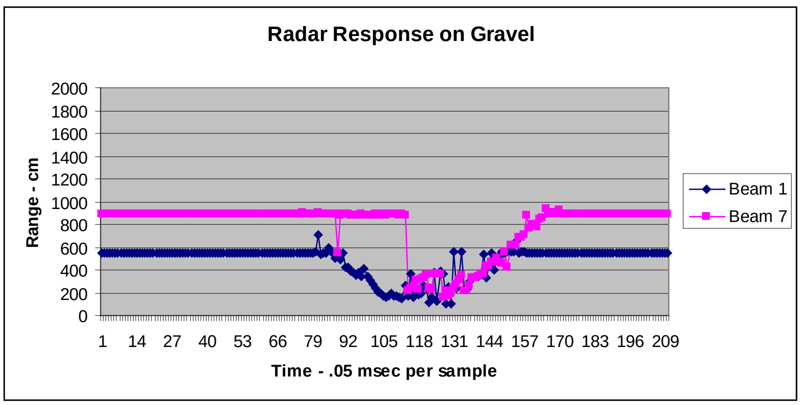

Figure 40. Radar view across gravel. Note the "floor" of ~600cm and ~900cm for the radar beams (Beam 1 is to the front of the bus and Beam 7 is to the rear). Speculation is that radar detected the gravel.

After examining radar plots in the gravel condition, the radar was re-positioned at a slight upward angle such that the trajectory of the beams was slightly higher. The experiment was conducted again with results very similar to the asphalt condition (Figure 41). The conclusion from these tests was that triggering violating vehicles using radar is feasible, as long as the radar units are adjusted appropriately. It is important to note that the radar units used in this experiment were not developed for this particular application. However, discussions with the vendor indicated that a radar unit could be developed specifically for this application. It is recommended that this should be investigated for future system development efforts.

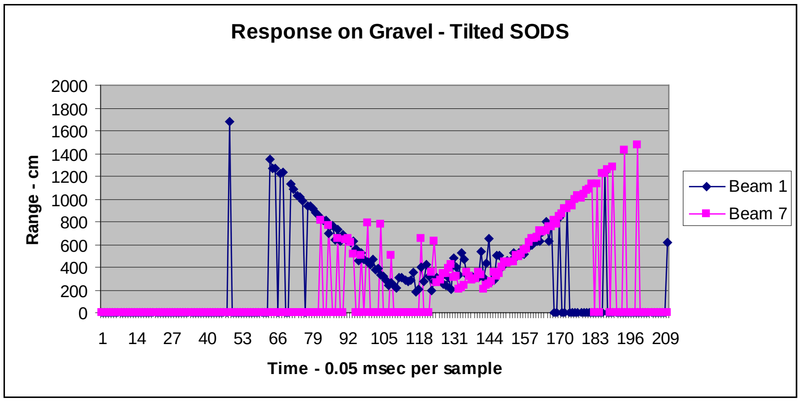

Figure 41. Radar tilted back ~15 degrees. Note that the "floor" disappears and the return is similar to "ideal" case on asphalt as shown in Figure 39 (again, beam 1 is to the front of the bus and beam 7 is to the rear).

In the fourth test condition, the radar was tested in inclement weather (i.e., rain). The amount of rainfall on the days that the radar was tested varied from a light drizzle to a heavy downpour. In light to moderate levels of rain, the radar triggered passing vehicles when expected. However, when the rain was very heavy, passing vehicles were not detected by the radar.

CAMERA RESULTS

Tests were conducted under various conditions to assess the quality of captured images. The conditions tested included distance, lighting, vehicle size, inclement weather, multiple vehicles, and day/night.

The first set of tests investigated the impact of distance (from the bus/camera to the object) on image quality. A vehicle was driven past the bus in distance increments of 5 feet from the system to a maximum of 30 feet. Distance measurements were recorded by setting up marks directly out from the prototype system. The vehicle moved past the system at 15 mph so that the license plate was in-line with the road markings (Figure 42).

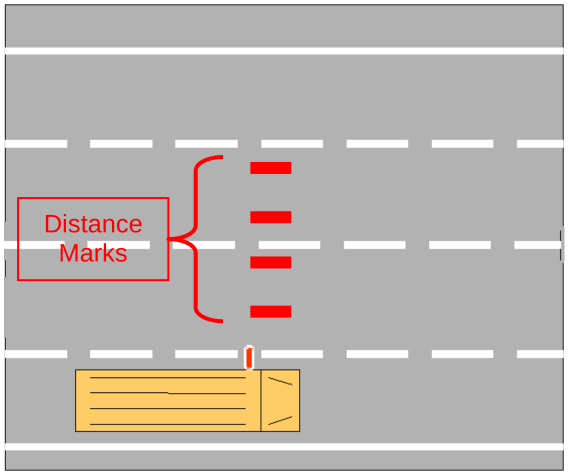

Figure 42. Mark positions for distance testing of quality image captures.

Results for the daytime tests indicated that legible license plate images and discernable facial images could be acquired at distances up to 20 feet from the system (approximately two lanes from the bus). As shown in Figure 43, if the entire vehicle stayed within two lanes of the bus, then obtaining quality license plate and facial images (with the use of post-processing as necessary) was possible.

Figure 43. Violating vehicle at 10 feet from system (left picture), and same violating vehicle at 20 feet from the system (right picture). Vehicle is traveling approximately 15 mph.

Nighttime testing results showed that acquiring readable license plate images required the distance of the vehicle to be no more than 15 feet from the system (Figure 44). With a distance of more than 15 feet, the license plate was no longer in line with HID lights, thereby degrading the image beyond recognition.

Figure 44. Fifteen feet from system at night with post-processed license plate.

A second set of tests was performed to determine how image quality was affected by different levels of lighting, glare, and headlight interference. Light from the sun affects the image quality of the system in two ways. If the sun is low, either at dusk or dawn, and it aligns directly with the license plate of the violating vehicle, the license plate can be washed out allowing only partial to no recognition (Figure 45).

Figure 45. License plate washed out from sun; color and monochrome cameras.

Also, the sun can add glare to the windshield of the violating vehicle. To combat this glare and obtain a quality facial image, polarized lenses were used on all cameras. This reduced the windshield glare allowing a facial image to be obtained (Figure 46). Although polarized filters are useful for daytime conditions, they create a problem for nighttime conditions. These filters need to be removed from the cameras to acquire quality images in low ambient conditions (twilight, nighttime). The images shown in Figure 46 show a profile shot of the driver and are only shown here as an example of the increase in quality with the use of polarized lenses. Profile shots were not used in this study and it is recommended that they not be used with future systems. It was determined in testing with the original system that attempting to capture a profile view through the side window was not reliable.

Figure 46. Facial image quality improved with the use of polarized lenses.

The potential impact of headlights on image quality was also tested. Researchers were unaware if headlights from the violating vehicle and/or other vehicles would degrade the image quality of facial and license plate images. This was of particular concern in the twilight period of the day (between 5 fc, 53.8 lux and 70 fc, 753.2 lux). Headlights are not a factor during the daytime, and facial images cannot be captured at night. A handheld light meter was used to determine light levels during the twilight tests. A stationary vehicle was positioned two lanes out from the system, as shown in Figure 47.

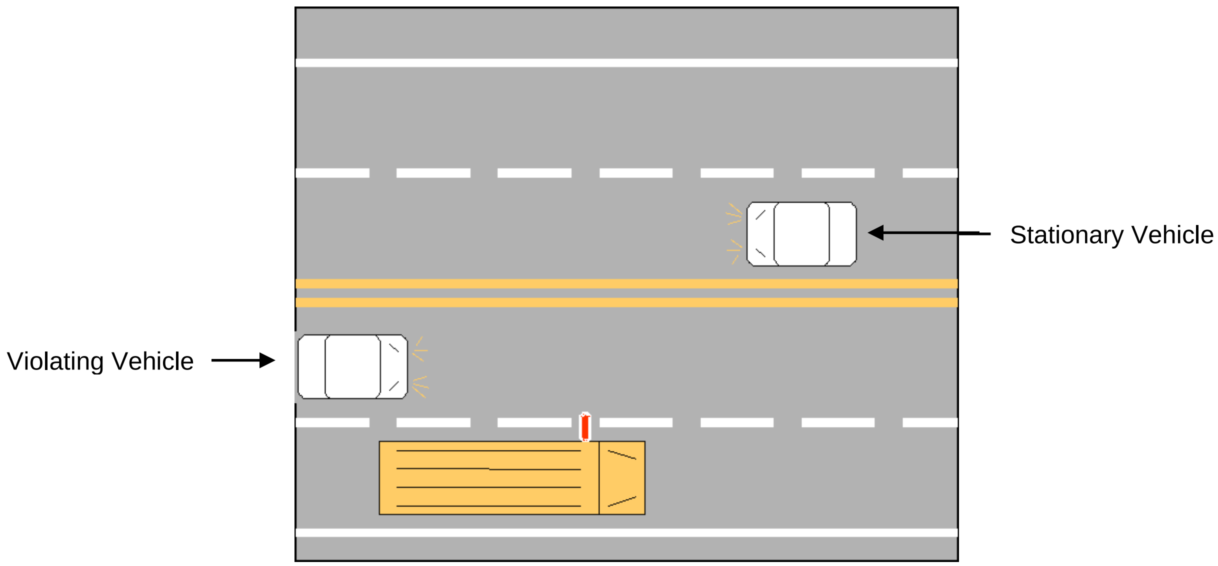

Figure 47. Vehicle position for headlight interference testing.

A violating vehicle was driven between the bus and the stationary car. The stationary vehicle's headlights were turned on, and tests were conducted with both low and high beams. The violating vehicle passed with its lights on and then off across both of the stationary vehicle's headlight conditions. Findings indicated that headlights can indeed cause interference for the cameras at twilight. The violating vehicle's headlights caused interference in the image by overdriving the image sensor on the camera. In these twilight conditions, it was difficult to extract a quality facial image (Figure 48). The results showed that capturing a quality facial image was possible at twilight as long as there was no headlight interference. However, if headlight interference was present, a facial image was not identifiable. It is important to note that the presence of headlight interference did not have any adverse effects on license plate image quality.

Figure 48. No headlight interference (left) and headlight interference (right). Headlight interference from the violating vehicle and/or other vehicles can degrade facial image quality, but has no noticeable impact on license plate image quality. Violating vehicle is traveling approximately 15 mph and the secondary vehicle is stationary.

Tests were conducted with vehicles of different sizes to determine the impact that the height of a vehicle might have on capturing license plate and facial images. Facial images were of particular concern as the height of a windshield generally impacts the visibility of the driver inside that vehicle. If a driver is sitting in a high profile vehicle, will the camera be able to capture a facial image? Three different vehicles, with varying heights, were tested to determine the maximum threshold for capturing the face of a violator. The top of the windshield was measured on a 1985 Ford Bronco (68 in, 172.72 cm), a 1999 Nissan Pathfinder (61 in, 154.94 cm), and a 1999 Ford Crown Victoria (53 in, 134.62 cm). The three vehicles were driven past the bus in the immediately adjacent lane. The closer the vehicle is to the bus, the smaller the field-of-view becomes due to the lens angle (the immediately adjacent lane is the closest to the camera vehicle height and may not be as limited in adjacent lanes farther away from the bus). Results showed that the highest windshield (68 in, 172.72 cm), was near the limit in which a quality facial image could be captured. As shown in Figure 49, it would be difficult to acquire a full-facial image for any vehicle with a windshield higher than 68 in, 172.72 cm.

Figure 49. Facial image capture at maximum height of 5 feet 2 inches. Vehicle is traveling approximately 15 mph.

Image quality was also assessed in inclement weather. The testing described up until this point was conducted in dry weather. Due to the season in which testing occurred (spring), the only available inclement weather for testing was rain. The results indicated that, after making multiple passes by the bus and acquiring many license plate and facial images, rain did not affect the quality of the captured images (Figure 50). In some frames of the video, windshield wipers would block the view of the face, but the software developed for the project allowed for the selection of frames in which the wiper was not blocking the driver's face.

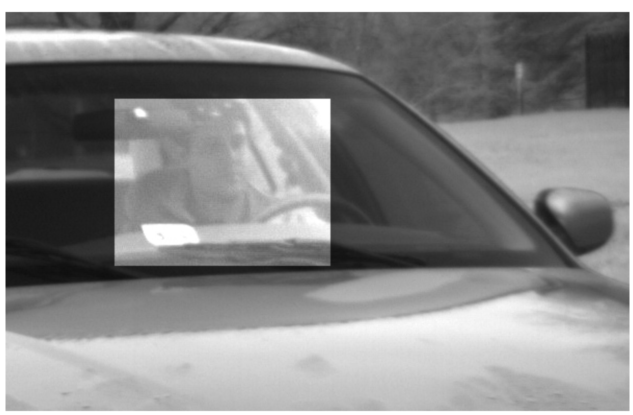

Figure 50. Rain did not noticeably affect facial image quality. Vehicle is traveling approximately 15 mph.

During the testing, the question of how would multiple violating vehicles impact system operation was raised. That is, can the system handle multiple violating vehicles? Testing was performed with two violating vehicles, the secondary vehicle following at distances ranging from one to five car lengths. The test results showed that the radar system re-triggered quickly on the secondary vehicle. However, depending on the distance between vehicles, the camera capturing program may not refresh in time to record the secondary vehicle. Note that the system takes approximately as long to process acquired images as it does to capture them. For example, if the capture time is set to 10 seconds, the processing time will take approximately 10 additional seconds. Therefore, all vehicles that pass by within the first 10 second window will be captured. However, vehicles passing during the 10 second processing period will be missed. Though the radar will re-trigger almost instantly, the limiting factor is the image processing software. Future technology may reduce processing time and will not be as limiting as current technology.

SUMMARY OF RESULTS

Summaries of the test conditions, the results of these tests, and general acceptability ratings are shown in Tables 60 and 61. As can be seen, the system functioned as intended in most conditions. Conditions in which the system did not perform as intended included heavy rainfall, excessive sunlight glare on the license plates, and multiple violating vehicles passing after the initial capture interval. It should be noted that the testing did not include all conditions that a bus might encounter in the real-world. For example, testing did not occur in snow or foggy conditions. Follow-on development and testing work should include testing the system in conditions that will be encountered in real-world situations. Experimentation may be further reduced in a future system; however, some tests may have to be repeated to determine limitation and constraints of potentially different technology.

Table 21. Radar test conditions and associated results

Radar Conditions	Results
Capture Speeds- Examination of the range of speeds of a violating vehicle that would trigger the radar. Range tested: 5 mph – 65 mph.	The radar triggered at each speed conducted from both directions.
Capture Distances- Examination of distances perpendicular to the bus in which the radar would trigger. Range tested: Lanes 1 – 3.	The radar triggered for all 3 lanes tested from both directions.
Road Surfaces - Examination of radar operation on asphalt and gravel. Testing began on an asphalt road surface. After radar triggers were obtained and plots were recorded, testing on a gravel road surface was then conducted in the same manner.	Results showed that the radar tracking in the asphalt condition showed less interference than the gravel condition. After examination of the radar plots, researchers adjusted the position of the radar and changed the trajectory of the beams to a slightly higher angle. Additional tests were conducted and the results from the gravel surface were then similar to that from the asphalt surface.
Weather - Examination of radar operation in different weather conditions. Testing was performed in low to heavy rain.	Heavy rain was shown to have negative effects on the radar (passing vehicles were not detected). In low to moderate amounts of rainfall, the radar detected violating vehicles consistently with very good radar plots.

Table 22. Camera test conditions and associated results

Camera Condition	Daytime Results	Nighttime Results
Image Distances – Examination of distances to acquire quality images of the license plate and face. A vehicle was driven past the bus in distance increments of 5 feet from the system.	Results for daytime acquisition indicated that legible license plate images and high quality facial images can be acquired at distances up to 20 feet from the system (approximately 2 lanes from the bus). At this distance, obtaining quality license plate images is possible, as well as obtaining quality facial images with/with out the use of post-processing.	For nighttime acquisition, results indicate that acquiring sufficient license plate images requires the distance to be no more than 15 feet from the system. Any further than this and the license plate is no longer in line with lights, thereby degrading the image beyond recognition. Facial images are not available at night.
Sunlight on Plate – Examination of effects from sunlight on the image quality of the license plate.	If the sun is low, either at dusk or dawn, and it aligns directly with the license plate of the violating vehicle, the license plate can be washed out allowing partial to no recognition possible.	*NA*
Glare – Examination of windshield glare.	To combat windshield glare, and to obtain a quality facial image, polarized lenses were used on all cameras. This reduced windshield glare, allowing a facial image to be obtained.	Although filters proved useful for daytime conditions, they create a problem during nighttime conditions. Filters need to be removed from the cameras in order to acquire better images during twilight and the nighttime.
Headlight Interference - Examination of headlight interference. Twilight was the specific area of examination.	Findings indicate that headlights can cause interference for the cameras at twilight. Therefore, capturing a quality facial image is possible at twilight as long as there is no strong headlight interference. If headlight interference does occur, only a license plate image may be able to be extracted.	*NA*
Vehicle Size – Examination of vehicle size and its effects on license plate and facial image captures. Face heights	Results showed that the highest facial height, 5’ 2” was sufficient enough to capture a quality facial image. It will	

were measured in a 1985 Ford Bronco, a 1999 Nissan Pathfinder, and a 1999 Ford Crown Victoria. Face heights included 5’ 2”, 4’ 6”, and 4’ 0”, respectively.	likely be difficult to acquire a full facial image for heights greater than this.	*NA*
Weather – Examination of image quality in an inclement weather condition. Due to the season, only rain was tested.	Rain did not affect the quality of the images obtained. Occasionally, windshield wipers blocked the view of the face, but the available software for the system allows for the selection of different frames in which the wiper is not blocking line of sight.	*NA*
Multiple Vehicles – Examination of a multiple vehicle situation where more than one vehicle illegally passes the bus in unison. After the system captures a vehicle, it was uncertain as to the ability of the prototype system to capture a second passing vehicle. Testing was performed with two violating vehicles, the secondary vehicle following at distances ranging from one to five car lengths.	The radar system retriggered quickly on the secondary vehicle, however the camera capturing takes too much time to refresh thereby creating a problem in capturing the secondary vehicle. For example, if the capture time is set to 10 seconds, the processing time will take approximately 10 additional seconds. Therefore, secondary vehicles passing the triggering vehicle traveling within this 10 second window will be captured by the system. However, secondary violating vehicles that pass during the processing time will not be captured (though radar of the passing will be recorded).	No difference between day and night conditions.

CONCEPTUAL POD DESIGN

In the testing reported here, the refined system, shown in Figure 51, was enclosed in a simple Plexiglas housing that was not securely locked or designed for use in severe inclement weather conditions. As shown in Figure 52, Brooks Stevens Design created a conceptual prototype enclosure in which the system could be housed. This pod, designed to contain the components of the system, could be manufactured to be weather-hardened and lockable in order to keep the system safe. Furthermore, the pod is aesthetically pleasing and works well with the general bus design. Note that at this time, this pod is simply a concept drawing. However, the designer has indicated that it could be fabricated for production purposes. Figures 53 and 54 show the refined system and the conceptual pod side-by-side. This is intended to show that the pod would contain all system components. Because the Brooks Stevens Design pod is conceptual, it should be noted that the final version may be slightly different than the pod shown here. For example, the current conceptual pod has tinted glass panels in front of the camera lenses; this may be modified if the tinting degrades the quality of captured images. Additional experimentation would be required, and in some cases repeated, for further refinements such as this. At this time, it is uncertain what effect the pod enclosure would have on system performance.

Figure 51. Bus with existing refined system.

Figure 52. Bus with conceptual prototype pod.

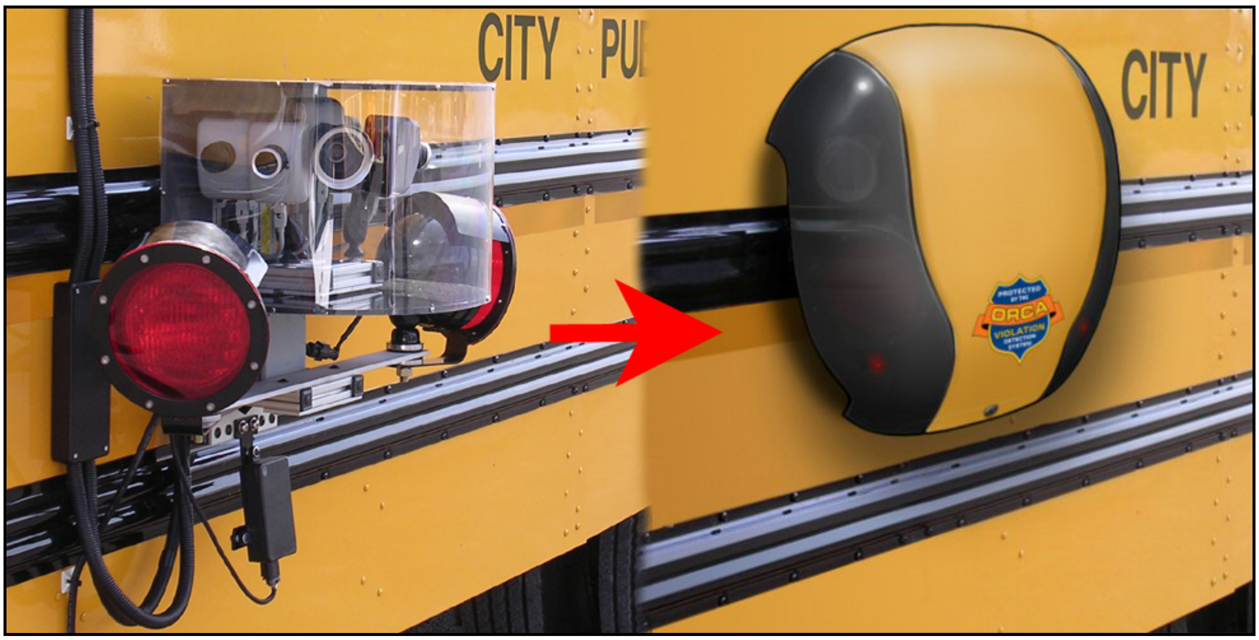

Figure 53. Existing refined system and conceptual prototype pod.

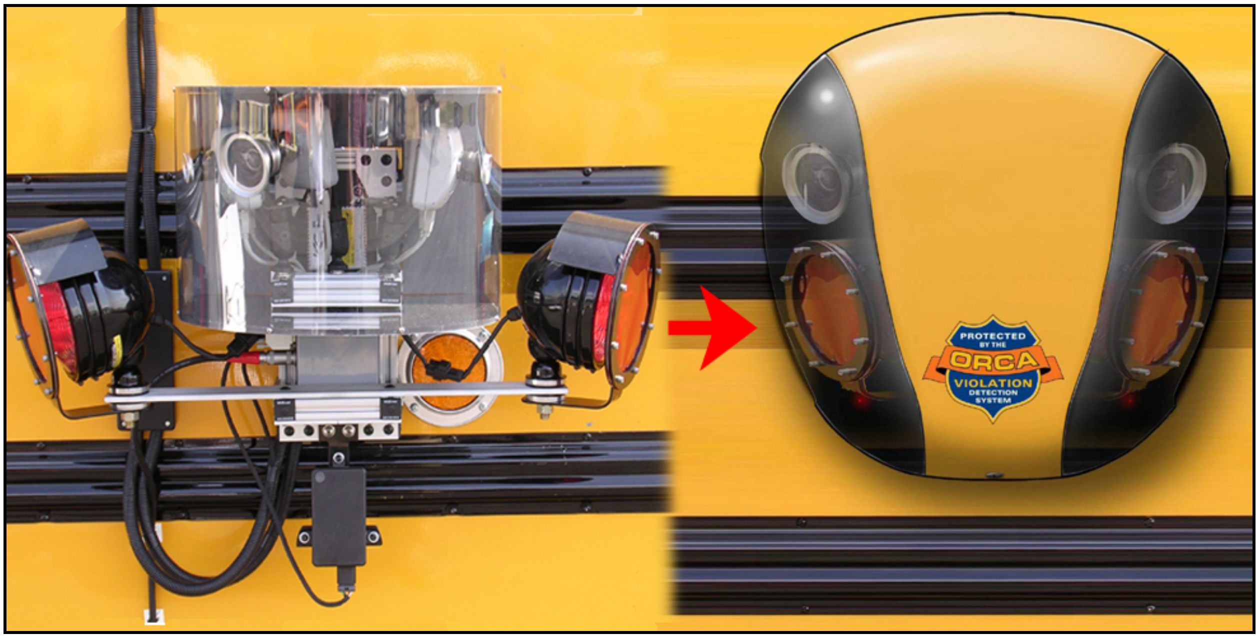

Figure 54. Existing refined system and conceptual prototype pod (beneath the tinted glass covering, the HID lights and camera lenses can be seen).

REFINED PROTOTYPE SYSTEM DEMONSTRATION

PURPOSE

A demonstration of the refined prototype system was held to ensure the system's functionality. The purpose of the demonstration was to provide government officials and other interested experts with an overview of the capabilities of the refined prototype system. The demonstration was held at the Turner Fairbank Research Center in McLean, Virginia on April 28, 2004. Officials from organizations such as NHTSA, FHWA, local school system personnel, and local police department personnel were in attendance. The demonstration consisted of a school bus containing the refined system parked along a two-lane road, whereby a driver in a car could pass the bus and be captured by the system.

DEMONSTRATION PROTOCOL

The demonstration was held on a day with very heavy rain. The prototype was not designed to work in severe weather conditions, therefore, the inclement conditions, involving very heavy periods of rain and limited visibility, tested the system to its limits. Even though the environmental conditions were very poor, the system functioned and was able to capture images and video of a violating driver.

Two monitors (one on each side facing the rear) were installed inside the bus and viewable by the passengers. Monitors were mounted on tripods and placed so that everyone seated on the bus was able to see the system in operation. The violating vehicle passed the bus at 15 mph and again at 25 mph from both the rear (Overtaking) and front (Oncoming) directions. Radar was triggered and the violating vehicle was recorded. The event was loaded into the viewing software and video of the violation capture was displayed. Clear images of the driver's face and license plate were seen. In addition, post-processing software (*Jasc Paint Shop Pro*) was used to enhance images of the violating vehicle.

DEMONSTRATION RESULTS

Examples of the resulting images from the demonstration are shown in Figures 55 and 56. Figure 55 shows before and after post-processing of a black and white image of the violating vehicle. Figure 56 shows before and after post-processing of a color image. These photos show that although conditions were very poor, it was still possible to obtain a clearly identifiable image of the violating driver's face and the license plate.

Figure 55. Black and white image of a violating vehicle taken in rainy weather. Violating vehicle is traveling approximately 15 mph.

Figure 56. Color image of a violating vehicle taken in rainy weather. Violating vehicle is traveling approximately 15 mph.

DEMONSTRATION SUMMARY

The demonstration audience was able to view the refined prototype system in full operation. The audience witnessed that the system was capable of capturing violating vehicles in inclement weather conditions yet still recording clear images of the license plate and the driver's face. Attendees were able to view the entire process from beginning to end, starting with the passing violation and ending with a viewing of captured images with a legible license plate and identifiable face. Attendees of the demonstration were vocally positive about the demonstration, receptive to the work conducted, and indicated support of further research, development, and testing.

CHAPTER 7:

SUMMARY, CONCLUSIONS AND RECOMMENDED NEXT STEPS

PROJECT SUMMARY AND CONCLUSIONS

The purpose of this project was to address the problem of illegal school bus passing by developing an automated system that would record the driver's face and license plate of illegally passing vehicles. Before this development work could be conducted however, an effort was required to determine the feasibility of developing such a system. This work was co-conducted by the VTTI and WESTAT; the results were described in Chapter 2. The bottom line of this feasibility study was that it was indeed technically, administratively, and legally feasible to develop an automated system that would record violating vehicles.

Following the feasibility analysis, VTTI performed work to build an initial prototype system. This initial prototype system was tested in both a controlled and real-world setting. The results of this development and testing work indicated that license plates could be recorded, with fairly high reliability, during daytime conditions. However, the system was not capable of capturing license plate images at night. A second shortfall of the initial system was that images of the driver's face were not reliably captured. A feature of the initial system was that a profile driver facial image was taken through the side window. This did not prove to be a reliable approach for capturing clear facial images.

Lessons learned from the initial system development effort were applied to follow-on work that resulted from a modification to the original contract. This effort was described in Chapter 6. This follow-on work entailed technology refinement where the limitations of the initial prototype system were addressed with a more sophisticated design by using higher resolution cameras and a radar triggering device. It is important to note that this follow-on work involved technological development and not other areas of development that must still be addressed before such a system could be deployed. For example, the "back-end" processing (i.e., determining how, and by whom violation captures are processed) is a critical area that still needs to be addressed through additional research.

The system refinement research documented in this report has illustrated that the refined prototype system is much improved over the original system, and the major shortfalls of the original system have been addressed. The system was demonstrated at the FHWA Turner-Fairbank Research Center for invited persons, including government staff from both FHWA and NHTSA. As documented in this report, the results of the demonstration were positive. Inadvertently, the system demonstration was held on a rainy day which represented a condition that had not previous been thoroughly tested. Nonetheless, under these adverse and inclement conditions, the system worked reliably. This demonstration, in less-than-optimal conditions, showed the robustness of the prototype system to reliably capture license plate and driver facial images.

The demonstration results were consistent with the limited informal testing that was conducted. These test results showed a marked improvement over the initial system. Areas in which the initial prototype system fell short have been addressed and improved upon in the refined prototype design. Most importantly, to address the two main limitations with the initial system, the refined system captured high quality license plate images during both day and night conditions and driver facial images during the day.

NEXT STEPS

Moving toward a goal of full-scale deployment/implementation of an automated violation capture system, it is recommended that the next phase of the program be directed at two primary areas: further technology development; and administrative processing. Each of these areas is highlighted below.

FURTHER TECHNOLOGY DEVELOPMENT

The results from the research presented in this report indicated that a system which automatically captures high quality license plate and face images of drivers that illegally pass stopped school buses can be developed with off-the-shelf technology. It is important to note that the systems developed for the current project was a *prototype* device. With regard to further technology development, additional work is needed to move from a prototype to a deployable system. The current refined prototype system has demonstrated what is possible. A deployable system must not only function reliably, it must do so in the field under potentially harsh environmental conditions (including inclement weather and vibration, which has not yet been tested). As such, before a field test using such a device can be performed, which is expected to be the next logical step in this program, the prototype system must be hardened and readied for operation without a researcher/technician present.

Additionally, further research is required to streamline the system and develop a final design that may be more limited in functionality (as compared to the refined system), but more appropriate for the field. For example, the current prototype has five working cameras: two monochrome, two color, and a third color camera with a "fish-eye" lens. For the field system, it is suggested that only the two monochrome cameras be used. It is suggested that to capture the required information needed to administer a warning or ticket, two monochrome cameras with a similar perspective (field-of-view) that was demonstrated in the refined system, would suffice. Moving from five cameras down to two cameras would streamline the system giving it a smaller footprint on the side of the bus and likely requiring only one computer (as opposed to three computers used in the refined design). It is expected that the HID spotlights would still be necessary along with the radar unit to trigger the cameras. It is possible that if three cameras and two computers could be eliminated from the design then the entire system, including the computer, might fit into the system pod (rather than requiring storage space under the bus seats). This part of the design needs further consideration.

Additional system work is also necessary to design and produce a water-tight, tamper-proof, and resilient pod. Though a conceptual drawing of a pod was developed in the current project, the further development of the pod to match the further development of the field system (e.g., reduced number of cameras), and the manufacturing of pods, is necessary before a field study can be undertaken.

In summary, it is recommended that the next phase of technology development for this program be directed at implementing the necessary system design changes to ensure reliable system functionality in the real-world. This effort should include continuation of the design and manufacture of system pods.

ADMINISTRATIVE PROCESSING

As detailed in WESTAT's assessment of the initial project work, a number of non-technological, administrative-type activities are required as the program moves forward. These activities include developing a "back-end" processing protocol (i.e., what to do with recorded violations). Also, a clear definition of agency roles and responsibilities is needed. As previously noted, it is a long path from the system installer to the maintainer, to 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. A detailed responsibility/process document is required and should be developed during the next phase of the project. Other issues described previously, such as ensuring the legislative and judicial integrity of the program, should also be conducted in a future project phase.

FINAL THOUGHTS

It is recommended that two additional research phases are needed to fully develop and test an automated school bus violation capture system. The first phase would involve a field study where one or more systems are tested in a real-world environment. That is, one or more systems could be instrumented on in-service school buses and a test with the system could be conducted. A subset of this effort could be directed at resolving the administrative processing issues highlighted previously.

The field study could involve tasks directed at:

- Developing a research plan.
- Developing, producing, installing, and maintaining a hardened field study system.
- Recruiting and working with a school system.
- Developing a violation processing protocol.
- Developing and implementing a media campaign to instruct and inform the public of the dangers of illegally passing buses, and to inform them about the field system that will capture license plate and facial images.
- Collecting field data in which buses instrumented with the system are integrated into a test county's school bus fleet.
- Conducting a survey of people within the test community to gather opinions and assess support for the system.
- Reducing the data captured in the study and processing violations.
- Analyzing the data captured in the study and documenting the work conducted.

Upon successful completion of the field study, a more extensive field operational test (FOT) could be conducted. The FOT research model could involve a system vendor, a data collector, and an independent evaluator. Multiple systems and multiple test communities would likely be included. The experimental design could involve multiple buses instrumented with the system and implementation lasting two school semesters (one school year). Assuming the successful implementation of such an FOT, and with promising results, the next step for the program may be to implement these systems on a larger scale throughout the U.S.

The research presented in this report constitutes the first major phase in this program. It is suggested that further research, development, and testing are needed to move the program forward and to realize the safety benefits associated with a system that automatically detects and records vehicles that illegally pass stopped school buses.

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APPENDIX A: TERMS AND DEFINITIONS

Bus

A motor vehicle with motive power, except a trailer, designed for carrying more than 10 persons including the driver.

Bus Body

The portion of a bus that encloses the bus' occupant space, exclusive of the bumpers, chassis frame, and any structure forward of the forward-most point of the windshield mounting.

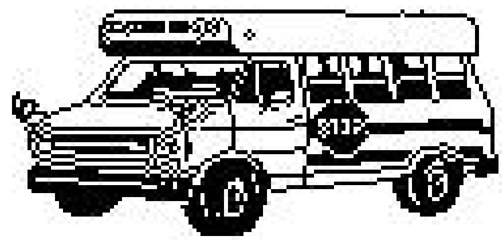
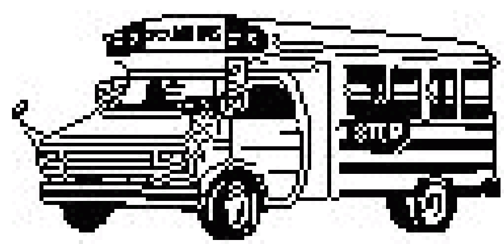
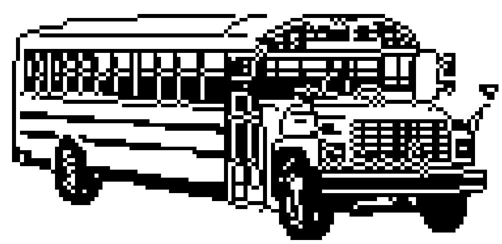
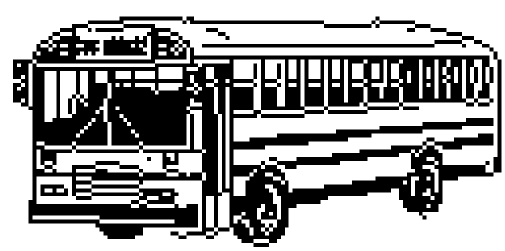
Bus Identification Number

An identification number (perhaps related to or synonymous with the license plate) that uniquely identifies a given bus within the fleet. This number allows vehicle-specific data to be stored for use in setting aim, coverage, and other parameters. It may even allow GIS-based filtering of route and roadway geometry information to reduce false alarms, etc.

Bus Types

The bus types depicted in Table A-1 represent the breadth of school bus types. Types C and D are two of the most popular and widely used types. They will be the types on which this specification is focused for initial application.

Table A-1. Bus type descriptions.

The Type A school bus is a conversion or body constructed upon a van-type or cutaway front-section vehicle with a left side driver's door, designed for carrying more than 10 persons. This definition shall include two classifications: Type A-I, with a Gross Vehicle Weight Rating (GVWR) over 10,000 pounds; and a Type A-II, with a GVWR of 10,000 pounds and under.	 Type A
The Type B school bus is a conversion or body constructed and installed upon a van or front-section vehicle chassis, or stripped chassis, with a GVWR of more than 10,000 pounds, designed for carrying more than 10 persons. Part of the engine is beneath and/or behind the windshield and beside the driver's seat. The entrance door is behind the front wheels.	 Type B
The Type C school bus is a body installed upon a flat-back cowl chassis with a GVWR of more than 10,000 pounds, designed for carrying more than 10 persons. The engine is in front of the windshield and the entrance door is behind the front wheels. Type C school buses are often referred to as "conventional" buses and represent one of the target platforms for this system specification. Typical length for such buses is about 37 feet.	 Type C
The Type D school bus is a body installed upon a chassis, with the engine mounted in the front, mid-ship, or rear with a GVWR of more than 10,000 pounds, and designed for carrying more than 10 persons. The engine may be behind the windshield and beside the driver's seat; it may be at the rear of the bus, behind the rear wheels; or midship between the front and rear axles. The entrance door is ahead of the front wheels. Type D school buses are referred to as "transit-style," RE for "rear-engine," or FC for "forward control." This body type represents one of the target platforms for this system specification. Typical length for such buses is about 37 feet.	 Type D

Clearance

The distance from a stopped school bus to other vehicles.

Clearance Lamp

A lamp used on the front and the rear of a motor vehicle to indicate its overall width and height.

Conspicuity Equipment

Reflex markers, flashing lights, and stop-arms are components of conspicuity equipment. Their role is to increase the visibility of the bus to the driving public and thereby improve the safety of passengers and loading or unloading pedestrians.

Curb Weight

The weight of a motor vehicle with standard equipment; maximum capacity of fuel, oil, and coolant; and, if so equipped, air conditioning and additional weight of optional engine. Curb weight does not include the driver, passengers, or cargo.

Bus Driver

The occupant of a motor vehicle seated immediately behind the steering control system. This person may be an employee of the public jurisdiction within which the bus operates or may be contracted by the school district to provide pupil transportation. Training and physical requirements for these persons vary by employer and jurisdictional requirements. However, most drivers of these buses must possess a valid Commercial Driver's License (CDL) intended for drivers of vehicles of more than 10 passengers.

FMVSS (Federal Motor Vehicle Safety Standard)

These are standards developed by NHTSA to govern the design or performance of various components of vehicles allowed to be driven on public roadways.

Geographic Information System (GIS)

A system that allows GPS information to be linked to real-world information, such as roadway features or geometry. Having access to this information may allow more descriptive labeling of locations than simply latitude and longitude and, in some cases, may allow sources of false alarms (e.g., medians, etc.) to be considered and accommodated automatically by the system.

Global Positioning System (GPS)

The global positioning system uses a network of satellites to triangulate the location of ground-based receivers. This information is typically provided in latitude and longitude coordinates and can easily and inexpensively be integrated into various electronic systems that require some intelligence of their location on the globe. This information can then be compared to GIS information to link those coordinates to real-world geographic, political, and engineering features.

Illegal Passing

Uniform Vehicle Code (UVC) § 11-706 states that:

> "The driver of a vehicle meeting or overtaking from either direction any school bus stopped on the highway shall stop before reaching such school bus when there is in operation on such school bus the flashing red lights specified in § 12-228(a) and said driver shall not proceed until such school bus resumes motion [or he is signaled by the school bus driver to proceed] or the flashing red lights are no longer actuated."

Thus, the act of passing during this situation is illegal. State laws often include further stipulations to this federal law that are related to particular conditions or exceptions of its application. Some states, for example, define specific clearance distances; when defined, these range from 10 to 30 feet. Other factors include type of roadway (e.g., divided highways).

Longitudinal or Longitudinally

Parallel to the longitudinal centerline of the vehicle.

Manufacturer

Any person engaged in the manufacturing or assembling of motor vehicles or motor vehicle equipment, including any person importing motor vehicle equipment for resale.

Meeting

This is defined as a type of passing in which the passing vehicle is moving in the opposite direction of the bus' forward direction. This type of passing is also referred to as head-on or oncoming.

NHTSA

The National Highway Traffic Safety Administration.

Passing

The act of moving past a vehicle longitudinally. In the case of this specification, it also describes the passing acts that occur in the same direction as the bus' forward direction. This type of passing may also be referred to as overtaking. Otherwise, such events are referred to as meeting.

School Bus

A bus that is sold, or introduced in interstate commerce, for purposes that include carrying pre-primary, primary, and secondary school students to and from school or related events. This definition does not include a bus designed and sold for operation as a common carrier in urban transportation.

Sensor Coverage Area

The sensor coverage area is a rectangle extending from 10' in front of the front bumper to 10' behind the rear bumper and laterally across two lanes of traffic as shown in Figure A-1. This area represents the area adjacent to the bus where the vast majority of illegal passing occurs. This area is distinguished from the “violation zone” in that vehicles moving into or through it are not necessarily in violation of the relevant laws. That determination is more complex; that is, this area illustrates the concentration of sensing resources for detecting violators, but **not** a simple space definition in which any vehicle that enters or passes through is guilty of an illegal passing violation.

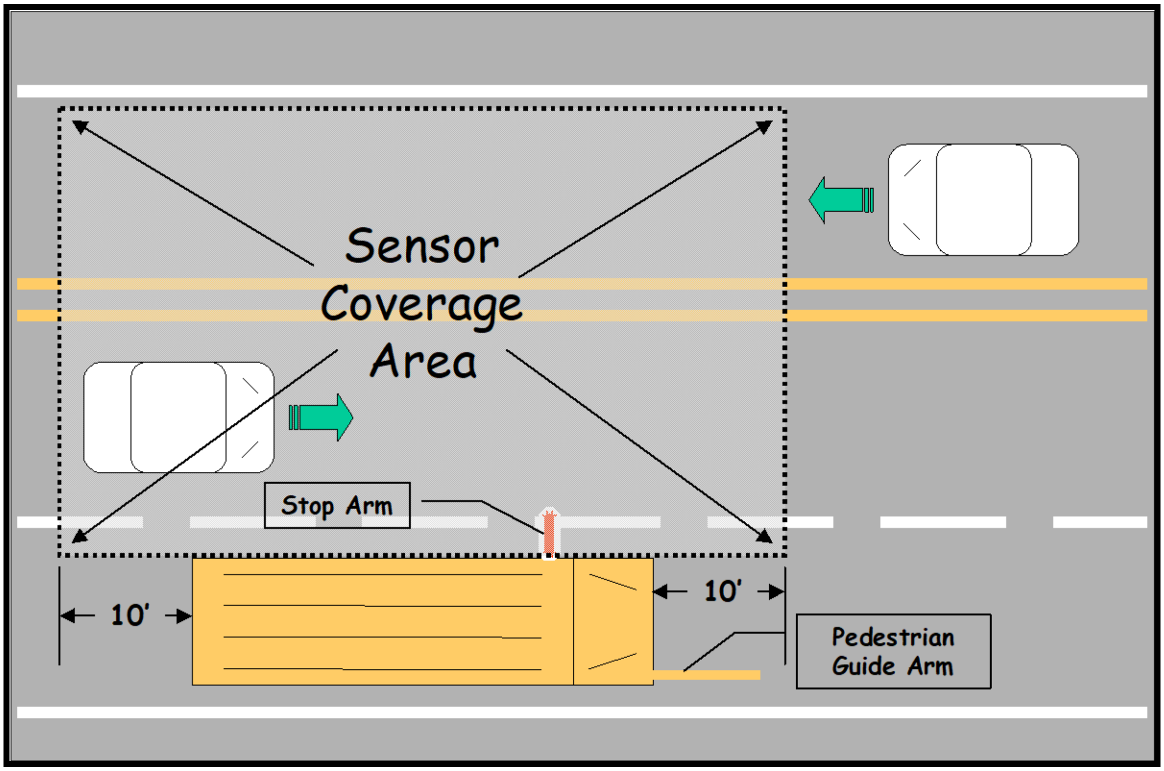


Figure A-1. Sensor coverage area illustration.

Stop-Arm

A device that can be extended outward from the side of a school bus to provide a signal to other motorists not to pass the bus because it has stopped to load or discharge passengers. Its form is that of an octagonal stop sign (about 18" in diameter) with alternately flashing red lights above and below the word "STOP." The specifications for its form and function are in FMVSS 131. The location of this arm is standardized. It is to be no more than 6" below the lower edge of the passenger windows and immediately behind the driver's window on the driver's side of the bus. Although incandescent lamps are required to have a typical combined duty cycle requirement of around 100%, xenon bulbs may be much shorter (i.e., 50% duty). The implication of the shorter duty cycle of the xenon bulbs is that a still photograph may not show a lit lamp, unlike the incandescent alternative that would almost always have at least one light illuminated. Some buses may include a supplemental stop-arm near the back end of the bus. Its operation is similar to that of the singular units. However, there are design differences required of the rear sign, if one is to be used. Specifically, the rear sign cannot have any markings on its front side (when deployed).

Telltale

A display that indicates the actuation of a device, a correct or defective functioning or condition, or a failure to function.

Threshold Speed

The minimum speed required by the detection component of the system before a passing vehicle is classified as a violator/violating vehicle. Current red light and speed enforcement systems often use such a threshold. It is not clear whether such a threshold is necessary or practical for this application.

Vehicle Identification Number (VIN)

A series of unique arabic numbers and roman letters which are assigned to a motor vehicle for identification purposes.

Violation Zone

The violation zone is a set of criteria that must be met for a vehicle to be in violation of illegal passing laws. Illegal passing is defined in Section 0 according to the UVC and is further modified by stipulations in individual state laws. These stipulations limit the types of situations under which the law applies, the clearance distance required by approaching vehicles, relevant approach direction, special exceptions in which a vehicle may pass, the necessary conditions for allowing vehicles to legally pass, and the requirements for pre-stop warnings for approaching drivers, etc. A violation of the law does not occur until these stipulations (which do differ amongst states) are met. The ability to modify the violation zone through system configuration changes will make the system compatible with local laws and roadway configurations. Since individual state laws vary with regard to what constitutes an illegal passing violation, the violation zone is intended to infer that the approaching vehicle/driver meets the criteria for violation (for a given state or roadway situation) and is thus identified by the system as a likely violator according to its filtering algorithms.

Violator/Violating Vehicle

This is defined as a vehicle that enters and passes through the Violation Zone, meeting criteria for illegal passing.

APPENDIX B: TECHNICAL, ADMINISTRATIVE, AND LEGAL FEASIBILITY

Introduction

The early development of the prototype system involved an effort to investigate the technical, administrative, and legal feasibility of pursuing the development of a system aimed at recording school bus passing violations. The results of this early project work, conducted by WESTAT, are highlighted in the following sections. Details of the technical, administrative, and legal feasibility analyses are documented in interim project task reports (Huey and Llaneras, 2001b).

Application

Figure B-1 shows the overall system operational concept. It was envisioned that the system would be capable of detecting and capturing visual evidence to facilitate the prosecution of illegal school bus passing incidents under a variety of operational conditions. After capturing violations, data and visual images should be processed to allow human assessment of the evidence and development of the evidence into a citation for the violator. Adjudication involves the processes that see the citation from delivery to the suspected violator to appearance in court and/or assignment of fines or points.

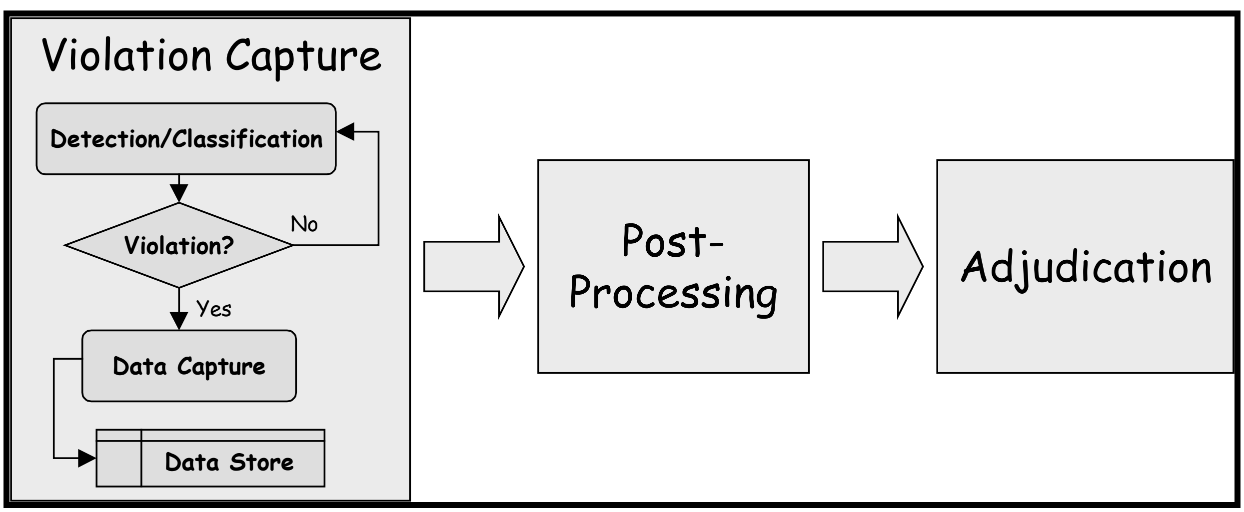
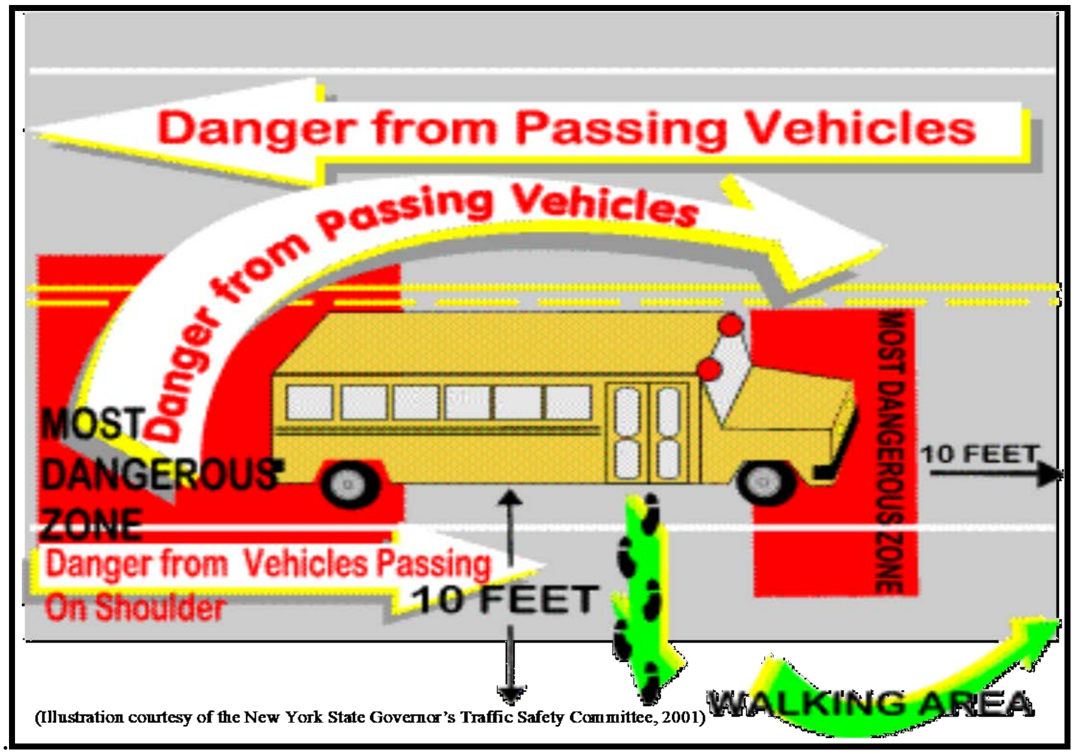


Figure B-1. System operational diagram.

Figure B-2 depicts some of the dangerous areas around a stopped school bus (i.e., loading or unloading passengers). In some cases, limited visibility of pedestrians by the bus driver makes these areas dangerous (e.g., directly in front of the front bumper and near the wheels), while others represent exposure to the hazards caused by motorists that pass the bus illegally. The initial development for this application was aimed at conventional school buses (Type C and D), which is detailed in Appendix A. These bus types represent a large proportion of the school bus fleet and are considered to be the most challenging due to their size. While the specifications and designs do not intentionally exclude smaller (Type A and B) bus designs, these were not the primary focus for this effort.



(Illustration courtesy of the New York State Governor's Traffic Safety Committee, 2001)

Figure B-2. Dangerous areas around the school bus

Accomplishments Under this Project

This project began with a short list of principles aimed at guiding the development process, such as the use of conventional, off-the-shelf hardware to yield an affordable system.

A series of feasibility analyses were conducted in support of the project with the intention to assess the technical, administrative, and legal feasibility of automated enforcement systems. Specific issues explored as part of this work addressed the following items:

- How feasible is a system for identifying drivers who illegally pass stopped school buses?
- What are the deficits in current off-the-shelf technology?

- What is the acceptability of the various system technologies among school, judicial, and police authorities, as well as among the general public?
- Are there any legal impediments and, if so, how should they be addressed?

Two expert panels and a detailed legal review were conducted to explore these issues. Each activity is summarized and presented in the feasibility review document prepared under Subtask 4 of this effort (Huey and Llaneras, 2001b).

Technology and Application Review

A preliminary review of the literature and other documentation of relevant systems and technologies was conducted. The purpose of this review was to identify the existence and availability of current integrated systems targeted to this specific application and its functionality as outlined in the preliminary system specifications. Sources of information reviewed for this effort included:

- Research reports conducted for NCHRP, NHTSA, and other scientific organizations.
- Articles in transportation related journals and trade publications (e.g., ITE Journal, Traffic Technology International, ITS World).
- Reviews of internet sites such as manufacturers' web sites and sites devoted to enforcement (including resistance thereof).
- Manufacturers' literature obtained through contacts with manufacturers and their vendors.

Although the review found no systems that adequately addressed this application, some systems do use components that would be capable of performing at least some of the functions targeted for this application (e.g., detection and image capture). In the absence of systems aimed specifically at the problem, this effort concentrated on providing information about technologies and automated equipment capable of recording external roadway events and saving them for further review and analysis. This included video systems and photographic systems as well as vehicle sensing systems (especially microwave and laser). Basic information on equipment and technology was gathered from some manufacturers, vendors, and users of these technologies and components. Ultimately, performance specifications from vendors and known or estimated performance levels from both users and vendors were used to further focus the development of the prototype system from the list of viable candidates.

Specification Development

Starting with a list of desirable features at the beginning of the project, WESTAT developed preliminary specifications for the system design and operation. Essentially, the system should be capable of detecting illegal school bus passing on the left (driver's) side of the bus, documenting the offense, archiving the data, allowing law enforcement review of the infractions, notifying offenders (or vehicle owners) of the offense, and providing status tracking through the remainder of the adjudication process. Although these specifications attempted to cover the entire process of enforcement from detection/classification to adjudication, the emphasis was on the front-end processes. This was intended to ensure adequate image and data collection to allow the latter portions of the process to be turned into defensible citations in an operational system.

It is important to note that the specifications were directed at a final system design, not at a prototype developed under this project effort. Under the current project, a functional prototype was developed in order to determine the feasibility of continuing development toward a final system design. As such, the prototype was not expected to satisfy all of the specifications. Rather, the prototype was meant to demonstrate the primary technical functionality. Neither the time allotted to complete the (initial) project (18 months), nor the budget for the development of each prototype unit, allowed for the complete set of specifications to be incorporated into the prototype.

As an example, consider that a red-light violation camera (a similar application) installed at an intersection is much more costly (estimated at approximately $200,000 per unit) than the prototype systems being developed for the current effort. It was also the intent of the study not to constrain the hardware or the methods used by other automated enforcement applications. Thus, some flexibility remains in this specification to accommodate innovation and technological advances in components necessary to perform detection, data capture, and storage, among others.

The requirements outlined in the following sections are meant to specify minimum performance for the various components or functions of an automated illegal school bus passing enforcement system. The detection, image capture, and archiving portions of this process were the chief concerns of the initial specification effort. The rationale for this focus is that the post processing and status tracking systems are being used effectively for an ever-increasing number of red-light running and speed enforcement applications. The extrapolation of those applications will likely not be substantially different from these predecessors. However, it is possible that the legal, enforcement, and public support will be somewhat different. Those issues were addressed to some degree during the feasibility reviews, although more thorough reviews will be needed as these systems are placed into operational settings.

The section that follows is organized according to system functions. There are also placeholders for system tests that will ultimately be used to verify adequate functional levels to ensure detection, image capture, etc. with the goal being high rates of violator recognition and prosecution.

General Requirements

The guiding principles for this specification and prototype development effort include the use of off-the-shelf technology and incorporate low-cost, low-maintenance components, to the extent possible. Although other applications of automated enforcement currently exist, many have subtle but relevant differences that make components for various aspects of the overall purpose irrelevant or poorly suited to the present task. One of the primary goals was to make a system that was economically practical and effective, or that could be such with foreseeable economies of scale, technological advancements, or minor tradeoffs in capabilities. However, innovation had to be framed within the constraints of evidence integrity for violation prosecution.

Minimal bus driver involvement to accomplish its mission was another primary goal. Ideally, the bus driver should not have to add any tasks to his or her list of daily duties, especially technically complex or time-consuming ones.

It must be pointed out that the system under development is in essence a law enforcement tool. While it provides an aid to school bus drivers who may have difficulty in identifying and documenting violators of school bus passing laws, it is ultimately to be used to promote law enforcement and safety. Thus, it is likely that much of the technical interaction of this device will be the responsibility of the police. As such, many of the same considerations of evidence collection, protection, and use are similar to other applications (e.g., red light cameras). Readers are referred to the feasibility review document prepared under Subtask 4 of this effort (Huey and Llaneras, 2001b).

"First, do no harm" was another guiding principle in that the addition of such a law enforcement aid should create no additional hazards to the driver or passengers of the bus. Incitement of aggressive behavior or erratic maneuvers should be avoided by design, and policies to maintain at least the current level of safety and security for drivers and passengers of these vehicles was a necessity.

Security of evidence data and images and maintenance of the system integrity during daily use and storage were also considered in the specification's general requirements. Readers are referred to the preliminary specification document prepared under Subtask 2 of this effort (Huey and Llaneras, 2001a) for a comprehensive list of requirements. The sections that follow, however, provide a condensed overview of the specification contents and implications.

Violation Capture

Detection encompasses the sensing of targets in or near the Violation Zone, classifying targets as being violators or not, and capturing images that can be used as evidence. Some of the key factors in this function are the coverage parameters (including environmental considerations), activation control, modes of operation, and outputs to the other components of the system. There are also issues of data storage as well as roles and responsibilities that must be specified for those who will interact with the system and its data (evidence).

The initial definition of the Violation Zone includes the two lanes adjacent to the driver's side of the bus and stretches the full length of the bus with an additional 10 ft on either end. Figure B-3 depicts the dimensions of coverage for Class C and D buses with an approximate dimension of 24 x 60 ft. Again, these bus types were the initial focus of this effort, but other types will be serviceable as well. While the stop-arm is extended and the red lights are flashing, vehicles that pass the bus on the driver's side from either longitudinal direction would be considered violators. Any such vehicle movements would not be ignored unless they do not meet statutory requirements for a violation (e.g., a physical median, excessive lateral separation from the bus, trajectory, etc.). This portion of the specification also outlines physical conditions under which the detection system should work, such as weather, lighting, vibration, and violator vehicle or bus dynamic situations.

There are other factors to consider as well. Many jurisdictions have slight variations in requirements in order for passing to be considered a violation. To the extent possible, these subtle differences should be considered and handled by the detection and classification system (e.g., lane considerations, warning requirements, bus dynamics, direction of passing, etc.). However, these variations and subtleties also point to the need for human review of violations after they are captured.

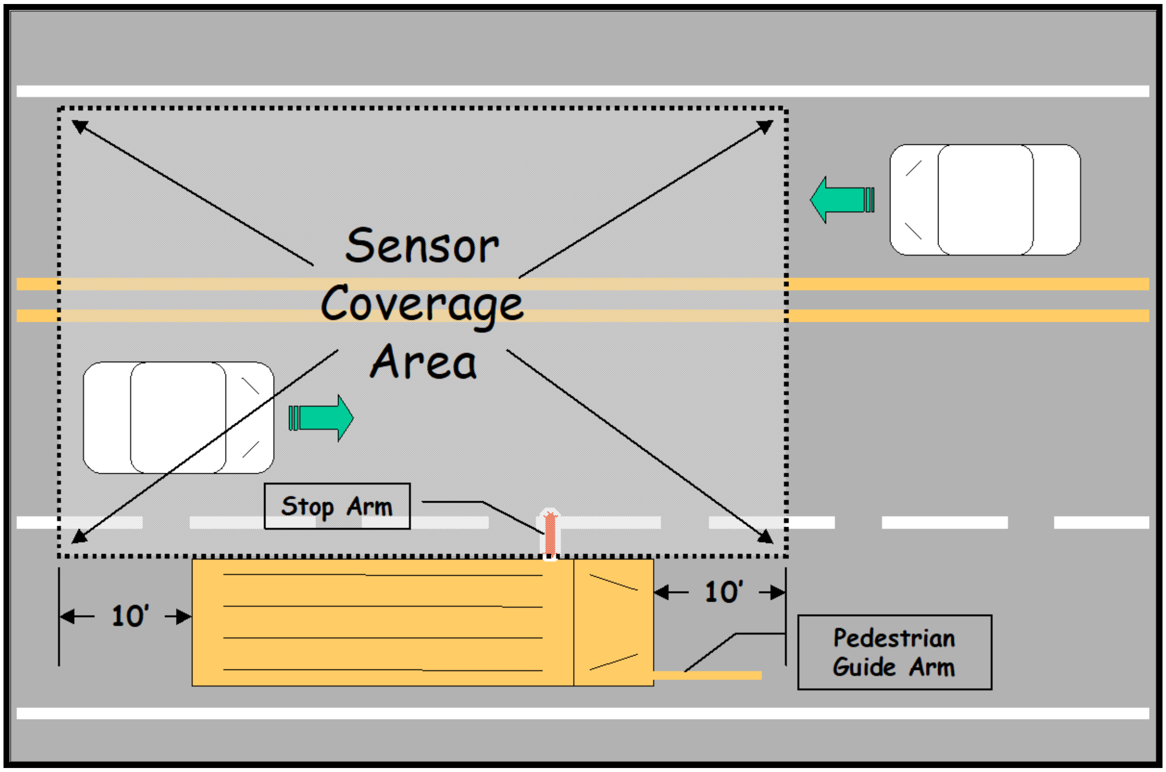


Figure B-3. Required "sensor coverage area."

In addition to the conditions under which the violation detection portion of the system must operate, the specifications outline the modes of operation and provide an overview of the system operation in Figure B-4. This portion of the specifications also recommends driver input to the violation capture algorithm. Although this is not a necessary component of the violation capture procedure, it provides a back-up method for capturing violations and an extra confirmation in the event that a violation is captured.

Other information included in this section of the specifications addresses aspects of labeling, documentation, outputs to other system components, radiation emissions, and requirements for power for the violation capture subsystem. Although the majority of these specifications are relevant to the system design, use of cameras with image processing for incident detection makes radiation emissions irrelevant. That is, the sensing mechanism is non-radiating so there is no potential harm to pedestrians or bus passengers.

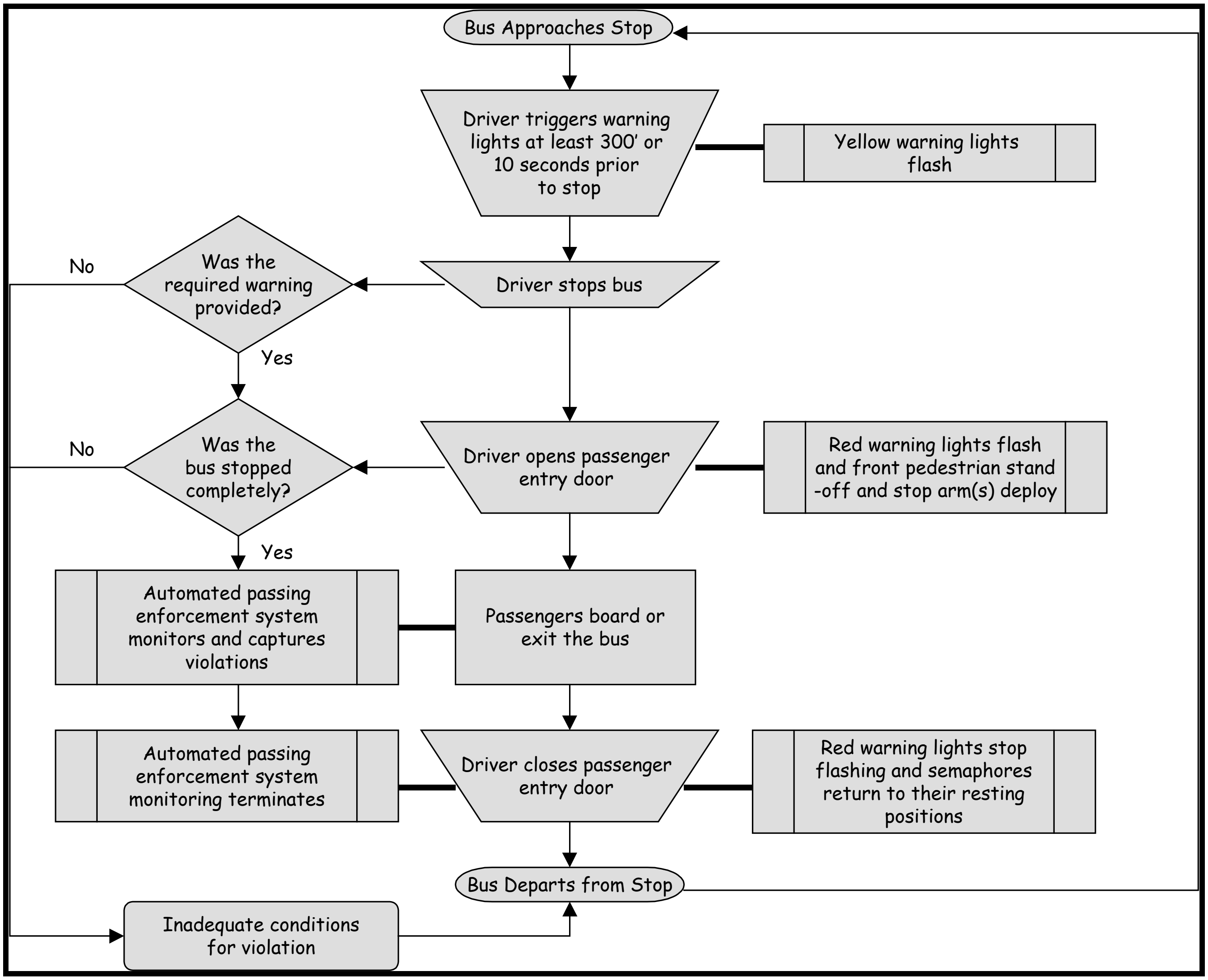


Figure B-4. Flow diagram for violation capture at a bus stop.

The portion of the specifications covering image capture is intended to govern the violation documentation aspect of the automated enforcement process. These components specify the camera perspectives, image quality, needs for data integration, and the format of the images. Generally, the system is required to capture images near the front and rear of the vehicle, as well as the driver. For purposes of documenting motion, it is desirable to capture more than one image while the bus is stopped, with the potential video capture being a viable alternative. At least one of the images needs to be of sufficient quality to allow unique identification of the vehicle (i.e., via the license plate). The need for capturing the driver facial image, though debated during the various feasibility discussions, remains one of the specified requirements. This image should be of sufficient quality to identify the driver, especially in cases where statutes do not automatically assume that the owner is the driver. Quality is specified to ensure that adequate resolution and contrast will be available, even during high and low ambient brightness conditions. The direction in which the cameras should be aimed is also covered in the specification to ensure coverage of the Violation Zone and to capture the stop-arm in one or more images to provide context and redundancy for use in verification of a violation.

In addition to the camera images, data provided from other sources on the bus platform are important and require integration or coordination with the images. Some of this information is accounting and/or archival in nature. However, for purposes of providing violation context, key information on bus systems status (e.g., warning light timing parameters and bus location) is also covered. While this portion of the specifications largely deal with required information content in data and images, it also includes guidance for how that information should and should not be captured (e.g., minimize distraction to the bus driver and suspected violators that might lead to crashes, etc.).

The specifications also detail how and under what circumstances images and other data should be stored. Characteristics such as volatility and capacity are addressed as well. The level of periodic maintenance is directly related to these storage issues. Furthermore, evidence integrity is an important function of the method of storage. The content of data is also outlined under this heading within the specifications. In addition to the key information items to be stored regarding each violation event, information related to calibrations and platform identification must also be defined and controlled.

Responsibility for these systems must fall into the hands of the bus driver since he/she will be the primary guardian during the active portion of any bus' daily activity. However, this is a law enforcement activity and, as such, personnel trained and sworn to those duties should be responsible for most of the interactions with these systems. This section outlines that separation of duties.

Post-Processing

Post-processing may or may not be done by the same system that detects violations, captures images of those violations, and stores them. Ultimately, there must be a compatible relationship between the post-processing system and the system that performs these aforementioned tasks. Furthermore, integrity of the data, which may ultimately be used as prosecution evidence, must be maintained. The elements of post-processing include format conversion, transfer of data from the capture system to archives, synchronization of evidence with license information, and packaging for law enforcement review. Inherent in each of these activities is a need to maintain the "chain of evidence" to ensure that no potential exists for tampering with the original evidence. Although processing and enhancing the original data may be necessary or desirable to complete post-processing efforts, integrity of the original evidence must not be compromised. Therefore, requirements for these activities, with an eye toward maintaining integrity, are outlined in this portion of the specifications.

Adjudication

The adjudication process carries the captured evidence through an enforcement review, delivery to the suspect, and then uncontested response or judgment in court. A law enforcement officer or designated contractor must validate each violation according to legal criteria set forth in relevant statutes. Figure B-5 illustrates a decision tree example for determining the validity of a violation. "XX" and "YY" represent placeholders for relevant distances and durations provided by legislation governing a given jurisdiction. If MVA synchronization is possible, attribution of the violation to the owner or driver must be performed. Depending on the jurisdiction and legislative guidelines, attribution of the violation may be assigned to the owner with the assumption that he/she was the driver, unless proven otherwise. Delivery of the citation, once the event has been verified as a violation, is not implicitly simple either. Laws may govern the delivery means and schedule as well as the content. At that point, the accused may either decide to pay the fine and accept any point sanctions or to contest the indictment. If the violation is contested, there are further issues regarding the admissibility of evidence, the requirement for witnesses, etc. The goal of the specifications, in this regard, is to minimize the need for further bus driver interactions with the adjudication process beyond simple confirmation of a violation. The feasibility review prepared under this project effort (Huey and Llaneras, 2001b) provides further insight into the issues and requirements surrounding the adjudication process.

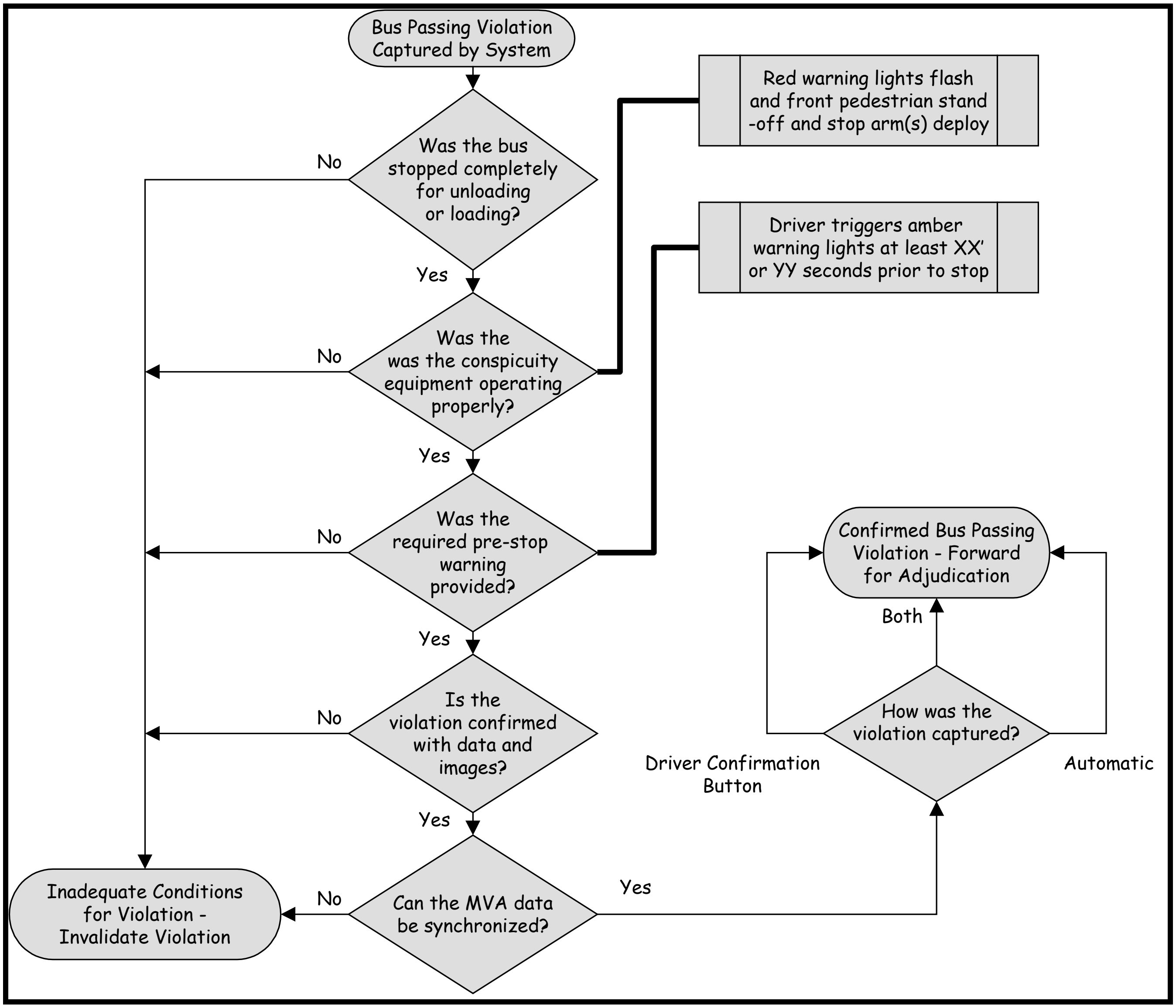


Figure B-5. Decision tree for violation definition.

Application Feasibility Assessments

After developing preliminary specifications and assessing the availability of existing systems, WESTAT performed assessments of the technical, administrative, and legal feasibility of automated enforcement systems. The findings of these feasibility analyses include summaries of technical and administrative expert panels and a detailed legal review. Readers are referred to the feasibility review document prepared under Subtask 4 of this effort (Huey and Llaneras, 2001b).

The first expert panel addressed the basic technical issues of violation detection and image capture for the illegal school bus passing application. The intent was to discuss technical issues and reach a consensus on how to build a viable prototype system that would allow proof-of-concept. Alternative technologies for this application were discussed and included conventional wet film and digital still cameras, analog and digital video, or combinations of these technologies. Systems using a combination of still images and video recordings were perceived to offer the best approach, providing the capability to capture high resolution, still frame images of the license plate as well as lower resolution video of the violation in context. Two proposed system configurations were recommended, both using digital video cameras. Experts agreed that prototypes based on these designs would provide suitable coverage and result in relatively low-cost and reliable systems. The system would provide 1-2 lanes of coverage, capture targets approaching from the driver's side of the bus (in either direction), activate when the bus' amber warning lights are switched on, and record images and data following a violation. This configuration is shown in Figure B-6.

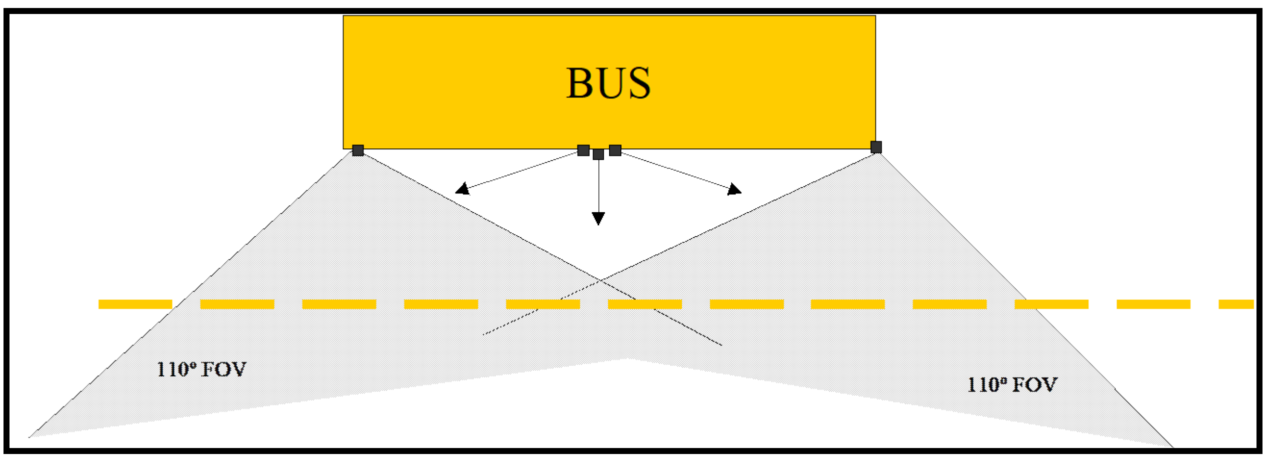


Figure B-6. Proposed system configuration.

Key recommendations are outlined below:

- The panel recommended the use of video cameras to fulfill both the detection and image capture functions.
- Ideally, the system should automatically activate once the bus' amber warning lights are illuminated. Images and sensed data should only be recorded if a violation occurs (assuming that doing so does not result in an unacceptable rate of missed detections).
- The system should be designed to capture targets approaching from the front, driver's side of the bus. Sensors and cameras should cover 1-2 lanes and be positioned at heights compatible

with cars. Capturing direct driver facial views is likely to yield relatively few usable images. Experience with red-light running cameras (mounted in fixed locations) suggests that fewer than 20% of the photographs reliably capture intact driver facial views.

- The following parameters should be recorded and documented when a violation occurs; date, time, bus ID, bus speed when stop-arm is deployed, bus distance traveled from amber to red warning lights, status of red warning lights, and location context. Text overlays should be used to provide key information directly on the video.

Issues impacting system implementation and administration were addressed by means of a second expert panel. Members were unanimous in their perception that illegal school bus passing represents an ideal application for automated enforcement technology. The link between the violation and safety is clear and direct, and since the issue involves the safety of children, the public is likely to rally behind such systems. Many felt successful implementation of these devices will be largely based on accurate and reliable systems, an enforcement process that is fairly administered, focused on safety, and promotes early partnerships between law enforcement, legislative representatives, and school systems.

When implementing or field testing such a system, states or jurisdictions with enabling legislation that can facilitate enforcement should be sought (i.e., states which have established legal definitions or criteria for what constitutes a violation and/or established rules regarding admissibility of video or digital images as evidence). As a system becomes operational, sufficient resources should also be made available for “back office” operations required for processing and issuing citations. Criteria for defining a violation must be clear and objective. The panel recommended reconsidering the definition of the Violation Zone defined in the initial specifications to emphasize areas most likely occupied by pedestrians during loading and unloading. An operational definition of a violation should take the following aspects into account: warning time; bus configuration (speed, position, etc); lane position and road configuration; operation of the bus safety /warning equipment (stop-arm, lights, etc.); typical pedestrian trajectories, etc. Key recommendations outlined by this panel included:

- Data captured by the system should be accurate and reliable, and clearly establish the violation. Panel members recommended using video with a field of view that also includes the bus’s stop arm when extended and flashing.

- Successful deployment depends on coordination with law enforcement agencies and personnel. Experience with similar efforts suggests early formation of these relationships to foster cooperation and stewardship of the project at each of the necessary levels. The system should be used to supplement and support enforcement by police and not be viewed as a replacement.
- Bus drivers should understand and execute proper stopping procedures, since invalid stops can contribute to increased incidents of false positives or marginal cases. Training programs should be instituted to ensure that proper stops are executed. The automated system should operate and trigger when a set of pre-specified conditions have been met (i.e., the bus is stopped, stop-arm is extended, lights are flashing, etc.). It should also have the capability to filter cases where insufficient warning time is provided.
- Systems should require minimal maintenance and interaction from the bus driver. Procedures should be simple, quick, and able to be completed with no specialized tools.
- Methods for downloading violation data should be flexible, since some counties or jurisdictions do not have centrally located lots to house buses. Approaches that minimize the administrative burden associated with downloading violation images/records are desirable (e.g., systems may provide an indication that a violation has been captured).

The third component of the feasibility analyses was a review of the legal issues surrounding the application of automated enforcement techniques to this problem. The review of federal and state statutes found that legal issues associated with the implementation and administration of an automated school bus enforcement system do exist (evidentiary issues, due process, privacy, etc.). However, there were no insurmountable legal obstacles. Generally, in order for automated school bus enforcement to be accepted by the courts and the public, the following must be considered:

- The technology must be based upon accepted scientific principles and techniques.
- The equipment must be reliable and properly maintained.
- Images collected must be clear, accurate, and tamper-proof.
- Information depicted in the captured image must establish the elements of the violation.
- Authenticity of the evidence must be documented through a carefully recorded chain of custody, thus ensuring its integrity.

The following guidance is based upon experience with legislation addressing other existing photo enforcement applications (red-light enforcement, photo/radar, etc.).

- Statutes that create a presumption of owner liability and provide for civil fines make it generally unnecessary to capture the image of the driver. Automated enforcement programs that cite the vehicle's owner with a civil infraction rather than a "criminal" moving violation appear technologically, administratively, legally, and politically easier to implement.
- Although the specific elements that constitute a violation may vary across states, all have as their foundation the act of passing a stopped school bus. However, absence of such legislation does not necessarily preclude implementation of this type of application. Certain jurisdictions may permit automated school bus enforcement under present statutory schemes. Some jurisdictions require that a vehicle stop at a specified distance from a stopped bus (usually not less than 30 feet). Therefore, the area defined as the Violation Zone may differ across jurisdictions. The laws of individual states must be examined vis-à-vis this application.
- Unless waived by statute, all tangible items entered into evidence, including photographs and other images, must first be authenticated. Showing that it is what it reports to be and that it has not been altered in any significant manner authenticates evidence. Providing "chain of custody" documentation is an effective way to authenticate evidence.
- Courts may become considerably more cautious when dealing with digitized images. Therefore, precautions should be taken to convince courts and the public that digital images have not been tampered with or modified. Use of an encryption system is an essential safeguard for image transmission applications.
- Due process challenges to photo enforcement of traffic laws are likely to focus on notice issues, specifically with signs warning of the presence of automated traffic enforcement devices and delays in issuing a citation to alleged violators. Citations notifying drivers of an offense should be issued in a timely manner.
- Claims that photo enforcement violates an individual's common-law or statutory right to privacy are unlikely to succeed. The legal merit of any privacy concerns may constitute less of an impediment to the implementation of photo enforcement programs than the public perception of photo enforcement devices as a tool of "Big Brother."

Implications for System Design

A number of technical, administrative, and legal issues were identified as a result of the feasibility analyses. Some have direct implications for the design and implementation of an automated illegal school bus passing enforcement system. These are outlined below:

- WORM (write once, read many) drives/disks are particularly relevant for securing digital images and ensuring the integrity of evidence.
- Driver facial views are not necessary, assuming that violations are treated as civil offenses. However, they will be required if offenses are to be pursued as criminal violations. Clear frontal photographs of the driver are always required to establish a moving violation.
- The system must be able to detect the following parameters which may used as a basis for establishing a violation: bus speed (the bus must typically be completely stopped); status of the warning lights and stop-arm (the red warning lights and stop-arm must be activated); the passenger door must be open and the bus must be stopped to load/unload students.
- The system should record and document a number of parameters when a violation occurs, including date, time, bus ID, bus speed when stop-arm deployed, distance traveled from amber to red warning lights, status of red warning lights, and violation context (location).
- The system must capture the key elements of the violation, including images of the offending passing maneuver with the bus' stop-arm clearly visible.
- The system should emphasize violations approaching from the front of the bus where the vast majority of cases are likely to result. Systems should be designed to capture targets approaching from the front, driver's side of the bus. Sensors and cameras should cover 1-2 lanes and be positioned at heights compatible with cars.
- The system should be able to filter out instances where the bus driver executes an inappropriate stop.
- The system should provide an indication to the bus driver that it has captured a violation.

APPENDIX C: 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 11th and/or Sunday November 18th. 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: 540/231-1513.

APPENDIX D: 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 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		Unknown					
Oncoming	2	2	Moderate	White	Down	Daytime Running Lights	Fog	Light		Unknown					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	3	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	3	Low	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Oncoming	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Oncoming	2	2	High	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Oncoming	4	3	High	White	Down	Daytime Running Lights	Clear	Dusk		Unknown					
Oncoming	4	3	Low	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Oncoming	4	3	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	3	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Oncoming	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Late Afternoon		Unknown					
Oncoming	4	2	High	White	Down	Standard Lights	Clear	Late Afternoon		Unknown					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Unknown					

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	Low	White	Up	Standard Lights	Rain	Light		Unknown					
Oncoming	2	2	Moderate	Black	Not Recorded	Standard Lights	Cloudy	Light		Unknown					
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		Unknown					
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		Unknown					
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					
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dusk		Unknown					
Oncoming	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
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		Unknown					
Oncoming	4	3	High	White	Down	Standard Lights	Clear	Dawn		Unknown					
Oncoming	2	2	Low	White	Up	Standard Lights	Rain	Light		Unknown					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Rain	Light		Unknown					
Oncoming	4	3	Low	White	Up	Standard Lights	Rain	Light		Unknown					
Oncoming	4	3	Moderate	White	Up	Standard Lights	Rain	Light		Unknown					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Unknown					
Oncoming	2	2	Moderate	Black	Up	Standard Lights	Cloudy	Light		Unknown					
Oncoming	2	2	High	White	Up	Standard Lights	Cloudy	Light		Unknown					
Oncoming	2	2	High	Black	Up	Standard Lights	Cloudy	Light		Unknown					
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dawn		Unknown					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Unknown					
Oncoming	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dark		Unknown					
Oncoming	2	2	Moderate	White	Up	Standard Lights	Clear	Dark		Unknown					

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	Dk Blue	Up	Standard Lights	Clear	Dark		Unknown					
Oncoming	4	3	Moderate	White	Down	Standard Lights	Clear	Dark		Unknown					
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		Unknown					
Oncoming	4	3	Moderate	White	Down	Daytime Running Lights	Fog	Light		Unknown					
Oncoming	4	4	Moderate	White	Down	Daytime Running Lights	Fog	Light		Unknown					
Oncoming	4	4	Low	White	Down	Daytime Running Lights	Fog	Light		Unknown					
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		Unknown					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Late Afternoon		Unknown					
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		Unknown					
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					
Oncoming	4	4 to 3	Low	White	Not Recorded	Headlights Off	Clear	Light		East					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Dusk		Unknown					
Oncoming	4	4	High	White	Down	Standard Lights	Clear	Dusk		Unknown					
Oncoming	4	4	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Oncoming	4	4	Moderate	White	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	4	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Late Afternoon		Unknown					
Oncoming	4	4	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					

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	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		Unknown					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Light		Unknown					
Oncoming	4	4	Low	White	Down	Standard Lights	Clear	Light		Unknown					
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		Unknown					
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		Unknown					
Oncoming	2	2	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Unknown					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Light		Unknown					
Oncoming	4	3	Low	White	Down	Standard Lights	Clear	Light		Unknown					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Unknown					
Oncoming	4	4	Low	Dk Blue	Down	Headlights Off	Clear	Light		Unknown					
Oncoming	4	3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Unknown					
Oncoming	4	4	Low	White	Up	Headlights Off	Clear	Light		Unknown					
Oncoming	4	4 to 3	Low	Dk Blue	Down	Headlights Off	Clear	Light		Unknown					
Oncoming	2	2	Low	White	Down	Headlights Off	Clear	Light		East					
Oncoming	4	4	Low	White	Down	Headlights Off	Clear	Dawn		Unknown					

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		Unknown					
Oncoming	4	4	Low	White	Up	Standard Lights	Clear	Dark		Unknown					
Oncoming	4	4	Moderate	Dk Blue	Down	Standard Lights	Clear	Dark		Unknown					
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		Unknown					
Overtaking	4	2	Moderate	White	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Overtaking	2	2	Low	White	Down	Daytime Running Lights	Fog	Light		Unknown					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Fog	Light		Unknown					
Overtaking	2	2	Low	White	Down	Standard Lights	Fog	Light		Unknown					
Overtaking	2	2	Low	White	Down	High Beams	Fog	Light		Unknown					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Fog	Light		Unknown					
Overtaking	2	2	Moderate	White	Down	High Beams	Fog	Dawn		Unknown					
Overtaking	2	2	Moderate	Dk Blue	Up	Headlights Off	Clear	Light		East					
Overtaking	4	2	Low	Dk Blue	Up	Headlights Off	Clear	Light		Unknown					
Overtaking	4	2	Low	White	Down	Headlights Off	Clear	Light		Unknown					
Overtaking	2	2	Moderate	White	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	High	White	Down	Headlights Off	Clear	Light		East					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Late Afternoon		Unknown					
Overtaking	2	2	High	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Overtaking	2	2	High	White	Down	Standard Lights	Clear	Late Afternoon		Unknown					
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		Unknown					
Overtaking	2	2	Low	White	Up	Standard Lights	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Low	White	Down	Headlights Off	Clear	Light		West					

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	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		Unknown					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Dusk		Unknown					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Dusk		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dusk		Unknown					
Overtaking	2	2	High	White	Down	Standard Lights	Clear	Dusk		Unknown					
Overtaking	4	2	Low	Dk Blue	Down	Headlights Off (Standard Lights on car stopped in lane 4)	Clear	Dusk		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Overtaking	2	2	High	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Late Afternoon		Unknown					
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		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Dawn		Unknown					
Overtaking	2	2	High	Dk Blue	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Low	White	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dawn		Unknown					
Overtaking	2	2	Low	White	Up	Standard Lights	Rain	Light		Unknown					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Rain	Light		Unknown					

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	High Beams	Rain	Light		Unknown					
Overtaking	2	2	Moderate	White	Up	High Beams	Rain	Light		Unknown					
Overtaking	2	2	Low	White	Down	Standard Lights	Rain	Light		Unknown					
Overtaking	4	2	Low	White	1/2 Down	Headlights Off	Clear	Light		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Overtaking	2	2	Low	White	Down	Standard Lights	Clear	Dusk		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dusk		Unknown					
Overtaking	2	2	Low	White	Down	High Beams	Clear	Dusk		Unknown					
Overtaking	2	2	Moderate	Dk Blue	Down	Headlights Off	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Moderate	White	Down	Daytime Running Lights	Clear	Late Afternoon		Unknown					
Overtaking	2	2	Moderate	Dk Blue	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Moderate	White	Down	Standard Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Dawn		Unknown					
Overtaking	2	2	Low	White	Down	Daytime Running Lights	Clear	Dawn		Unknown					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	Moderate	Black	Down	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	High	White	Up	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	High	Black	Down	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	High	White	Up	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	High	Black	Down	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	Moderate	White	Down	High Beams	Clear	Dawn		Unknown					
Overtaking	2	2	Low	Dk Blue	Down	Headlights Off	Clear	Light		South					
Overtaking	2	2	Moderate	White	Not Recorded	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	Moderate	Black	Not Recorded	Standard Lights	Cloudy	Light		Unknown					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Unknown					
Overtaking	2	2	Moderate	White	Up	Standard Lights	Clear	Dark		Unknown					
Overtaking	2	2	Low	White	Up	High Beams	Clear	Dark		Unknown					
Overtaking	2	2	Moderate	White	Down	High Beams	Clear	Dark		Unknown					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Unknown					
Overtaking	2	2	Low	Dk Blue	Up	Standard Lights	Clear	Dark		Unknown					
Overtaking	2	2	Low	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	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						
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 E: DESCRIPTION AND MAP OF ROUTE

The Blacksburg, Virginia map below, in Figure E-1, outlines the actual school bus route that was used in the Phase II test. A brief description of each site is also presented.

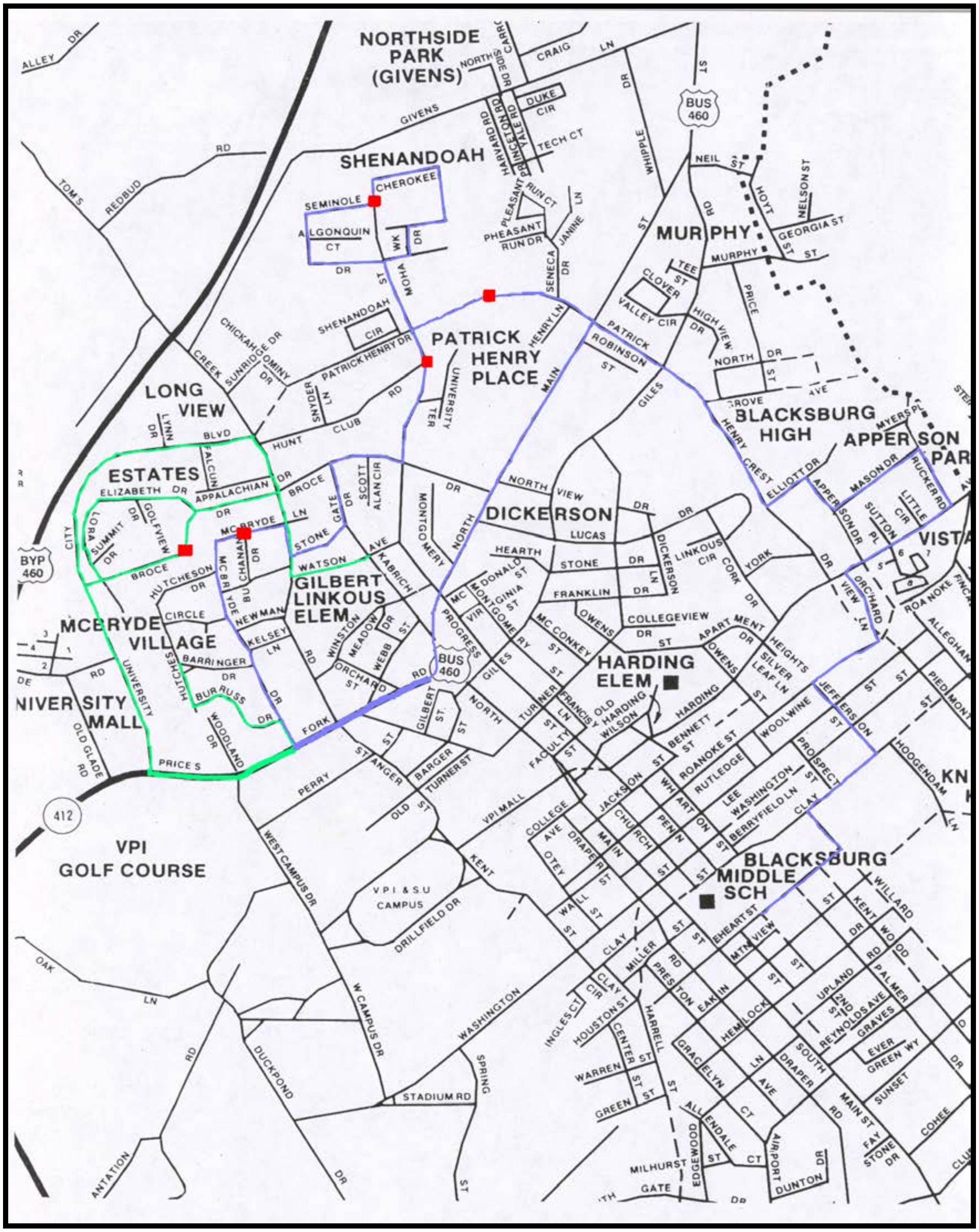


Figure E-1: Map of bus route used in the test.

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 road 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 road 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 F: INSTRUCTIONS ON RATING LICENSE PLATE AND PROFILE PICTURES

File Description

Each *Microsoft PowerPoint* file on the enclosed CD-ROM contains all of the information from each system test. If testing occurred at two different times in one day (e.g., November 7), there are separate files for the morning and evening sessions (e.g., 11_7AM.ppt and 11_7PM.ppt).

Each Power Point file contains multiple violations/tests. The number at the top of the page is what was used to identify each individual test; this number corresponds to the number used to label the video clip and the data file. Following the test identification number is a description of the passing type (i.e., Oncoming or Overtaking), the total number of lanes on the road, the lane that the violating vehicle was in, and the speed of the violating vehicle (i.e., for Phase I, low speed = 10 mph, moderate speed = 20-39 mph, high speed = 40 mph). An example of the heading for a file is shown below:

026 – ONCOMING – 2 lanes (2nd lane); Low Speed

For each test, there is one full frame from each of the three cameras (the camera is noted under each frame), as shown below. Note that the frame is the "best" shot of the license plate, profile, and facial image that was in the video.

Figure F-1: Front Camera

Figure F-2: Profile Camera

Figure F-3: 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 shown.

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.

Figure F-4: Front Licence Plate – Front Camera

Figure F-5: Profile – Middle Camera

Image Enhancement

It was determined that some of the images could be enhanced using the various tools in *Adobe PhotoShop*. For images that could be enhanced, there is a page in the file with the enhanced image.

Figure F-6: Front License Plate

Figure F-7: Profile

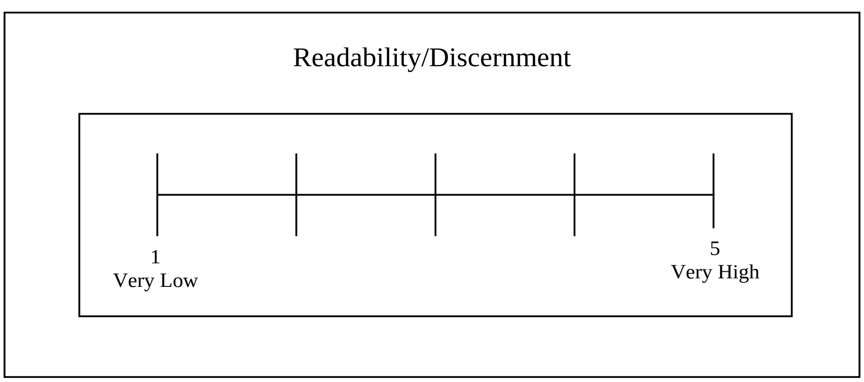
Video Data

The last page in each test condition contains the non-video data that was collected for each violation (trigger type, bus heading, speed, etc.) and any additional information on the particular condition (weather condition, light reading, etc.).

Qualitative Ratings

A *Microsoft Excel* spreadsheet is provided with the test condition labeled as well as a number of cells to enter your ratings. The rating scale and levels are shown below:

Table F-1: Rating scale.



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 do 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:

Figure F-8: License Plate Rating 1

Figure F-9: License Plate Rating 2

Figure F-10: License Plate Rating 3

Figure F-11: License Plate Rating 4

Figure F-12: License Plate Rating 5

Figure F-13: Profile Rating 1

Figure F-14: Profile Rating of 2

Figure F-15: Profile Rating 3

Figure F-16: Profile Rating 4

Figure F-17: Profile Rating 5

Figure F-18: Frontal Facial Rating 1

Figure F-19: Frontal Facial Rating 2

Figure F-20: Frontal Facial Rating 3

Figure F-21: Frontal Facial Rating 4

Figure F-22: Frontal Facial Rating 5

Images That Cannot Be Rated

In the *Microsoft Excel* spreadsheet, you will notice large numbers in some of the cells to be rated. These numbers are explained as follows:

A “999” rating is given if any of the following conditions apply (may be given for either plate or profile images):

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.
4. There is no data on the video (the system did not record a vehicle).

A “777” rating is given if there is not an enhanced image.

As indicated, we have provided you with a spreadsheet for use in the rating process. If a rating of 999 or 777 was appropriate, it was so noted and does not require you to rate it.

Rating Process

The rating process was conducted in the following order. First, each condition was rated for Readability/Discernment, 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

You will also notice columns in the spreadsheet that provide a space for you to rate the "enhanced data." The enhanced images were those that were cropped and the readability/discernment improved using *Adobe Photoshop*. These images are found on the *Microsoft Power Point* page labeled "After Enhancement." Not all of the images were able to be enhanced, therefore, there is not always a rating in these columns. 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 used for the images from each camera. 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). This is indicated in the heading of the condition, and there are frames and cropped images for each car involved. Therefore, though this was considered one test, each car was rated separately for readability/discernment.

APPENDIX G: MAPPING OF PROTOTYPE COMPREHENSIVENESS

This section describes the degree to which each of the preliminary specifications was met by the initial prototype system developed under this project. It is important to note that the prototype developed here was not expected to reflect all the features in the specifications. The specifications were aimed at a system that could eventually be fielded and used to perform all of the required activities of an automated illegal school bus passing enforcement system, not at this preliminary prototype. The intent of this document is to show where limitations exist in the prototype system and/or the implications of its functionality to help focus future development efforts.

Since the bulk of the functional requirements are located in paragraph 7.0 of the Subtask 2, Functional Specifications document (Huey and Llaneras, 2001a) and its subparagraphs in the specification document, only those sections are provided here. To the degree possible, this document includes only a high-level indication of each requirement and the extent to which it did not meet the requirements. Paragraph numbers have been preserved to allow referral back to the original document, and a brief description of the extent to which the requirement was fulfilled within the prototype development is provided. The full text of the specification is not provided here.

7.0 Requirements

Essentially, the system should be capable of detecting illegal school bus passing on the left (driver's) side of the bus, documenting the offense, archiving the data, allowing law enforcement review of the infractions, notifying offenders (or vehicle owners) of the offense, and providing status tracking through the remainder of the adjudication process. The detection, image capture, and archiving portions of this process are the chief concerns of this initial specification effort. Thus, the items related to them are much more likely to be captured in the prototype, while the post-processing details are, in many cases, minimal or overlooked completely.

7.1 General

The prototype system developed under the current project serves its purpose as a proof-of-concept. However, it does have a number of issues related to aspects of the ultimate product design that fall short in the prototype system.

7.1.1 Security

Little security is provided at this point. All components are exposed to tampering and no encryption is provided for the data. No tamper-proof evidence is created during the data capture phase.

7.2 Installation

7.2.1 Bus Identification

For accounting and evidence control, bus-specific information must be provided to the system. Information regarding the identity of the bus and some key measurement parameters will need to be available for evidence related to each violation. This will be especially true for cases in which a single system is rotated among various buses.

7.2.2 Mounting Location

The detection sensors are well located to provide coverage in the desired area, including the stop-arm. Packaging to reduce conspicuity and protrusions will need work in future versions.

7.2.3 Mounting

The system did not compromise the structural integrity of the bus body or chassis, nor disable any critical bus components. A modular system that allows swapping the system from bus to bus with minimal recalibration and decoy value for passing motorists was not considered in this version. It will be more important to do so in future versions that will be operationally tested.

7.2.4 Alignment

Little attention was paid to repeatability or ease of aiming, and no tamper resistance was provided for interior or exterior components. Both factors will require attention for future versions of the system.

7.2.5 Power Requirements

Power requirements, like packaging, were not considered beyond levels necessary to make the prototype functional. Isolation from the vehicle electrical noise, shorts, and over-voltage, as well as weather-proofing, will all need to be considered in the next generation prototype.

7.3 Maintenance

7.3.1 Cleaning

Consideration of cleaning requirements was not addressed for the initial prototype.

7.3.2 Calibration

7.3.2.1 Aiming

Consideration of periodic alignment requirements or calibrations was not addressed for the initial prototype.

7.3.2.2 Detection Coverage

Detection coverage adjustability to accommodate differences in mounting location and vehicle type is certainly possible in the prototype system. This flexibility will need to be considered and accommodated in future generations as well. Specific aim points to be used as markers for aim calibration will need to be documented for re-application to this particular bus and other buses on which the system is mounted

7.3.2.3 Speed Threshold

The speed threshold is adjustable under software control. No mechanical adjustments are required.

7.3.2.4 Tools

It is unlikely that any special tools will be required for calibration.

7.3.2.5 Responsibility

Responsibilities for personnel interacting with the operational systems will need to be assessed and assigned. Although some discussions regarding these allocations have taken place, initial field deployments will require detailed duty allocations based on legal and administrative requirements of the application.

7.3.2.6 Media

Strict procedures governing the documentation and access control of each step in the data chain were discussed but not implemented as part of this functional prototype implementation. Access control will be critical for more operational tests, but not for this effort. Encryption and write protection will also be important for future generations as well.

7.3.2.7 Operation Confirmation

The bus driver is able to see a telltale on the driver's console from his/her driving position. This allows confirmation of proper operation within the constraints of the system's self-test procedures and visually confirms detections. It would be more appropriate to have a green indicator to signify proper system operation than the current red indicator used for both system operation and trigger indications.

7.3.3 Programmability

Modifications to data collection and storage functions are possible in the field through access to system functions. Remote access may be useful for field deployments if system faults require technicians to interact with or diagnose the system functions.

7.4 Violation Capture

7.4.1 Detection/Classification

Detection encompasses the sensing of targets in or near the Violation Zone, classifying them as violators or non-violators, and providing violation capture inputs to the image capture component of the system. The key factors in this function are the coverage parameters (including environmental considerations), activation control, modes of operation, and outputs to the other components of the system.

7.4.1.1 Coverage Parameters

The detection coverage area extends along the driver's side of the bus out to the distances initially specified. However, the coverage area is not rectangular as depicted in Figure G-1 in the specification (shown here as Figure G-1). In more advanced systems, it may be desirable to extend the coverage area to 30 feet beyond the front of the bus. The system is capable of detecting vehicles entering the coverage area from either direction.

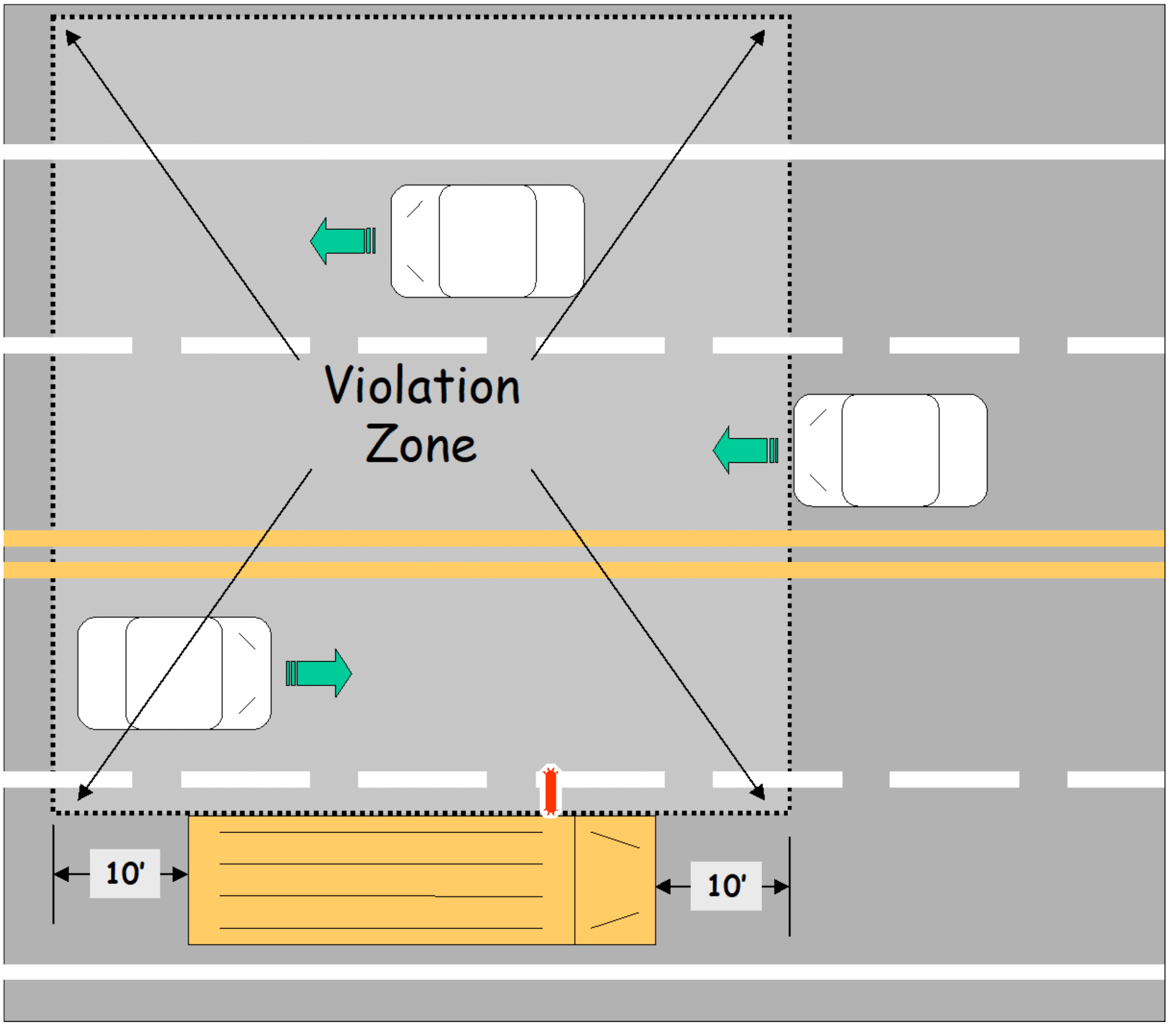


Figure G-1. Required coverage area.

The system appears to be viable for a variety of speeds. Whether the coverage includes speeds up to the specified maximum or with varied acceleration profiles, it has not yet been demonstrated. The system appears to provide adequate triggering time to allow image and data capture for vehicles traveling below 40 mph. Image capture at higher speeds or with different acceleration profiles may be difficult or impossible. Since detection is controlled by software, a variable minimum speed threshold should be possible, but this was not demonstrated, however, it seems feasible that this system could be fitted to other bus types without much difficulty.

7.4.1.2 Accuracy

It was not clear from the demonstrations whether areas exempt from "no passing" restrictions (e.g., areas beyond a physical median) could be ignored to minimize false alarm rates

7.4.1.3 Environment

The system is capable, to some degree, of detecting and classifying violators during daytime or nighttime lighting conditions. Glare will be a problem for image capture, especially for cases in which the image must be captured with background conditions that are very sunny or when bright headlights are present. Temperature and humidity (including precipitation) were not accommodated well with the prototype. Some consideration will need to be given before more operational testing can be performed. Vibration was not a concern for the bus on which the system was tested, but may be an issue for buses that are not as well maintained. Also, loading and unloading passengers will add vibration to the system. Perhaps testing to the extent of this issue should be assessed before operational testing begins.

7.4.1.4 Activation Control

The prototype system does not possess the automatic features of a production system. Thus, it does not automatically power-up when the bus is running or go through a test of the operation mode in the way a production system should. However, it does demonstrate the capability to work in either an operational or test mode (for documenting system events and diagnosing operational issues whether or not the bus is operating in its conventional role). Driver confirmation/indication is possible, but not necessary to classify an event as an illegal-passing situation.

7.4.1.5 Outputs to Other System Components

Passing parameters for image capture triggering to other system components allows captured data to be minimized. It was not clear from the demonstration that this was performed with maximum efficiency. Such efficiency may be upgradeable in future generations in order to minimize the capture of data that is not useful.

7.4.1.6 Radiation Output

This system uses cameras and image processing to eliminate concerns over radiation outputs and their impact on passengers or pedestrians. If the environmental impacts to system effectiveness can be adequately addressed, this will be an outstanding feature of the system.

7.4.1.7 Labeling

Labeling issues were not addressed with the prototype system. They will need to be addressed before operational testing with the system (involving children and the public) can be performed.

7.4.1.8 Equipment Documentation

Equipment documentation was not addressed during development of the prototype system. Materials outlining instructions for each individual expected to interact with the system will be required for operational testing, etc.

7.4.1.9 Power

See Section 7.2.5.

7.4.1.10 Interference to/from Other Devices

Although sensor radiation will not be an issue for passengers, pedestrians, or personnel interacting with the equipment, electronic radiation must not interfere with other bus sub-systems. Conversely, those other systems must not adversely affect this system. This issue is typically addressed by component electronics, but it must be considered system-wide as this effort develops from the prototype stage.

<u>7.4.2 Image Capture</u>

7.4.2.1 General

Distraction to violators or the bus driver does not appear to be excessive in terms of audible or visual indications of a violation.

7.4.2.2 Coverage/Perspectives

The prototype system demonstrated the potential to meet image capture requirements for some typical operational situations. It provided views of approaching and receding vehicles during the period that they were in the Violation Zone with a time sequence to provide self-authenticating evidence by showing progress through the Zone during the prohibited period. It also captured facial images from side and head-on perspectives during test exercises.

7.4.2.3 Image Quality

The system resolution appears generally adequate in providing license plate information with sufficient detail to identify vehicle ownership and the driver's face with sufficient detail to identify the driver. The extent to which analysts can reliably extract license plate and driver facial views will need to be tested and documented. Software control of camera control parameters should allow some accommodation for non-optimal lighting situations related to ambient lighting and capture of the driver image through the vehicle windows over systems that do not allow such control.

7.4.2.4 Aim

The aim of the image capture component(s) provided adequate image quality for the demonstrated conditions. However, although a small piece of the stop arm was visible from the forward-facing camera, it may be desirable to provide more context information by including a portion of the side mirror, the side of the bus, or a supplemental flashing telltale (tied to the stop arm lights) in the periphery of at least one of the images.

7.4.2.5 Image/Data Integration

Integration of data and video were not demonstrated. However, most of the data elements defined in the specification were available during the data capture phase of the demonstration. Ultimately, the images and data must somehow be inseparably meshed to document the violation for use as evidence.

7.4.3 Data Storage

7.4.3.1 Modes

Modes were not specifically demonstrated, but must logically exist during development to monitor system performance during early functional testing. The ability to have similar test modes available in a production should be maintained to allow troubleshooting, aiming, etc.

7.4.3.2 Non-Volatile Memory Size

Data storage capacities were not confirmed or tested during the prototype development. Thus, the ability to capture a certain quantity or duration of violations was not assessed. Feedback to maintenance personnel regarding memory usage or capacity was not demonstrated. Downloading data or swapping media were also not demonstrated.

7.4.3.3 Volatility

Although evidence storage for a production system must be non-volatile and tamper-proof, the prototype did not demonstrate that capability.

7.4.3.4 Content

Information content captured by the prototype system was largely complete in terms of bus and violation dynamics and details of the offending vehicle's ownership and the driver. However, administrative details about the configuration of the system (which may change between installations) was not captured or demonstrated.

7.4.4 Responsibility

Detailed allocation of responsibility was not fully considered for the prototype. As the system (including all the phases of processing) is developed, these issues will have to be considered and documented.

7.5 Post-Processing

Only limited post-processing procedures and requirements were considered and demonstrated during this development exercise.

7.5.1 Chain of Evidence

Evidence control and integrity maintenance were not demonstrated in the prototype system, but were discussed and recognized as key issues for future developments.

7.5.2 Format Conversion

Format conversion was not demonstrated during the prototype development. Depending on the output format of the system, proprietary or encrypted images or video will need to be converted to allow use by citation development routines.

7.5.3 Data Transfer

Data was transferred out of the prototype system after the demonstration. No demonstration of that process was provided.

7.5.4 Synchronization with State Motor Vehicle Licensing and Administration (MVA) Information

No demonstration of this process was relevant for the prototype development or testing since vehicles were staged. However, this synchronization is not a new process and should work much as it does for red light or automated speed enforcement applications.

7.5.5 Packaging for Law Enforcement Review

The process for reviewing the images was demonstrated in its primitive form. A similar process will likely be required in order to identify the relevant frames from the three video streams being collected for each violation, since the best images for each view do not occur simultaneously. Ideally, heuristics that speed the review process will be provided in future generations of the software. Details of the requirements and responsibilities for this operation will need to be refined during future developments.

7.6 Adjudication

None of the details of the adjudication process were demonstrated.