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Enhanced Camera/Video Imaging Systems (E-C/VISs) For Heavy Vehicles: Final Report

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13. ABSTRACT (Maximum 200 words)

Tests were performed to determine the feasibility of developing an Enhanced Camera/Video Imaging System (Enhanced C/VIS or E-C/VIS) to provide heavy-vehicle drivers with better situation awareness to the sides and rear of their vehicles. It is well known that large blind spots currently exist in these areas and that sideswipe crashes can occur as a result. An additional goal was to extend the operating envelope of conventional video to nighttime and to inclement weather. A three-channel system was envisioned in which there would be a camera at each (front) fender of the tractor looking backward along the sides of the rig. The third channel would be aimed rearward from the back of the trailer. The current document describes the project results. Indoor tests involved selection of components having the best capabilities, while early outdoor tests used the selected components in a single-channel side mounted system. Subjects evaluated rain and dark conditions. Results were satisfactory. Once developed, the three-channel system was tested and found to work well in the nighttime and inclement weather environments. Street lighting was also included in the testing.

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METRIC CONVERSION CHART

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

EXECUTIVE SUMMARY

This document provides an overview of all tasks performed under research contract DTNH22-05-D-01019, Task Order 6. An earlier document (Task1 of Phase 1) in which technologies were investigated and approaches recommended for the development of an Enhanced Camera/Video Imaging System is briefly summarized. Thereafter, all additional work performed is documented.

The Enhanced Camera/Video Imaging System (also referred to as an Enhanced C/VIS or an E-C/VIS) is a system designed for use on heavy vehicles, having a greater envelope of operation than previously developed C/VISs. Specifically, such a system as defined in this document is intended to provide enhanced views to the sides and rear of a heavy vehicle with an operating envelope that includes daytime and nighttime, as well as clear and inclement weather. Such a system has the general objective of improving the situation awareness of the heavy-vehicle driver. It has the specific objective of reducing sideswipe crashes when heavy vehicles merge or change lanes. The system is intended to supplement the current side mirrors—not to replace them.

This document describes the methods and results used to develop a viable technological approach to E-C/VIS design. Such an approach necessarily had to be limited to technology that could be developed at a reasonable cost; otherwise there would be no way that the technology could be adopted by commercial carriers, the great majority of which operate on close financial margins. Several steps were taken in this process and are fully described in the various chapters of the report.

Work began with testing of one-of-a-kind components in a darkened laboratory. Numerous visible and infrared (IR) illumination sources, cameras, and filters were examined, with the objective of video chain development operating over the entire lighting envelope. The tests included an object vehicle or target, so that images could be compared.

Eventually a single camera and two different illumination sources were selected as viable candidates. A second camera had some usable capabilities, but was lacking in that it was only monochrome and did not possess sufficient sensitivity in subdued light. Many camera filters were tried, but none improved the video image. The selected "first place" camera had daytime color capability and nighttime monochrome (B/W) capability, and it was sensitive at night to both visible and near IR radiation illumination. One of the illumination source selected candidates was visible and the other was near IR. This testing produced a wealth of information efficiently.

Once the components had been selected, outdoor stationary tests were performed. A major outdoor "simulator" was developed which included a tractor-trailer equipped with multiple units of the visible and IR illuminators. A single camera was housed in a waterproof enclosure and was mounted at the passenger-side front fender. The corresponding monitor was placed in the cab in a position at the passenger-side A-pillar. The remainder of the facility produced wind at up to 73 mph (117.5 km/h) as well as rain. The rain system was composed of the wind

generation system with 10 nozzles, three overhead towers, two mist generation nozzles and all support systems for storing and pumping the water, including hoses and connections. This system allowed testing of highway rain conditions, but with the heavy vehicle and surrounding vehicles standing still. This made testing possible without having to drive the heavy vehicle and without having to generate rain artificially using multiple rain towers over long stretches of roadway.

Because the outdoor facility took a good deal of time to construct, parallel efforts were carried out regarding image processing and experiment design for use of the stationary outdoor facility. The image processing routines allowed "outlining" of targets or objects. This processing was incorporated in the outdoor stationary test setup, but required use of a monitor with vector graphics array (VGA) input, so that delays in presenting the video image would be short.

Once the facility was ready, testing took place using VTTI employees as subjects, each of whom experienced and evaluated all combinations of conditions. The combinations included daytime color and nighttime B/W combined with clear and rain conditions. Also included were a variety of target vehicle positions. For the nighttime/visible illumination conditions, the subjects also rated the discomfort glare and loss of discriminability when viewed from the target vehicle position (that is, outside the heavy vehicle).

Results demonstrated that all ratings provided by the subjects were satisfactory or better. Glare from the visible illumination was found to be well within an acceptable level; that is, not a problem. However, results showed that the IR illuminators had slightly better ratings and, of course, produced no glare. Therefore, the IR illuminators were considered to be the better choice. The image processing seemed to work well. A few problem areas were uncovered, and solutions were suggested for them.

Results of the outdoor stationary tests were then used to adjust the recommended three-channel system design somewhat. However, the basic concept remained the same. One change in particular was substantial, having to do with the rear camera. Originally this camera was to be a straightforward rear-looking camera. However, the redesign suggested that the camera should be a wide-angle multipurpose look-down camera mounted at the top rear of the trailer. This concept was developed in the original C/VIS project. By making this change, it was anticipated that heavy-vehicle drivers in an equipped tractor-trailer would be able to assess "where" object vehicles in adjacent lanes were relative to the trailer. In addition, the driver of the heavy vehicle would be able to assess the situation directly behind the trailer or cargo box. Consequently, heavy-vehicle drivers would be able to determine clearance or overlap with much greater accuracy. They would be able to do this by a combination of looks to the rear monitor, the side monitor, and the mirrors. This approach was intended to make it possible to avoid or at least reduce sideswipe crashes. In addition, the drivers would have greatly improved coverage of blind spots along the sides and to the rear with the full Enhanced C/VIS. Recommendations for redesign, along with the corresponding justifications, were proposed.

The later chapters of this document present the conditions and results of (dynamic) Smart Road tests. The Smart Road is an instrumented roadway closed to the public and used strictly for research and development. This roadway was used to test a full three-channel system under realistic highway conditions. The tests were performed using Class A commercial driver's license (CDL) drivers. Both Baseline (mirrors only) and Enhanced C/VIS (mirrors plus enhanced video) conditions were examined under nighttime and artificial lighting conditions. Both rain and clear conditions were examined so that comparisons could be made. Rain was generated using more than 70 rain-producing towers. Prior to the Smart Road dynamic tests, drivers also performed additional static tests directed toward determining object detection and recognition capabilities of the E-C/VIS compared to Baseline conditions. These tests demonstrated superior performance for the E-C/VIS while at the same time serving as a "warm-up" task for the following Smart Road tests.

The results of the dynamic (Smart Road) tests were quite promising. They indicated that the Enhanced C/VIS worked well under all conditions and that performance, eye glance, and opinion data all reflect improvements with the Enhanced C/VIS operating. The results show that the extended range of the Enhanced C/VIS is quite useful and should reduce sideswipe crashes, increase situation awareness of heavy-vehicle drivers, and also meet with their acceptance. Minor problems remain with the developed system, which are listed in the final chapter of the report, but these problems should not detract from the major conclusions considering that they were present during the gathering of data. In addition, further refinement might eliminate these problems.

In general, this project was successful in developing and demonstrating an Enhanced C/VIS with properties that provide an extended range of operation, using present-day equipment available at a reasonable cost, and providing performance, eye glance, and opinion improvements using CDL drivers. It is recommended, therefore, that field tests for an "operationalized" Enhanced C/VIS should be undertaken.

ABBREVIATIONS AND NOMENCLATURE

AGC: automatic gain control; electronic system for automatically adjusting the brightness or level of a video signal (in this research)

ANOVA: analysis of variance (a statistical analysis technique that allows condition comparisons)

A-pillar: the structure at the left or right side of the windshield

α: criterion level for statistical significance, set to 0.05 throughout all analyses in this report; however, in some cases, values above 0.05 are reported for clarity

baseline configuration: in this document, a heavy vehicle configured without an operating camera/video imaging system

B/W: a black and white (shades of gray) or monochrome video image or system

camera field of view: horizontal field of view in degrees of a camera in its normal or upright position, regardless of how the camera is oriented

CCD: charge-coupled device (a form of imaging surface technology)

cd: candela, a unit of measure of illuminance

CDL: commercial vehicle driver's license

channel: one video chain

cm: centimeter

CMOS: complementary metal oxide semiconductor (a form of solid state technology used in imaging surface technology, and in integrated circuits and processors)

confederate experimenter: a qualified individual who assists a lead experimenter in conducting an experiment

counterbalance: a technique used in behavioral research experiments to control for learning, fatigue, and time on task by systematically varying the order of presentation of conditions

C/VIS: camera/video imaging system; a video system composed of a camera, monitor, and all supporting subsystems including lens, interconnection, video processing, and power

deg; ^{o}: angular unit of measurement, degree

DGPS: differential GPS, differential global positioning system

DVI: driver-vehicle interface

Enhanced C/VIS; E-C/VIS: an enhanced camera/video imaging system; that is, one that has a wider operating envelope in terms of weather and illumination level; video processing may be used to further increase the operating envelope

enhancement: a camera/video imaging system that replaces a non-essential mirror, supplements a non-essential mirror, or provides an additional view around a heavy vehicle

FMCSA: Federal Motor Carrier Safety Administration

F.O.V., FOV: field of view

glance probability: the total number of samples that the driver fixates on a given device or location divided by the total number of samples taken; an indication of the information gathering use of the given device or location

IP: instrument panel

IR: referring to infrared radiation

LED: light-emitting diode

ma: milliampere

mm: millimeter

msec, ms: millisecond

NHTSA: National Highway Traffic Safety Administration

nm: nanometer

NTSC: National Television System Committee

Post-processing: processing of a video image after it is in video form, based on spatial operations of the image itself

processing: as used in this document, a method of image manipulation having the goal of improving distinction of image features or objects

Smart Road: the Virginia Smart Road, located at the Virginia Tech Transportation Institute in Blacksburg, VA. The Smart Road is used for roadway, vehicle, and driver research. It is closed to the public.

SNK: the Student-Newman-Keuls post hoc statistical test

surrogate: a camera/video imaging system that replaces either the flat or convex (essential) mirror on the driver or the passenger side of the tractor

SUV: sport utility vehicle

Tukey HSD: the Tukey Honestly Significant Differences post hoc statistical test

VAC: volts a.c. (alternating current)

VGA: vector graphics array/adapter; a display standard referring to a video adapter capable of resolution of up to 640 (horizontal) by 480 (vertical) pixels

video chain: a single video system composed of a camera, monitor, and all supporting subsystems including lens, interconnection, processing, and power

VTTI: Virginia Tech Transportation Institute

within-subject: a term used to indicate that the same participants in a research experiment are used in differing conditions. In other words their measures are taken for differing settings of one or more independent variables.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER 1. INTRODUCTION

BACKGROUND

The National Highway Traffic Safety Administration (NHTSA) funded an earlier research project at Virginia Tech Transportation Institute (VTTI) involving the use of Camera/Video Imaging Systems (C/VISs) in heavy vehicles (earlier portion, Contract DTNH22-00-C-07007, Task Order 18, Track 2; later portion, Contract DTNH22-05-D-01019, Task Order 6, Track 2). This project was completed in June 2007 with both a supporting research document and a final specifications document submitted to NHTSA at that time (Wierwille, Schaudt, Spaulding, Gupta, Fitch, Wiegand, and Hanowski, 2007a; Wierwille, Schaudt, Gupta, Spaulding, and Hanowski, 2007b). This project had the objective of devising, developing, and testing these systems so that recommendations could be made and specifications written. Both surrogates (which take the place of existing side mirrors) and enhancements (which provide augmented views not ordinarily available to the driver) were studied. Tests were limited to conventional video systems with cameras at appropriate locations on the exterior of the vehicle and with monitors in the cab at locations that were selected on the basis of human factors considerations and preliminary testing. Sixteen different concepts were studied both conceptually and experimentally. The concepts were then revised or discontinued, based on the results. A final set of 11 concepts was recommended, and specifications were written accordingly (note that several of the concepts were composed of pairs; that is, driver and passenger-side versions).

As the original work drew to a close, VTTI was awarded a contract addition (Contract DTNH22-05-D-01019, Task Order 6, Track 4). Its purpose was to extend the work of the original contract into less favorable environmental conditions, namely nighttime and inclement weather. This contract also introduced the concept of situation awareness to the sides and rear of the heavy vehicle. In other words, it was more specific in that a three-camera system was to be further developed: one camera on each side of the heavy vehicle and one at the rear (Figure 1). The intended purpose of the work was to reduce or eliminate blind spots and other uncertainties that might occur along the sides and to the rear of the heavy vehicle. The objective in so doing was that the driver of the heavy vehicle would be better informed regarding the environment around the sides and rear of the heavy vehicle; that is, he or she would have better situation awareness. This was to be accomplished under the widest possible environmental envelope, while also considering costs. Clearly, costly technologies would not be appropriate because of the highly competitive nature of commercial motor carrier operations. Consequently, VTTI developed a system using "best available technologies" with consideration given to total cost of implementation of a final system for use in a heavy vehicle. Specifically, it was assumed that the total cost in production should not exceed $6,000.

The system was envisioned as an enhancement; that is, the side mirrors would remain on the vehicle even though the video system was to be added. Under such circumstances, malfunction of any of the three video chains would still allow the heavy vehicle to be driven in a conventional manner.

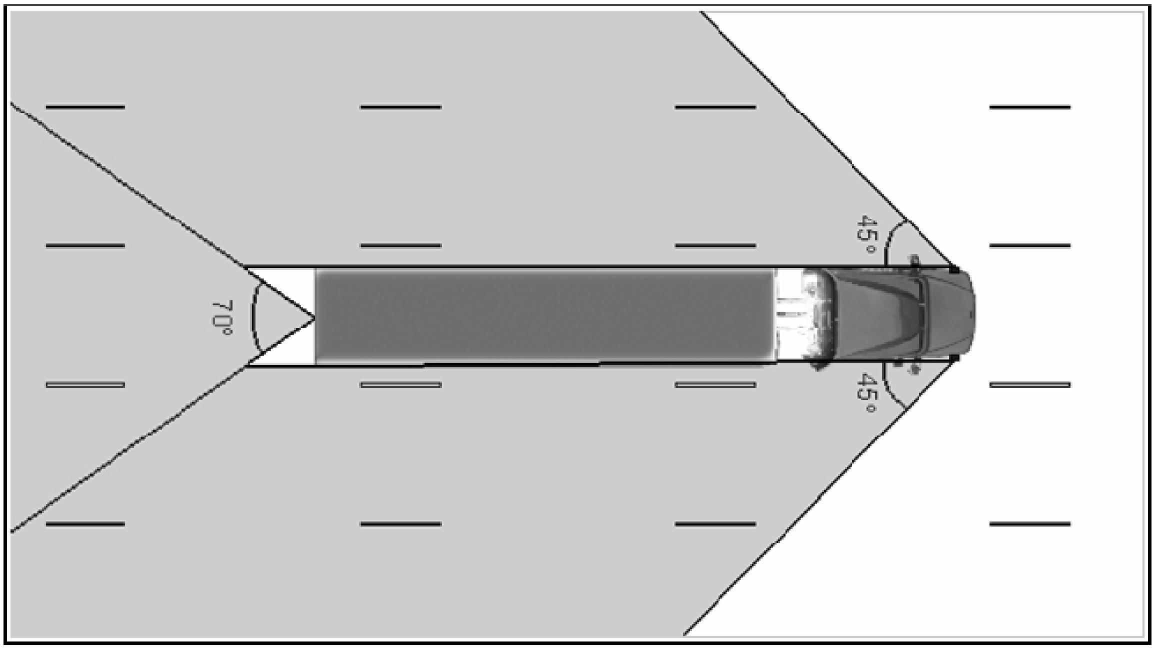


Figure 1. Proposed Initial Concept of an Enhanced Camera/Video Imaging System

Overview of the Technology Review Report (Submitted Previously)

In November 2006 VTTI submitted its first major report under the new contract (Wierwille, Bowman, Alden, Gibbons, Hanowski, Blanco, Leeson, and Hickman, 2006). This report reviewed available, applicable technologies relevant to "all weather" video systems as applied to heavy vehicles. Report topics included radiation capture/image acquisition, scene illumination (including ultraviolet, visible, and infrared [IR] radiation), camera components and requirements, post-image acquisition processing (both analog and digital), monitor location and size, driver-system interface, and current night vision systems.

Following this technology review, a recommended approach was developed and presented. It included the technologies to be tested, the camera and display locations, the post-processing to be used, and the driver-system interface.

Organization of the Current Report

The current report details the remainder of the project tasks. These are briefly described so that the reader can understand the logical progression of events that took place in completing the project.

Initial Laboratory Testing

Prior to any formalized human factors testing, it was deemed necessary to reduce the number of alternatives to a manageable level. This testing involved evaluation of combinations of cameras, filters, and illumination sources in hopes of finding combinations that worked well in darkness. Tests on candidate components were performed in a storage building in which lights were extinguished. This testing saved resources because a wide variety of combinations could be tested using one-of-a-kind items. A single viable system (with two possible sources of illumination) was derived from these tests. Chapter 2 describes these tests and the results obtained.

Stationary Outdoor Testing in Daytime and Nighttime with Rain and Clear Conditions

A major research facility was developed specifically to allow stationary human factors testing of the system derived on the basis of the initial laboratory testing. This facility was basically an outdoor stationary simulator of highway conditions. The facility included a high-power wind/rain generation system, rain towers, wheel mist generation systems, a rain production system, a target vehicle, a lead vehicle, a passenger-side video chain, visual and near IR illuminators, digital processing, and, of course, a tractor and trailer. Experiments were devised as the equipment was being developed. The system design and the experimental design for human factors testing are described in Chapter 3.

Processing was accomplished digitally and was designed to emphasize shape outlines so that vehicles and other objects could be distinguished more easily in the monitor images. A second major objective of the processing was to reduce bloom due to bright spots caused by headlights of vehicles alongside.

System Modifications Following Initial Trial Runs

Once the outdoor simulation system was up and running, informal tests of the recommended configuration were run on an initial trial basis. The main reason for these initial tests was to ensure that the video system would be capable of producing images at night with at least one form of illumination. It became clear from these tests that dark colored vehicles presented a problem in that it was virtually impossible to produce an image of the vehicle aside from headlight bloom. Light colored vehicles could be seen, but for dark vehicles (black or dark blue) only the headlight blooms could be seen. Apparently, the walls of the darkened laboratory (a dark vehicle was used for the indoor tests) reflected sufficient radiation to allow discernment of the vehicle outline, unlike the outdoor tests.

A multifaceted approach was used to find a solution for the dark vehicle problem; however, none of the available solutions worked well. An additional idea was to shift the *rear* camera to the top of the trailer and use the "rear wide-angle trailer multipurpose look-down enhancement" concept that was developed in the previous contract. This approach changed the objectives slightly in that the headlight blooms could then be used to determine whether or not there was clearance at the side of the trailer near the rear end. This approach did not require any modification of the experiments to be performed, because only the side camera was instrumented. The only modification made to the original protocol was to use an "olive-colored" vehicle as the object vehicle, instead of dark blue. This vehicle was considered to represent a more-or-less neutral or representative vehicle; that is, one that was neither too light nor too dark. Use of this vehicle was, of course, a compromise, because all colors of vehicles are encountered on the highway. The system modifications prior to formal human factors testing are described in detail in Chapter 4.

Formal Human Factors Stationary Testing

Once the issues of preliminary outdoor testing were resolved, formal human factors testing was carried out. Eight subjects participated in both a day and a night session, and experienced every one of the experimental conditions. Thus, a totally within-subject experimental design was used. Results of these tests are presented in Chapter 5. The daytime and nighttime testing involved clear and rain conditions. The rain conditions were set up so that they simulated highway-speed conditions along the side of a heavy vehicle, with a large engine-driven fan, a lead vehicle, an object vehicle, and a variety of rain towers, spray nozzles, and support equipment to generate realistic highway rain conditions.

Results demonstrated that the video system fared well in the tests. All ratings for image quality were at the moderately good level or better, suggesting that the system met requirements under all conditions tested. In addition, the glare created for other drivers by the nighttime visible illumination (added to the heavy vehicle) was well within tolerable limits, as determined by rating values of discomfort and visual discrimination of the lead vehicle. The results taken together suggest that the final system design should be similar to the tested system which, of course, had already been heavily optimized by the indoor testing and the preliminary outdoor development testing.

Final Recommended Three-Channel System Design

Results of all the tests were combined and analyzed to determine any reconfiguring necessary for the final three-channel system design. A list of conclusions was constructed having bearing on the hardware and software. These were then transformed into modifications of the originally designed system. Chapter 6 describes these conclusions and modifications. Some of the more important recommended modifications were the use of the wide-angle look-down enhancement at the rear of the trailer, deletion of the backlight control in the driver-vehicle interface (DVI), development of common switching from daylight color to B/W nighttime video for the three channels, use and re-aiming of the IR illuminators, elimination of the visible illuminators, glare shading of the cab interior monitors and the outside cameras, shading of the side marker lamps from the side cameras, use of processing, and retention of the side mirrors on the tractor. Many of the recommendations were simple confirmations, while others represented changes from the preliminary design.

Smart Road Tests and Other Tests

Once the recommended changes in the final design were developed, work began on planning the Smart Road tests using naïve CDL (commercial driver's license) drivers. Chapter 7 describes the design of these tests. They were intended to serve as verification of the static findings, to obtain an initial impression of CDL driver acceptance, and to take a further look at rain effects on the image quality. The tests were also intended to determine if improvement occurs in *locating* object vehicles along the sides of the tractor-trailer in nighttime and inclement weather. This work represented an extension of the results obtained with the daytime C/VISs tested in the original C/VIS contract.

Additional goals were set regarding the Smart Road tests; namely, the determination of any highway lighting effects or interactions with rain. In addition, it was considered desirable to study object detection and recognition. However, careful study suggested that object detection and recognition could best be studied using a blacktopped area and stationary conditions. This provided comparative information while affording maximum safety in data gathering. The object detection and recognition tests had a secondary benefit of providing drivers with initial familiarity of the Enhanced C/VIS, prior to taking the equipped vehicle onto the Smart Road for dynamic tests.

Chapter 8 provides the results of the static object detection/recognition tests and the Smart Road dynamic tests. This chapter contains the statistical results as well as plots of important comparisons. It generally demonstrates that both driver object detection/recognition and driver performance in dynamic situations is improved with the Enhanced C/VIS. It also shows that driver opinion of the Enhanced C/VIS is positive.

Summary

The final chapter of the report (Chapter 9) provides a summary of what has been learned and what minor problems remain, and then makes recommendations for further developments regarding Enhanced C/VISs. Appendices are included providing greater detail regarding hardware and rating scales used during the various studies.

CHAPTER 2. PRELIMINARY INDOOR TESTING OF ILLUMINATION SOURCES, FILTERS, AND CAMERAS

Early in the project, it was recognized that there were many available illumination sources, filters, and cameras. It was particularly recognized that there were too many combinations for formal human factors testing. Consequently, it was decided that preliminary nighttime testing of various combinations would be needed in order to select those with the most promise. The tests were intended to provide an indication of image quality obtained in clear nighttime conditions, as simulated in a dark storage building.

To undertake the testing, illumination sources were studied for visible, near IR narrowband, and near IR broadband candidates. Filters and cameras were also studied for potentially viable candidates. Immediately thereafter, equipment was specified and placed on order. Thirteen visible sources of various kinds, three narrowband near IR sources, and one broadband near IR source were obtained. The visible sources are shown in Figure 2 and the four IR sources are shown in Figure 3. The visible sources (Figure 2) were primarily amber (yellow), but some of the sources were also red or white, so that these could also be checked for any marked differences. In Figure 3, the three IR sources to the left are narrowband light-emitting diode (LED) sources and the IR source on the right is a broadband incandescent source.

Figure 2. Visible Illumination Sources used in the Preliminary Testing

Figure 3. Near IR Illumination Sources used in the Preliminary Testing

Four cameras were also obtained. These cameras had specific characteristics that made them viable candidates. Three of the cameras were capable of daytime color and nighttime B/W (black and white, i.e. monochrome) video signal generation, with relatively high nighttime sensitivity. The fourth camera was a B/W camera designed for automotive use and having the capability of overcoming large variations in picture contrast *within a given image*, thus possibly being suitable for suppression of headlight glare within an image.

The cameras were:

- Toshiba CCD (charge-coupled device) color camera IK-65WDA. This camera had an extremely wide dynamic range and was supposedly capable of working at 0.001 lux.
- Mintron CCD color camera 63V5H. This camera supposedly had capabilities similar to the Toshiba IK-65WDA.
- Toshiba CCD color camera IK-64DNA. This camera also had a wide dynamic range, but specifically was intended for use with both visible and near IR nighttime illumination. A filter inside the camera could be electromechanically switched out for nighttime use to increase the sensitivity of the camera.
- Sensata (Previously Cypress) CMOS B/W camera ACM100. This camera possessed an "autobrite" feature which was capable of suppressing bright spots in the image and enhancing details in dark areas in the image. This camera was a sealed camera with a fixed but interchangeable lens that could be mounted in an automobile assembly, such as in the grill, with a protective clear cover. This camera was selected because of the

possibility that it would be capable of suppressing headlight blooming in the video image and because it was already "hardened" for surface transportation usage.

The cameras are shown in Figure 4. The two Toshiba cameras and the Mintron camera used the same lens, which is shown on the Toshiba IK-64DNA camera in Figure 4. The Sensata camera, as mentioned, had its own lens.

Figure 4. Cameras Used in the Preliminary Testing
(The three cameras to the left in the figure used the same lens, which is shown on the IK-64DNA.)

A wide variety of filters was obtained. These filters were intended to pass or block various parts of the light spectrum, including IR. All filters were obtained from Maxmax.com, an organization specializing in camera filters for daytime and nighttime use. The filters were as follows:

- XNiteBPG, a narrow pass-band filter passing illumination in the 840 to 850 nm range, intended for use with 850 nm IR LED illuminators.
- XNite780 and Xnite715 broadband filters, passing illumination in the entire near IR range of 780 to 1400 and 715 to 1400 nm, respectively, intended for use with broadband near IR illuminators and natural near IR.
- XniteCC2, a filter passing visible and broadband near IR illumination (to approximately 900 nm).
- XniteCC1, a filter passing visible light only (to approximately 650 nm), and intended for use with visible illumination.

The filters are shown in Figure 5 (all filters except the XNiteBPG fit the front of the camera lens used on the two Toshiba and the Mintron cameras). The XNiteBPG was larger and was temporarily affixed to the front of the camera lens using tape to hold it in place.

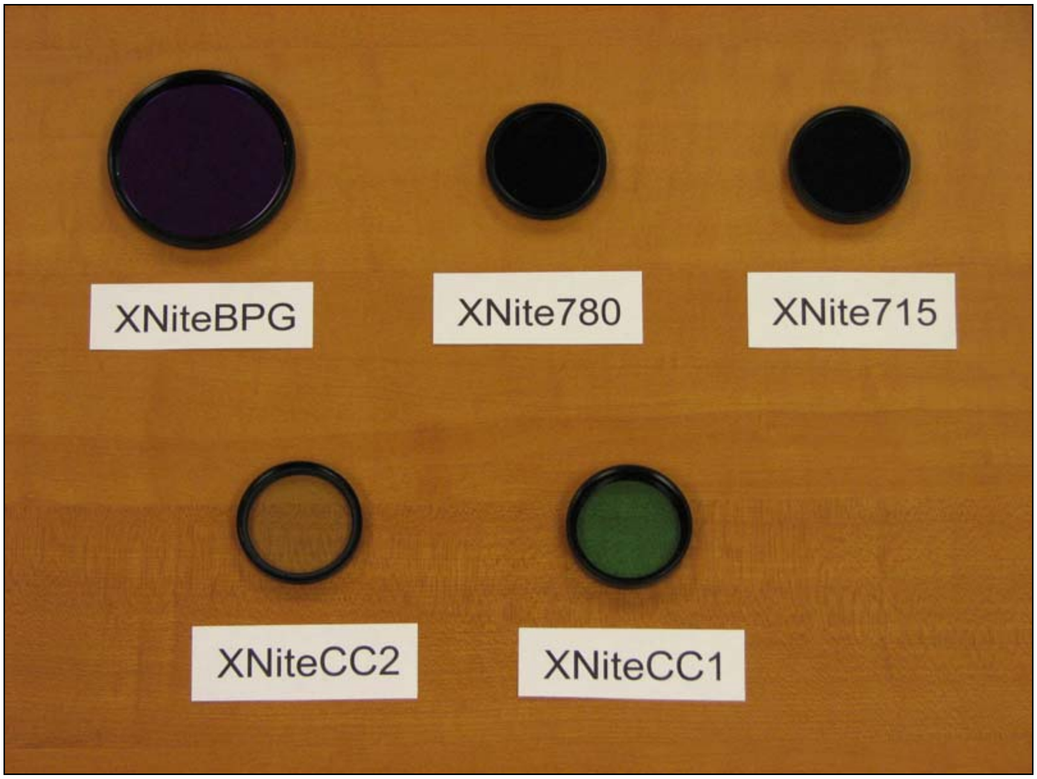


Figure 5. Filters Used in the Preliminary Testing

It should be mentioned that only one of each type of filter, camera, and illuminator was initially obtained, so that preliminary tests could be performed. The concept was to test various combinations with the idea of determining which systems worked effectively. This type of testing represented a form of efficiency that saved unnecessary expenditures prior to configurations being developed. The idea was that once the initially viable concepts were worked out, additional items could be ordered as needed for outdoor testing.

INDOOR PRELIMINARY EXPERIMENT

All initial testing was performed in a dark storage building. The testing was set up to be similar to a nighttime situation in which a car was alongside the heavy vehicle, as shown in Figure 6. The cameras had lenses set for approximately 45 deg horizontal fields of view, as would be the case for the side cameras on the tractor. A single illuminator was used for each test. It was located closer to the parked vehicle, similar to an arrangement in which the illuminator would be along the side of the tractor-trailer combination.

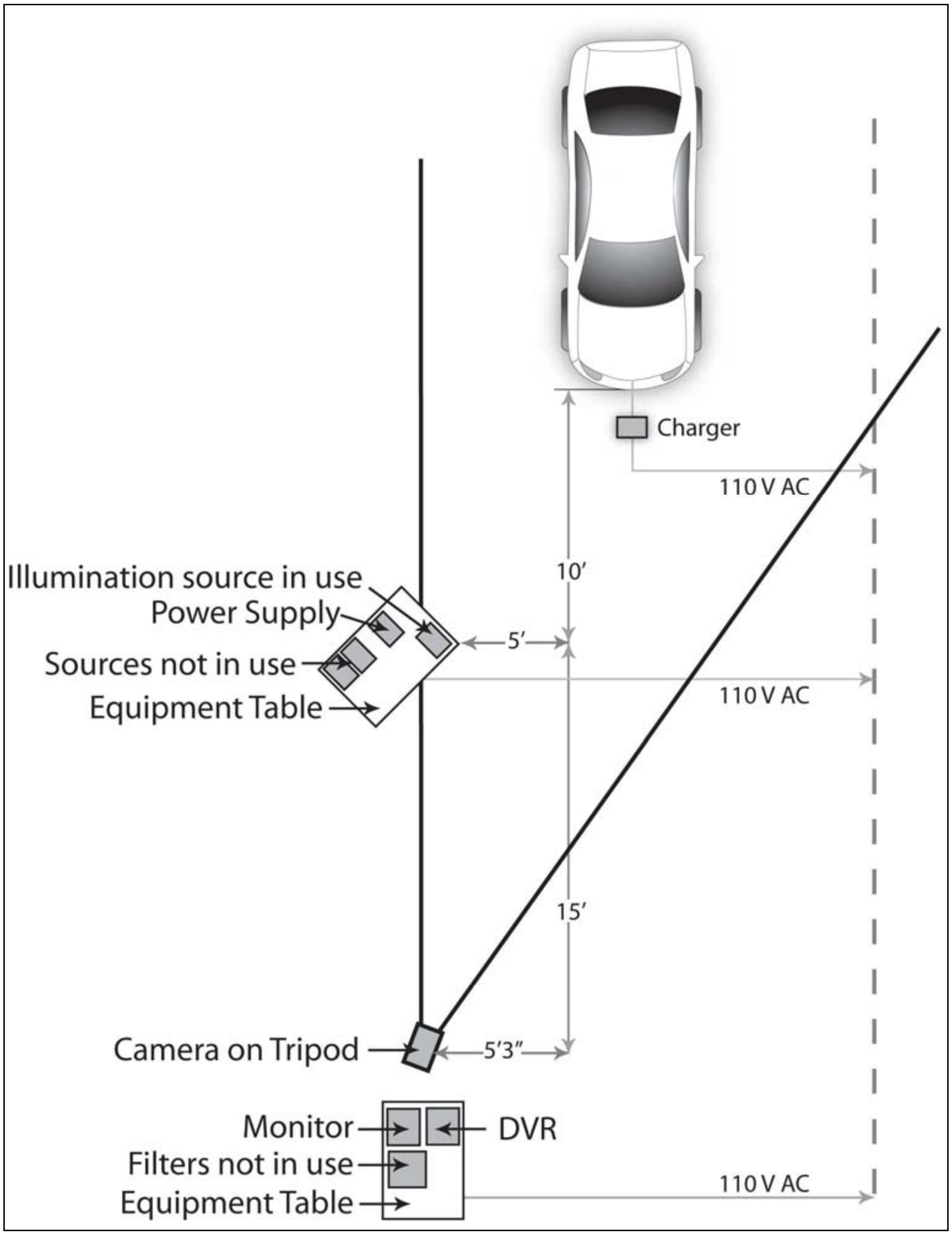


Figure 6. Equipment Layout for the Preliminary Testing

A dark blue, mid-size sedan was used as the object. This color had low reflectivity and was therefore deemed appropriate for the tests because the results for lighter-colored vehicles would probably be better. The image of the sedan could be tested both with its lights on and with its lights off. Both conditions were considered important. The lights-off condition would correspond to a dark object alongside, such as a vehicle or trailer without exterior lighting, whereas the lights-on condition would correspond to the usual situation in which a vehicle is alongside and illuminated in the usual manner for nighttime driving.*

* In this report, lights on and headlights on indicate that all night driving lights on the vehicle are on including the low-beam headlamps (high beams are not on).

Selection of Illuminators

It was initially found that the IK-64 DNA camera was sensitive to both visible and near IR illumination, as advertised. Therefore, this camera was used to reduce the number of candidate illumination sources by eliminating those that did not have adequate output or beam patterns or both.

Tests were run as follows:

1. The given illuminator was connected to a power supply at the rated voltage with sufficient current. All LED illuminators (visible and IR) were tested at 13.0 volts, which would correspond to truck lighting voltage. The incandescent broadband near IR illuminator required a 110 VAC (volts, alternating current) source, and was tested using that voltage.
2. The camera output was switched to B/W (nighttime) setting. In this setting, the built-in filter was electromechanically removed so that the camera had its greatest sensitivity.
3. The image from the camera was displayed on a video monitor for purposes of examination.
4. The beam width and output of the source were assessed by projecting the source on a side wall of the building and observing the result on the monitor.
5. The source was then aimed at the parked vehicle and assessed in regard to its ability to illuminate the vehicle, both with lights on and with lights off.

As previously mentioned, the illuminators are shown in Figures 2 and 3. The results of these tests were as follows:

1. Visible color had little effect on the apparent ability to illuminate the parked vehicle. While white produced slightly brighter illumination, red and amber produced results that were almost as good.
2. The size and number of LEDs had a dramatic effect on illumination, with smaller units (those containing only a few LEDs) found wanting in that they did not adequately illuminate the parked vehicle.
3. The majority of visible LED units produced beams that were too narrow to be usable. To broaden these beams horizontally, two of the most promising units were modified by removing a rectangular front section and adding a dispersive lens of the same color. The dispersive lenses were epoxied to the base units. Figure 2 shows these two units in the lower left and lower right corners. The red unit (lower left corner) used the oval unit above it as a base unit. The amber (yellow) unit (lower right corner) used a slightly different base unit that is not shown in the photo. An expanded view of the amber illuminator is shown in Figure 7. The red unit was intended for use at the back of the heavy vehicle, and the amber unit was intended for use along the sides (tractor and trailer or straight truck). The two units when modified were found to operate moderately satisfactorily. However, outdoor glare tests were expected to be run later on these two units.

Figure 7. Close-up View of the Recommended Amber Illuminator

4. As mentioned, three narrowband near IR illuminators were tested. They are the three shown to the left in Figure 3. The two units on the left produced beams that were too narrow and did not produce adequate output. Use of clear dispersive lenses had little effect in widening the beams, apparently because the original dimensions of the two LED arrays were relatively small. In addition, these units both produced a visible glow which, although not bright, might (in the future) draw a following driver's eyes to them.
5. The rectangular array LED system shown third from the left in Figure 3 produced superior results, both in terms of area of coverage and in terms of illumination level. The array contained 140 LEDs in a 12 by 12 array (with 4 LEDs deleted in one corner). This array was rotated 90 deg in use, so that the longer dimension was horizontal. This array produced *no* visible light output, which would make it unnoticeable to following drivers except by its form.
6. The broadband near IR illuminator is shown on the right in Figure 3. This illuminator was the only one of its type that could be found in a thorough search of all known vendors. It required 110 VAC for operation, and it used an incandescent lamp with a filter that removed most of the visible light. The incandescent lamp itself produced white light with a low color temperature (that is, somewhat biased toward the yellow-red end of the visible spectrum). This source produced adequate illumination, with results similar to the rectangular LED array just to its left in Figure 3. However, the beam width was slightly narrow, it used a great deal of power, it emitted substantial heat, and it produced a visible glow. Interestingly, the glow was brighter off axis as compared with on axis. The greatest glow appeared at an angle of 75 to 88 deg off the longitudinal axis.

The beam width problem could probably have been handled, but the other shortcomings suggest that the LED source should be given preference.

The tests of illuminators made clear that three illuminators were superior to all others. For visible illuminators, the tests showed that the red unit (lower left of Figure 2) should be used at the rear and the amber unit (lower right of Figure 2, also shown in Figure 7) should be used on the sides. For the narrowband near IR illuminators, the tests showed that the 140-LED array (third from the left in Figure 3) should be used both at the rear and along the sides of the heavy vehicle. Incandescent broadband near IR illuminators should not be used because they produce results similar to narrowband near IR illuminators and have several disadvantages, including higher power draw, substantial heat, visible light components, and greater probability of burnout.

Use of Filters

As previously described, five different filters were tested (Figure 5). These filters were tested with the purpose of improving the image of the parked vehicle, so that overall detection might be improved. Several tests were run in hopes of obtaining improvements, as follows:

1. A test was run that matched a narrowband near IR filter to the narrowband near IR source. The XNiteBPG filter allowed passage of 840 to 850 nm IR and was placed over the camera lens. (At this time, the 140-LED array was believed to emit wavelengths near 850 nm. Later tests, to be described, showed that the array emitted wavelengths at and near 940 nm.) The three IR illuminators were then used (separately) to illuminate the vehicle. In principle, this test was intended to suppress the largest part of the headlight bloom while retaining the image of the parked vehicle. Unfortunately, the filter seemed to suppress all aspects of the video picture and resulted in an image that simply showed a noisy image with two round spots representing the two headlights. This approach was considered to be unusable. It should be mentioned that the filter did not have such sharp cutoff values that it would suppress any wavelengths near the 840 to 850 nm pass band. Consequently, if the LED arrays were at slightly different wavelengths, there should not have been any great degradation. It was concluded that, in general, the pass band also suppressed the illumination to the point that the entire image was unusable.
2. A test was run using the Xnite715 and Xnite780 broadband IR filters with the broadband IR source. The objective was once again to obtain some reduction in headlight bloom. However, these filters had very little effect but did reduce image sharpness slightly. Headlight bloom was about the same, but was less well defined.
3. A test was run using the XniteCC2 filter which passes visible and broadband near IR to approximately 900 nm. This filter had little effect on the results when using either the broadband or the narrowband IR source. There was only a slight reduction in picture definition for each source but there was an increased diameter for headlight bloom.
4. A test was run using yellow visible illumination with the XniteCC1 filter. Here the concept was that the visible illumination would be passed while headlight blooming would be reduced. Unfortunately, the test showed that there was slight degradation of the image and headlight bloom size was increased slightly.

The results suggest that, in general, it is difficult to suppress headlight bloom using filters without also reducing the quality of the desired image. It is believed that the camera used (IK-64

DNA) is already optimized and that the addition of filters only reduces the capabilities of such a camera. Thus, in general, filters did not improve the quality of the image obtained and were therefore not included in any field test design.

Comparison of Cameras

As described earlier, four different cameras were tested (Figure 4). The three cameras on the left in the figure were selected because they had daytime color and nighttime B/W capability, and because they supposedly had good sensitivity at night. The use of combined daytime and nighttime capability meant that the entire system could be developed using only three cameras: one on each side of the vehicle and one at the rear. The fourth camera shown on the right in Figure 4 was selected because of its capability of providing appropriate contrast *within a given image*. The camera was limited to B/W capability, but it was hardened for automotive use. Use of this camera would mean that an additional camera and corresponding video switching would be required for daytime color video in each application (six cameras in total).

Tests were performed on each camera separately so that comparisons could be made. Tests included: no/amber/narrowband near IR-illumination crossed with car lights-off /on. While broadband near IR was also tested, results were always the same as for narrowband near IR. It should be noted once again that the amber illuminator used was that shown in the lower right corner of Figure 2 and also in Figure 7. The narrowband near IR illuminator was that shown third from the left in Figure 3. Test results for each camera were as follows:

Toshiba IK-65WDA Camera

1. There was no frame delay, and there was no apparent time integration with this camera (for the conditions tested).
2. For the no exterior illumination condition and with the car lights off, the car was barely visible in the video. Because of the very high noise level in the picture, the video could be considered unusable.
3. For the no exterior illumination condition and with the car lights on, there was some vehicle definition and very little noise. Headlight bloom diameter was approximately 9 in (22.9 cm). The video image could be considered barely usable.
4. For the amber illumination condition and with the car lights off, the car image was somewhat noisy but usable.
5. For the amber illumination condition and with the car lights on, the car image had reasonably good definition and the bloom diameter was approximately 10 in (25.4 cm).
6. The camera was found not to be sensitive to near IR illumination. Thus, results for this type of illumination were identical to the no illumination conditions described in 2 and 3 above.

The results suggest that this camera would be marginal for the envisioned application. In particular, it is not sensitive enough in darkness and does not respond to near IR.

Mintron 63V5H Camera

1. This camera exhibited frame delay and used time integration to achieve low light level capability. It is estimated that with no exterior illumination and with the car lights off that the camera produced approximately three new images per second. The images obtained were of poor quality and were considered to be unusable. Because the delays were considered to be unacceptable for the application, additional testing was not performed.

Toshiba IK-64DNA

1. There was no frame delay, and there was no apparent time integration with this camera.
2. For the no exterior illumination condition and with the car lights off, the car was visible and well defined. There was a small amount of noise in the picture, but it was believed the picture could be post-processed to obtain a totally acceptable picture.
3. For the no exterior illumination condition and with the car lights on, the picture of the car was of high quality. Headlight bloom was pronounced, having an approximate 1.5 ft (46 cm) diameter.
4. For the amber illumination condition and with the car lights off, the car image was of high quality and had little noise.
5. For the amber illumination condition and with the car lights on, the car image had reasonably good definition and the bloom diameter was approximately 10 in (25.4 cm).
6. For the near IR illumination condition and with the car lights off, the car image had good definition and very little noise.
7. For the near IR illumination condition and with the car lights on, the car image was of very high quality while the headlight bloom diameter was approximately 1.5 ft (46 cm).

Clearly, the IK-64DNA seemed to work reasonably well in all conditions tested. It was thought that post-processing might still be needed at low light levels, but the camera would be capable of operating over the entire range of illumination conditions likely to be encountered. Headlight bloom was larger than desired, but it was believed (at the time) that with post-processing the class of vehicle and its location would be identifiable under almost all conditions. In addition, there was no horizontal or vertical streaking (due to bleed-over) associated with the headlight bloom.

Sensata ACM100 Camera

1. There was no frame delay, and there was no apparent time integration with this camera.
2. For the no exterior illumination condition and with the car lights off, the car was totally invisible in the video. The video was composed entirely of noise and would be absolutely unusable in this test condition. It was also clear that post-processing would not produce a usable image.
3. For the no exterior illumination condition and with the car lights on, there was slight vehicle outline definition, but details in the image were missing. Offsetting this shortcoming was the fact that the headlight bloom was only about 7.5 in (19 cm) in diameter; that is, only slightly larger than the headlights' actual dimensions. Picture contrast was somewhat lower, but more uniform, than with the other cameras. Definition

of the car was below acceptable limits and it was considered unlikely that post-processing would produce an image within acceptable limits.

4. For the amber illumination condition and with the car lights off, the car image was still below acceptable limits, with the car difficult to see. Post-processing would not likely produce an acceptable image.
5. For the amber illumination condition and with the car lights on, the video image was of reasonably good quality and bloom diameter remained relatively small at about 7.5 in (19 cm). The picture was a bit lacking in contrast. It is expected that post-processing would produce a satisfactory image.
6. For the near IR illumination condition and with the car lights off, the car image had reasonably good definition, but the picture had some noise. In addition, the picture was low in contrast. Nevertheless, post-processing might possibly have produced a satisfactory image.
7. For the near IR illumination condition and with the car lights on, the car image was of good quality while the headlight bloom diameter was approximately 7 in (18 cm). Picture contrast was again somewhat low, but acceptable.

The tests with the ACM100 camera indicated that the camera was not particularly sensitive at low light levels, but it had the advantage of suppression of bright spots such as headlights. The camera seemed to work best with the IR illuminator. However, even though the camera produced a more uniform field across a given image, it also seemed to lack adequate contrast. It should be noted once again that this camera produced only a B/W image regardless of light level.

Camera Selection

Tests with the four cameras made clear that the Toshiba IK-64DNA had the best overall performance. It worked well under extremely low light level conditions, it was sensitive to near IR, and it had low-light B/W capability as well as daylight color capability. This camera came closest to meeting the overall needs of the project. However, there was some headlight bloom with the camera. This appeared to be its main disadvantage, and it was one that was considered tolerable. At the time of the tests, it was believed that post-processing of the image produced by the IK-64DNA might possibly be helpful in reducing the effects of headlight bloom. However, even if it did not help, it was believed to be possible to identify the type of vehicle (car, sport utility vehicle (SUV)/pickup, motorcycle, or heavy vehicle) and its location using the video image. While rain tests remained to be done, it appeared that this camera provided basic information that may not be obtainable using the mirrors.

The Sensata ACM100 was a less sensitive camera and was limited to B/W capability. Nevertheless, this camera was substantially better than any of the others in suppressing headlight bloom, using its "autobrite" feature. Consequently, it is recommended for further research, possibly for future applications.

Another important factor that should be mentioned is that all four cameras were programmable through a digital interface. Consequently, there were parameters that could be adjusted. However, it should also be remembered that the default conditions are probably set up in each camera to show its best overall capabilities. Therefore, it is unlikely that adjusting various parameters would lead to better overall performance. Particularly in the case of the Sensata

ACM100, care was taken to program and adjust sensitivity parameters. Doing so did not, however, lead to any overall usable improvement.

OVERALL LIST OF RECOMMENDATIONS CARRIED FORWARD TO THE INITIAL DESIGN

The results of the experiments performed in the storage building can be summarized as follows:

1. The recommended visible illuminator for the *rear* of the heavy vehicle is that shown at the lower left in Figure 2. This illuminator produces red illumination that has an appropriate horizontal spread. The illuminator is a composite device made up of a base containing the LEDs and a dispersive lens epoxied to the base (see Appendix A).
2. The recommended visible illuminator for the *sides* of the heavy vehicle is that shown at the lower right in Figure 2 and also in Figure 7. This illuminator produces amber (yellow) illumination that has an appropriate horizontal spread. The illuminator is a composite device made up of a base containing the LEDs and a dispersive lens epoxied to the base (see Appendix A).
3. The recommended near IR illuminator is that shown third from the left in Figure 3. This rectangular array produces *no* visible light and is composed of an array of 140 LEDs which produce narrowband illumination (see Appendix A).
4. There was no additional filter that provided an improvement in the video image. Therefore, no additional filters were recommended at the time the tests were completed.
5. The Toshiba IK-64DNA camera is recommended as the camera having the best overall performance. It is sensitive at very low levels of illumination, and it responds to both visible and near IR illumination. It has both nighttime B/W capability and daytime color capability. Consequently, for the intended application, only three of these cameras would be required: one on each side of the tractor and one at the back of the trailer or cargo box.
6. The Sensata ACM100 camera is recommended for further research because of its ability to suppress headlight bloom. It was the only camera tested that had this ability. However, the camera is not particularly sensitive and may not be adequate for some nighttime conditions. In addition, the camera is B/W only, thus requiring an additional three cameras if daytime color is required.
7. Post-processing should proceed with the idea of improving the images obtained with the IK-64DNA. It should be mentioned that digital video recordings were made of the candidate final arrangements, so that post-processing of the images could be examined. These recordings were available for use in determining the potential benefits of post-processing. Specifically, recordings were made of the final red, amber, and narrowband near IR illuminators, using the IK-64DNA camera, both with the car headlights on and with the car headlights off.

CHAPTER 3. EXPERIMENTAL DESIGN FOR THE STATIONARY OUTDOOR TESTS OF CANDIDATE SYSTEMS

Once the preliminary tests had been completed, outdoor stationary tests were developed to test the better configurations in both clear and rainy conditions. These tests were intended to determine image quality of an Enhanced C/VIS as judged by naïve VTTI personnel in a controlled experiment. An additional goal was to determine the degree to which visible illumination would affect "other" drivers as they approached the side and rear of the equipped heavy vehicle.

One of the most important factors included in the outdoor static tests was the effect of rain. Rain was simulated as if the heavy vehicle and the target vehicle were moving at highway speed. This was accomplished using a relatively complex equipment arrangement involving rain towers, a high-velocity wind generator, and both rain and mist nozzles operating under water pressure.

Tests were run both during daytime and nighttime; however, the nighttime tests required a larger number of conditions as will be explained. In particular, the effects of illumination sources had to be studied, and glare tests associated with the visible illumination sources had to be performed for the nighttime runs. These tests were not required for the daytime runs because the background illuminance was sufficient to make any glare effects negligible. Also, additional illumination was not used.

Tests were run using VTTI's 1994 Peterbilt tractor with a new Utility 4000 D-X 53 ft (16.2 m) trailer purchased specifically for the tests. Initially, the target automobile was a 2001 Saab 9-5 sedan, dark blue in color. Later on, this vehicle was changed for reasons that will be explained. An additional vehicle, an older Volvo sedan, was used to provide a readable lead-vehicle target for the glare/discriminability tests. The Volvo sedan's rear lighting was energized for the tests.

This chapter describes the details of how the tests were conducted. A following chapter reports on the results of the various tests. Thereafter, recommendations are made regarding changes and final design of an Enhanced C/VIS system for Smart Road testing.

Equipment Configurations Tested

Camera and Filters

The indoor tests described in the previous chapter demonstrated that the Toshiba IK-64 DNA camera had the capability of operating effectively both in daylight and at night. It was also sensitive to both visual and near IR illumination. This camera provided color capability for daytime use and black and white (B/W) capability for nighttime use. For use at night, a filter inside the camera was removed using an internal electromechanical device. This filter could be removed automatically, or it could be controlled externally. In the tests, the filter was controlled externally by using a switch connected to the control contacts of the camera. It should be noted that the final system was envisioned as having three cameras, in which all three cameras would switch simultaneously from daytime to nighttime operation or vice versa. Simultaneous switching would require that the switching be done externally.

The indoor tests had shown that none of the various filters tested improved image quality; in fact, in most cases, the filters degraded image quality. Consequently, no additional filters were used with the camera.

For the outdoor tests, the IK-64DNA camera was mounted at the passenger-side front fender of the Peterbilt tractor used for the tests. This was the same tractor and mounting as was used in the previous project for development of C/VISs (Wierwille, Schaudt, Spaulding, Gupta, Fitch, Wiegand, and Hanowski, 2007a; Wierwille, Schaudt, Gupta, Spaulding, and Hanowski, 2007b). In the previous application, the camera position corresponded to the convex mirror surrogate on the passenger side. However, in the current application it was intended as an "all weather" enhancement. The camera lens was adjusted for a 45 deg horizontal field of view and was mounted in a special enclosure designed specifically to protect the camera from rainwater. The camera enclosure was filled with nitrogen gas to limit moisture condensation inside the enclosure. Figure 8 shows the camera mounted at the front passenger-side fender.

It is important to understand why this position was chosen. One of the major problems with current side mirrors is that they leave a large blind spot along the side of the tractor. To offset this blind spot, fender- or hood-mounted convex mirrors are often provided. This requires drivers to search their side mirrors and their forward (fender- or hood-mounted) mirror to ensure clearance prior to maneuvering laterally. If the camera is placed at the fender, the blind spot is almost completely eliminated because a vehicle alongside cannot “get under” the camera without appearing in the camera image. Thus, the fender mounting position has a great advantage.

Figure 8. Test Camera Mounted in its Enclosure at the Passenger-side Front Fender of the Tractor

Monitor

The monitor viewed by the heavy-vehicle driver (actually, the test subject) was placed at the passenger-side A-pillar, as shown in Figure 9. It was intended that the monitor should be Size 2 (as defined in the previous research). That monitor produced an image that was 9.6 cm (3.78 in) high by 12.9 cm (5.08 in) wide, with a corresponding diagonal dimension of 16.1 cm (6.33 in). Tests demonstrated that the computer-processed image used in this research produced unacceptable delays if the processed computer image was re-converted to NTSC (National Television System Committee) format. Consequently, it became necessary to use a different monitor which would accept a signal in vector graphics array (VGA) format, making re-conversion unnecessary. This monitor had an image surface that was 10.2 cm (4.02 in) high by 13.4 cm (5.28 in) wide, with a corresponding diagonal dimension of 16.6 cm (6.54 in). The image produced was therefore very nearly the same size as the Size 2 monitor image. The monitor was mounted near the lower end of the A-pillar on the assumption that it would be the only monitor to be used on the passenger-side A-pillar. The image on the monitor was a mirror image; that is, it was reversed left to right (horizontally).

Figure 9. Test Monitor Mounted at the Passenger-side A-pillar

Illumination Sources

Two sources of illumination were added to the heavy vehicle: visible and narrowband near IR. These sources could be used at night either singly or together, allowing the testing of four nighttime conditions; those being: no added illumination, visible illumination, narrowband near IR illumination, or both forms of added illumination combined. All four of these conditions were tested during the nighttime conditions.

In regard to the near IR illumination sources, four units were installed on the tractor-trailer combination. One unit was installed at the lower rear portion of the tractor front fender, two units were installed along the passenger side of the trailer, and one unit was installed on the right rear corner of the trailer. The units were located and aimed as shown in Figure 10. The IR illumination units were 140 LED units. An example is shown third from the left in Figure 3 of the previous chapter. Major specifications are provided in Appendix A.

In regard to the visible illumination sources, four units were installed on the tractor-trailer combination at the same locations as the IR units. A fifth unit was installed on the driver-side rear of the trailer for use in the glare tests. The three units on the side were amber. A typical side unit is shown in Figure 2 (lower right corner) and Figure 7 of the previous chapter. The two units installed at the rear were red. A typical rear unit is shown in Figure 2 (lower left corner) of the previous chapter. The visible illuminator colors were selected to match current standards requiring amber lights on the sides and red (steady) lights at the rear. The visible illuminator locations and aim directions are depicted in Figure 11. Major specifications are provided in Appendix A.

Additional photos show how the various sources of illumination were mounted. Figure 12 shows the mounting at the tractor front fender, Figure 13 shows a typical mounting along the side of the trailer, and Figure 14 shows the mounting at the right rear of the trailer. The mounting at the left rear was the same, except that the IR illuminator was not connected for these tests because it was not needed.

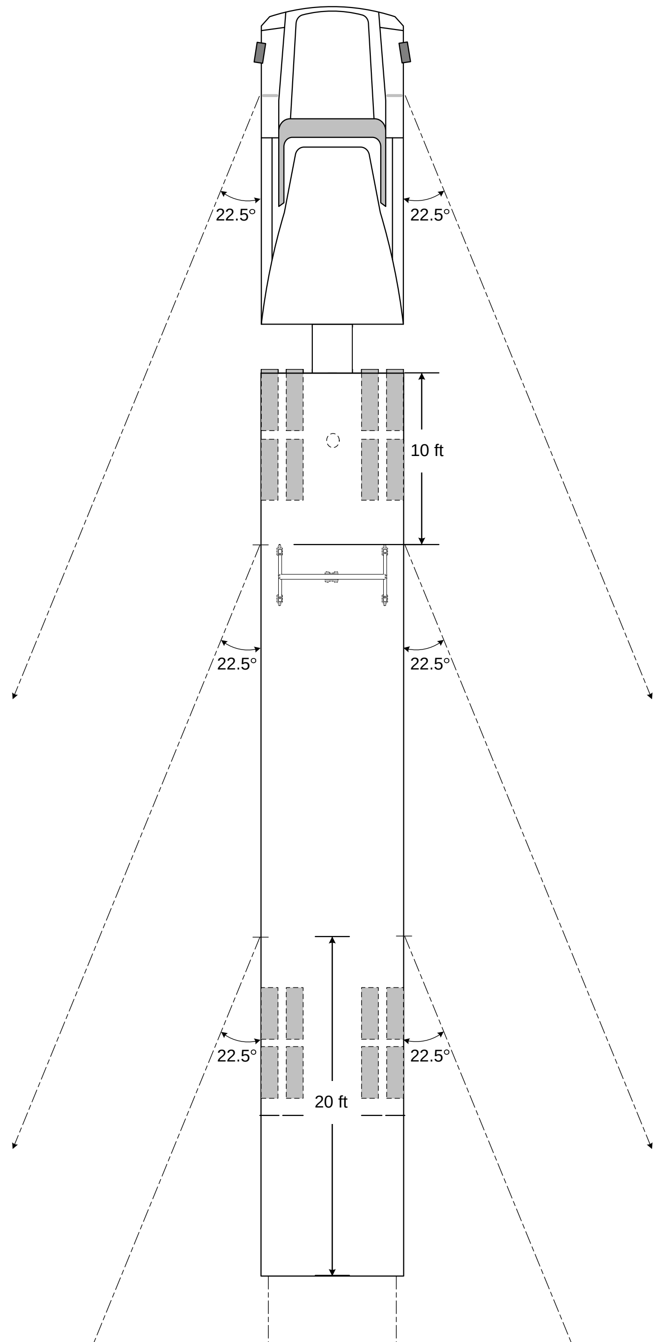


Figure 10. Mounting and Centerline Aim of the Narrowband Near IR LED Illuminators (Note that only the right side and right-side rear illuminators were activated for the static outdoor tests.)

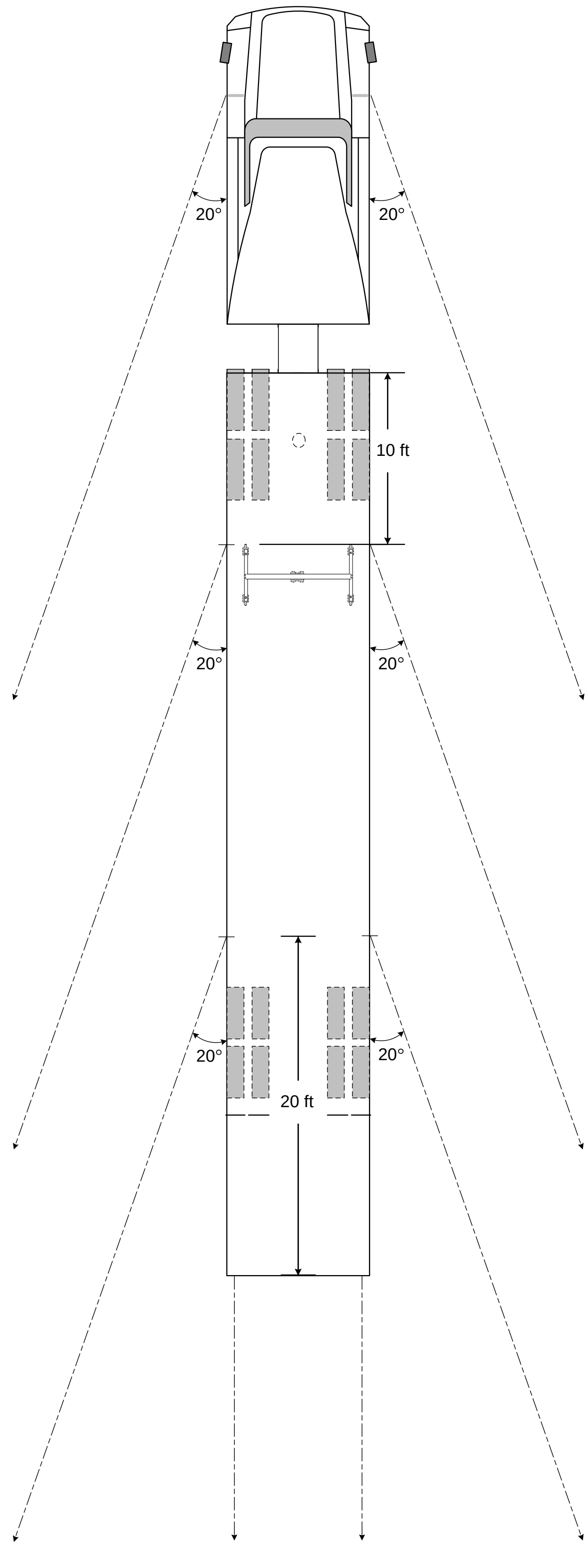


Figure 11. Mounting and Centerline Aim of the Visible Illuminators (Note that only the right side and (both) rear illuminators were activated for the static outdoor tests.)

Figure 12. Illuminators Mounted at the Tractor's Right Front Fender

Figure 13. Typical Illuminators Mounted on the Right Side of the Trailer

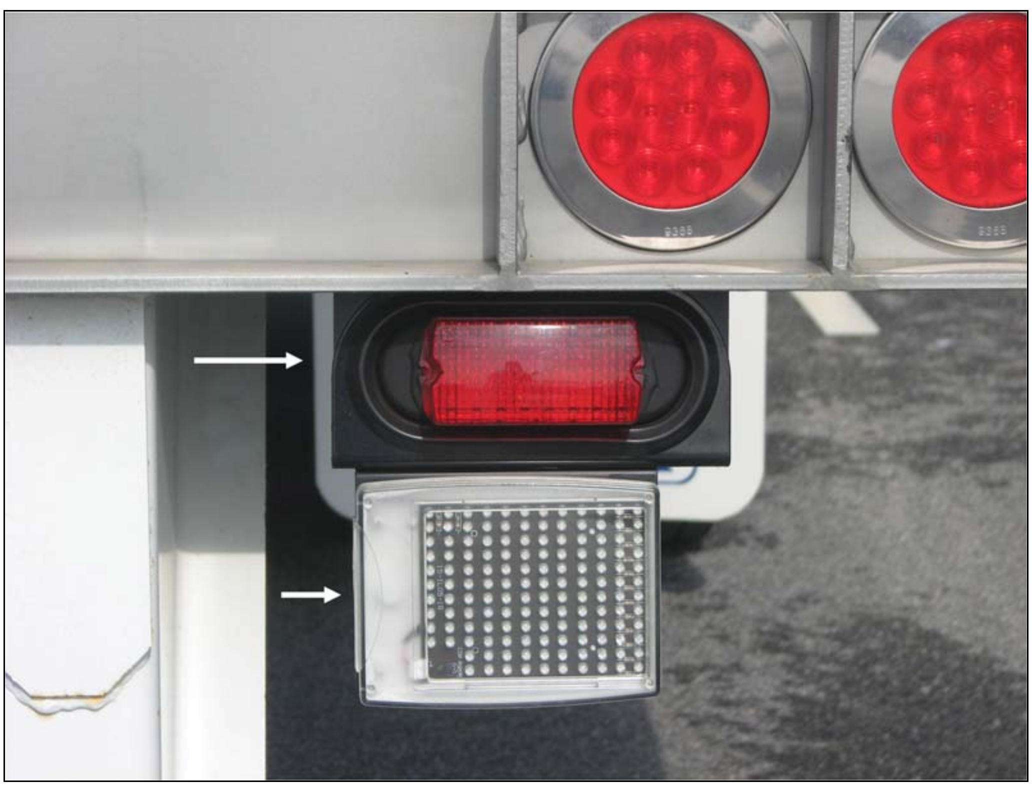


Figure 14. Illuminators Mounted at the Right Rear of the Trailer

Rain Generation and Setup of the Static Tests

Several steps were involved in obtaining a good simulation of rain at highway speed. These require explanation. Earlier, in preparation for the outdoor stationary tests, a typical sedan was equipped with a regular color camera mounted at the center of the windshield and aimed forward. The vehicle was then driven by one of the experimenters on a local multilane highway during rain. This driver approached several tractor-trailers for the purpose of obtaining recorded video of the spray pattern. Video was recorded as the experimenter closed in the adjacent right lane. The video continued as the experimenter's car approached and came alongside the heavy vehicle. The purpose of the video was to determine the specific elements of the spray pattern and then use them for simulating the artificial rain in the static experiments.

The recorded video was analyzed and showed that there were several main sources of spray associated with typical tractor-trailers. Principal among these was the mist pattern that emanates from between the two sets of tires at the rear of the trailer near the top of the tires. This mist pattern results from the fronts of the tires on the rear axle moving downward while the backs of the tires on the second-from-rear axle move upward. The effect is to produce a mist that exits to the side of the trailer. A similar pattern emerges from the two sets of tires at the rear of the *tractor*; these tires are actually under the trailer. The mist pattern for these rear tractor tires is almost identical to the pattern for the trailer tires in that the mist moves outward from the top between the two sets of tires.

The second aspect of the pattern is the general spray that comes from the tires as they sling water after it is forced out from under the tires or is picked up by the tires. This pattern produces a spray that is outward and rearward. Finally, there is the pattern of rain hitting the windshield of the car directly. This pattern is largely the result of the rain itself falling from the sky. Of course, the rain collides with the windshield at approximate highway speed horizontally and rain-falling speed vertically, because the car would also be moving at highway speed.

Figure 15 shows a diagram of the layout of the rain and wind-producing equipment. The mist between tires was simulated using two mist nozzles: one between the axles of the trailer and one between the rear axles of the tractor. The spray was simulated by using a coarser set of ten nozzles in a circular pattern in front of the fan, and the falling rain was simulated using overhead towers and spray nozzles. It should be noted that the fan was composed of a converted airboat power-plant and propeller in a safety cage. This system was obtained specifically for this project using VTTI cost-sharing funds. The system used the same type of vertical vanes that are used on an airboat. Figure 16 shows the wind/spray generation system. This system was capable of producing sustained wind speeds of 73 mph (117.5 km/h) as measured with an anemometer. For the tests, the speed used was approximately 60 mph (96.6 km/h). Figures 17 and 18 show photos of the overall setup including the wind generation system.

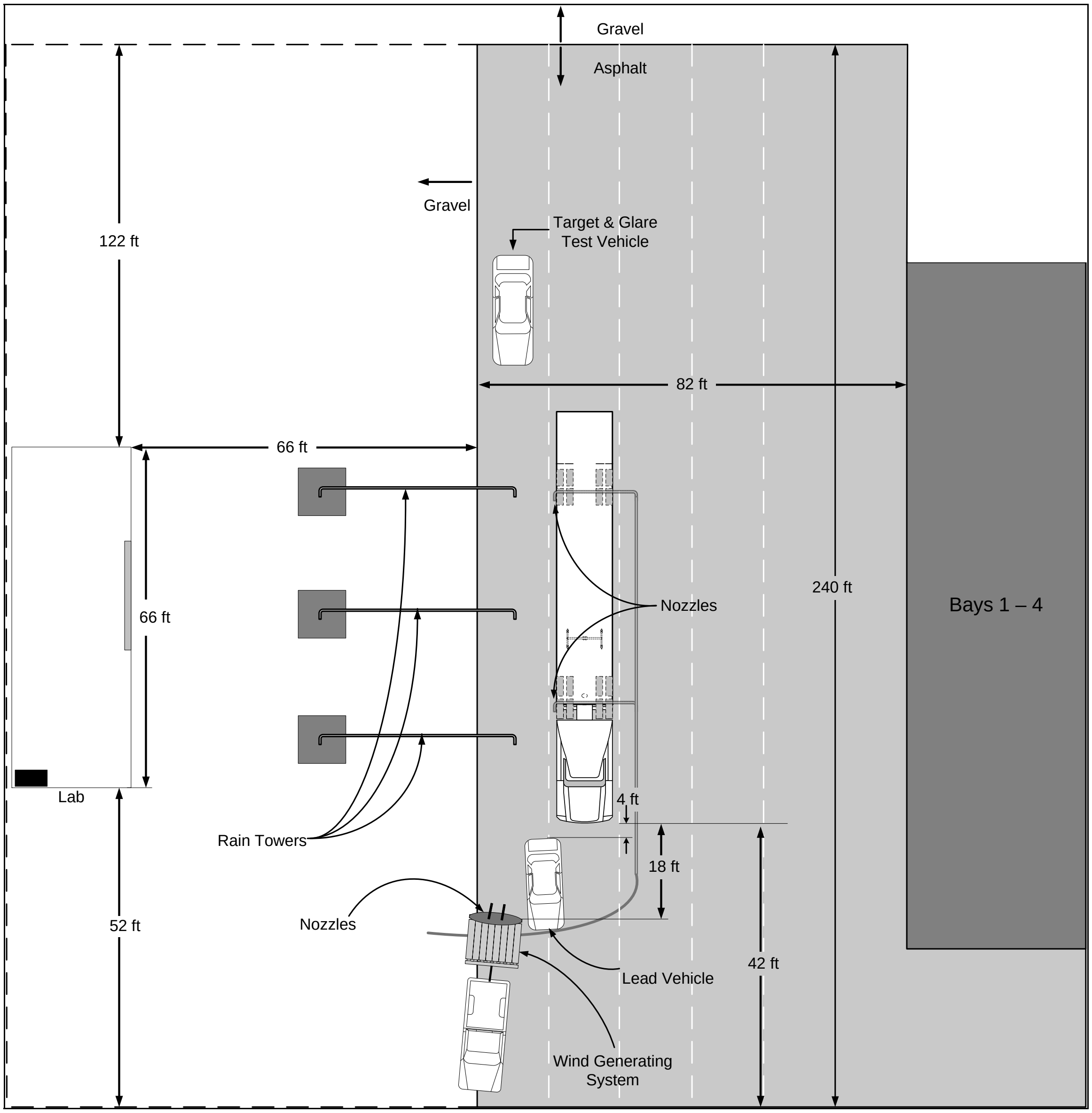


Figure 15. Layout of the Rain- and Wind-producing Equipment

Figure 16. Wind/spray Generation System

Figure 17. Photo of the Overall Setup (Rear Portion)

Figure 18. Photo of the Overall Setup (Front Portion)

It should be mentioned that special precautions were taken when the rain test runs preceded the clear runs. When this occurred, the target vehicle was wiped down after the group of rain runs was completed, to eliminate water beading that might affect the results of the following clear runs. This was considered to be a necessary procedure because water beading might have reflected stray light from the target vehicle, thereby making it more distinct from its background.

Nighttime Tests

The nighttime tests were the most comprehensive. They included factorial combinations of clear and rainy weather, four illumination conditions, and three target vehicle (automobile) locations. In addition, as mentioned earlier, tests were carried out to determine the effects of glare on the "other driver"; that is, the automobile (target vehicle) driver for the visible illumination condition. In this case, four positions were tested in the adjacent (passenger side) lane and two positions were tested behind the trailer. Only the adjacent lane tests involved ratings of ability to detect details associated with a lead vehicle in the same (adjacent) lane, because the view of the lead vehicle was obstructed by the trailer when the driver was behind the heavy vehicle. Details regarding the lead vehicle are provided in the section describing the glare and discriminability tests.

Tests were structured so that, once the artificial rain was started, a group of tests would follow. In other words, tests were grouped to minimize the startup and shut-down of the artificial rain.

Experimental Design for the Nighttime Image Quality Tests

The experimental design for the heavy-vehicle driver tests was a 2 (weather conditions: clear, rain) by 4 (illumination conditions: no added, visible, IR, visible plus IR) by 3 (target vehicle position: rear, intermediate, near) design. Weather and illumination were counterbalanced, but with the constraint that all clear conditions for a given subject would be grouped together and all rain conditions for that given subject would be grouped together. This was done, as mentioned, so that the number of activations and de-activations of the rain generation equipment would be minimized. Target vehicle position involved always using the same order; that is, rear followed by intermediate followed by near. This was done so that the target vehicle would not need to back during a given sequence of tests, particularly during the artificial rain. The target vehicle positions are shown in Figure 19. This figure applies to both the nighttime image quality tests and the glare/discriminability tests. In the figure, only the forward three positions of the target vehicle in the adjacent lane were used for the nighttime image quality tests.

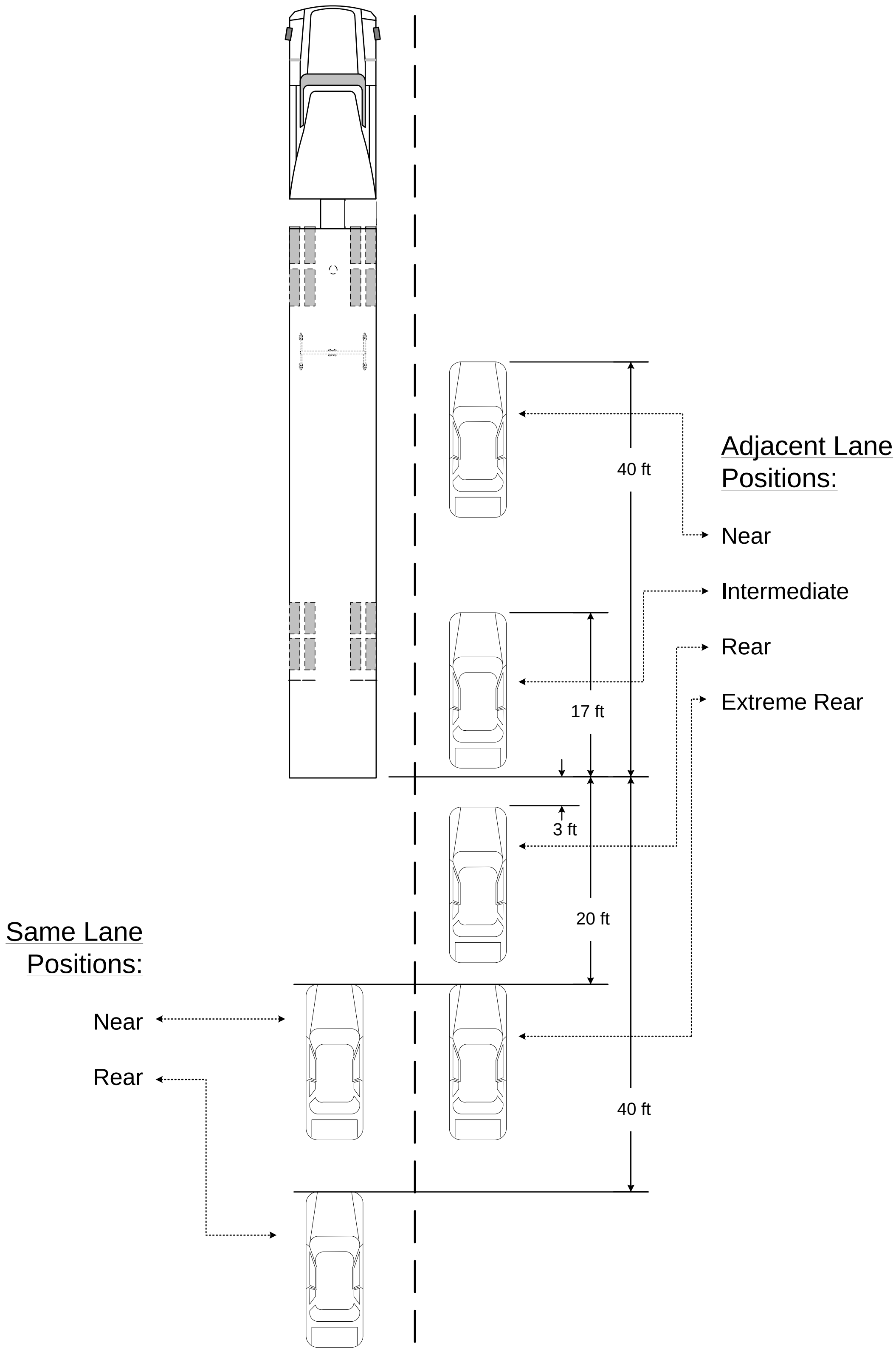


Figure 19. Positions of the Automobile Relative to the Tractor-trailer for the Image Quality and Glare/discriminability Tests (Dimensions are in feet; 1 ft = 0.305 m)

The target vehicle, driven by a confederate experimenter during the image quality tests, approached with its nighttime driving lights on and using low beams. Consequently, these tests were associated with normal nighttime driving. However, in driving on a highway, it may on rare occasions occur that a target vehicle may approach with minimal or no lighting. Therefore, at the intermediate position, ratings of image quality were also taken with the target vehicle's lights extinguished. After this rating was obtained, the target vehicle's nighttime driving lights were again illuminated before additional tests were run.

Eight subjects participated in the image quality tests. Subjects sat in the driver's seat of the tractor and observed the display at the passenger-side A-pillar. Counterbalancing was as shown in Table 1 for these subjects (S1 through S8). In the table, the image quality assessment with target vehicle lights off is not shown. This test always occurred immediately following the lights-on test at the intermediate position (and before the vehicle moved to the near position). Also in the table "None" refers to no additional lighting, "Vis" refers to visible additional lighting, "IR" refers to IR additional lighting, and "Vis + IR" refers to visible plus IR additional lighting.

Table 1. Counterbalancing for the Nighttime Image Quality Tests

ORDER ⟶

	Clear				**Rain**			
S1	None	Vis	IR	Vis+IR	None	Vis	IR	Vis+IR
S2	Vis+IR	IR	Vis	None	Vis+IR	IR	Vis	None
S3	IR	Vis+IR	None	Vis	IR	Vis+IR	None	Vis
S4	Vis	None	Vis+IR	IR	Vis	None	Vis+IR	IR

	Rain				**Clear**			
S5	Vis+IR	None	Vis	IR	Vis+IR	None	Vis	IR
S6	IR	Vis	None	Vis+IR	IR	Vis	None	Vis+IR
S7	Vis	IR	Vis+IR	None	Vis	IR	Vis+IR	None
S8	None	Vis+IR	IR	Vis	None	Vis+IR	IR	Vis

Each subject used the same rating scale for each position of the target vehicle and each illumination condition. Appendix C shows the scales used for the tests.

Experimental Design for the Glare/Discriminability Tests

As indicated, a separate set of tests was run to check for the level of glare. In this case the subject drove the target vehicle (the automobile) and stopped at the various positions. Both adjacent lane and same lane (behind the trailer) tests were performed, as mentioned earlier. This design was used for the visible illuminators only, because there was no observable illumination from the IR illuminators. Consequently, there was only one illumination condition. The illuminators were switched on and off at each location so that the automobile driver (the subject in this case) could observe the relative effects of the additional illumination at each location. In all cases, the tractor and trailer had nighttime driving lights on, including low beam headlamps and both tractor and trailer marker lamps.

The glare tests followed the image quality tests. The glare tests were counterbalanced for weather (clear, rain) and for lane (adjacent, same). Once again, all rain conditions were grouped to minimize turning the rain generation system on and off. In all cases the driver approached from the rear with the automobile low beam headlamps on. There were two positions for the same lane tests (rear and near) and four positions for the adjacent lane tests (extreme rear, rear, intermediate, and near).

Referring back to Figure 19, the figure shows the six positions of the automobile relative to the tractor-trailer. Note, once again, that the same diagram applies to both the image quality tests and the glare tests. However, only the three nearer adjacent lane positions were used in the image quality tests, while all six positions were used for the nighttime glare tests.

As drivers approached in the adjacent lane, they provided both a glare rating (how uncomfortable) and a rating regarding ability to discern details in a lead vehicle. The lead vehicle was a stationary car in the adjacent lane; that is, the lane in which the subject (who was driving) approached. The lead vehicle was a tan Volvo sedan with its rear taillights and license plate lights lit (as previously described). It was located 4 ft (1.22 m) in front of the tractor (measured longitudinally) from the front bumper of the tractor to the rear bumper of the lead vehicle. The rating scales for glare from the heavy vehicle and for reduction in discernable detail in the lead vehicle are shown in Appendix C. When the subjects approached in the *same* lane, they provided only the glare ratings because the lead vehicle could not be seen from behind the trailer. Table 2 shows the counterbalancing used for the nighttime glare tests. In the table, as previously mentioned, drivers always approached from the farthest position to the nearest.

Table 2. Counterbalancing for the Nighttime Glare/discriminability Tests

ORDER →

	Clear		**Rain**	
S1	Same lane	Adjacent lane	Same lane	Adjacent lane
S2	Adjacent lane	Same lane	Adjacent lane	Same lane
S3	Same lane	Adjacent lane	Same lane	Adjacent lane
S4	Adjacent lane	Same lane	Adjacent lane	Same lane

	Rain		**Clear**	
S5	Same lane	Adjacent lane	Same lane	Adjacent lane
S6	Adjacent lane	Same lane	Adjacent lane	Same lane
S7	Same lane	Adjacent lane	Same lane	Adjacent lane
S8	Adjacent lane	Same lane	Adjacent lane	Same lane

Daytime Tests

The daytime tests were limited to determining whether or not the configuration produced satisfactory images in both rain and clear conditions. These tests were performed to determine the effects of clear or rain conditions on the quality of the video image. In this case, the target vehicle was evaluated in rain both with lights on and with lights off. The reason for this was that most states now have laws requiring the driver to use headlamps when the windshield wipers are on, or when it is raining. However, drivers may fail to turn their lights on in rain in the daytime. Consequently, both conditions were tested during the rain conditions.

Additionally, there are also several manufacturers who now use daytime running lights on vehicles. These are often quite similar to headlamps. To account for these lights, and to account for drivers who may sometimes use their regular headlamps in the daytime, tests were also run with headlamps on in the clear, daytime condition. This had the effect of balancing the design for the daytime tests.

Experimental Design for the Daytime Image Quality Tests

The experimental design for the heavy-vehicle driver tests (image quality tests) was a 2 (weather conditions: clear, rain) by 2 (target vehicle lamps: on, off) by 3 (target vehicle/automobile locations: rear, intermediate, near) design. The three locations were identical to those used for the nighttime tests (Figure 19). Once again the two rain conditions were always grouped together and the three target vehicle (automobile) locations were always presented in the approaching direction (with the target vehicle driven by a confederate experimenter). Consequently, the experimental design was counterbalanced for clear and rain conditions, and separately for target vehicle lights on and off. Eight subjects participated in this portion of the experiment, and the counterbalancing scheme was that shown in Table 3. These tests were performed with the subject in the driver's seat of the tractor.

Table 3. Counterbalancing Procedure for the Daytime Image Quality Tests

	ORDER→			
S1, S5	Clear, Lights On	Clear, Lights Off	Rain, Lights On	Rain, Lights Off
S2, S6	Rain, Lights On	Rain, Lights Off	Clear, Lights On	Clear, Lights Off
S3, S7	Clear, Lights Off	Clear, Lights On	Rain, Lights Off	Rain, Lights On
S4, S8	Rain, Lights Off	Rain, Lights On	Clear, Lights Off	Clear, Lights On

As mentioned previously, during the daytime runs, additional lighting was not used on the tractor-trailer. Because of the high level of ambient illumination, the additional lighting did not have any noticeable effect on the image and was therefore not used.

Because additional tractor-trailer lighting was not used, there was no change in glare for the driver of the "other" vehicle. Likewise, there was no change in the ability to discriminate details in a lead vehicle in the lane ahead. Therefore, no glare or discriminability tests were included in the daytime runs. Appendix C shows the rating scales used for the daytime tests.

Subjects

All subjects were employees of VTTI. They were excused from work for participation during normal working hours. For the nighttime tests they received compensatory time off work. They read and signed an informed consent form. It detailed all of the important aspects of their participation. They were given visual acuity tests to ensure that their vision was adequate (20/25 or better, corrected if necessary).

Subjects were assigned randomly to conditions. However, some care was taken to ensure that the number of males and females was approximately equal. As it turned out, five males and three females volunteered.

Nighttime tests were run first because it was believed that subjects could be retained more easily for daytime runs. Daytime runs were performed during normal working hours, so it was somewhat easier to have subjects return for that session. Because nighttime data and daytime data were always analyzed separately, there was no confound effect in the analysis procedures.

Dependent Variables

These experiments were limited to rating scale results. Consequently, all dependent variables were ratings. The main reason for this was that driver acceptance and eventual use of a developed system would be heavily dependent on driver opinion. It was anticipated that the heavy-vehicle mirrors would remain in place and would be supplemented by the developed Enhanced C/VIS. Therefore, if a given system did not achieve good ratings, drivers would most likely revert to use of the mirrors.

In regard to glare ratings by the light-vehicle driver, if glare given off by the equipped heavy vehicle was perceived to be too high, it is likely that light-vehicle drivers would complain. In that case, it might become necessary to eliminate or substantially reduce the added visible light sources.

In regard to discriminability ratings by the light-vehicle driver, ability to see details in the lead vehicle is probably best judged by the driver in that situation. By asking drivers to try to examine the license plate on the lead vehicle, it was believed that drivers would be able to judge the degree of loss of detail. Consequently, ratings seemed to suffice in this situation.

CHAPTER 4. CONFIGURATION DEVELOPMENT FOR THE OUTDOOR TESTS PRIOR TO DATA GATHERING

INTRODUCTION

Shortly after the equipment was set up for the outdoor tests, video recordings were made of the camera output. These recordings were examined for development purposes and to ensure that the equipment was operating correctly.

The indoor tests had shown that the IK-64DNA camera was superior to the others, in that it allowed operation across the entire range of visible lighting and was sensitive to near IR as well. Blooming was somewhat of a problem, but image processing was expected to take care of the problem, because the outline of the vehicle used for the indoor tests was still visible at night. *Unfortunately, the results regarding blooming did not translate well to the outdoor situation.* When the dark-colored test car was driven forward along the side of the trailer, blooming at night was intrusive to the extent that the image of the vehicle outline was no longer visible in any form in some cases. Consequently, there was little hope that the post-processing of the image would be capable of obtaining an outline of the type of vehicle.

The reason for the difference between the indoor and outdoor tests was studied. Eventually, it became clear that the indoor tests provided an artificial source of illumination which was a result of reflected radiation off the walls of the building in which the tests were run. Even though these walls did not appear to affect the results, they apparently did. Of course, in the outdoor tests, there were no walls. Consequently, this reflected source of illumination was not present in the outdoor tests.

It is important to understand that while dark vehicles in a nighttime situation are certainly going to be present, they do represent a minority. First of all, daytime evaluations indicated that all vehicles could be easily discriminated in the video. In addition, nighttime vehicles with lights on that were moderate to light in color could also be discriminated. It was only a dark vehicle with lights on that could not generally be discriminated. Any dark vehicle with headlights off or with a dark trailer was easily discriminable using the IR illumination. Therefore, the situation was not quite as serious as it first appeared.

In summary, tests showed that a light-colored vehicle could be seen in the video, but that the dark vehicle outline remained invisible behind the headlight bloom. Therefore, remedies were examined. A multifaceted approach was used in which several proposed alterations to the system were studied. While this slowed the project somewhat, it was deemed important to obtain the best possible image or remedy. Five different approaches were examined:

1. The AGC (automatic gain control) was re-programmed so that the gain was higher than the AGC originally specified. The idea was that during headlight glare conditions the gain would remain higher than normal, making it possible to discriminate an outline of a dark vehicle. If so, processing could be used to help remove headlight bloom. This approach was unsuccessful because, as gain was increased, headlight bloom became even

worse, obliterating more of the image. It became clear that the image had already been optimized in terms of AGC setting and dynamics.

2. The concept of using filters was re-examined. It was considered somewhat surprising that earlier work did not result in the use of filters. As indicated, all of the filters resulted in degraded images in the indoor tests. The first step in this process was to obtain a spectral response of the IR illuminators. The results of this test for a typical illuminator are presented in Figure 20, which shows that the radiation was centered at 940 nm. Once this was known, a bandpass filter was obtained that was matched to this wavelength. This filter was different from those already tested in which it had been assumed that the illuminator had radiation centered at 850 nm. The new filter was an X-Nite BPR and was similar in appearance to the X-Nite BPG which is shown in Figure 5 of Chapter 2. The only difference in the filters was the change in the pass band. Otherwise the filters were essentially the same.

   Testing of the new filter revealed that it greatly suppressed the broadband headlight bloom, but it also suppressed the image of the dark target-automobile substantially. It was estimated that an additional factor of 10 in camera image gain would be necessary to produce a satisfactory nighttime image. However, achieving this additional gain factor would require the use of much more expensive, specialized equipment, which would make any system design prohibitively expensive. It would also necessitate the use of different cameras for daylight and nighttime operations. Because of these limitations, the approach of using filters was once again abandoned. However, the approach could be re-examined at a later time.

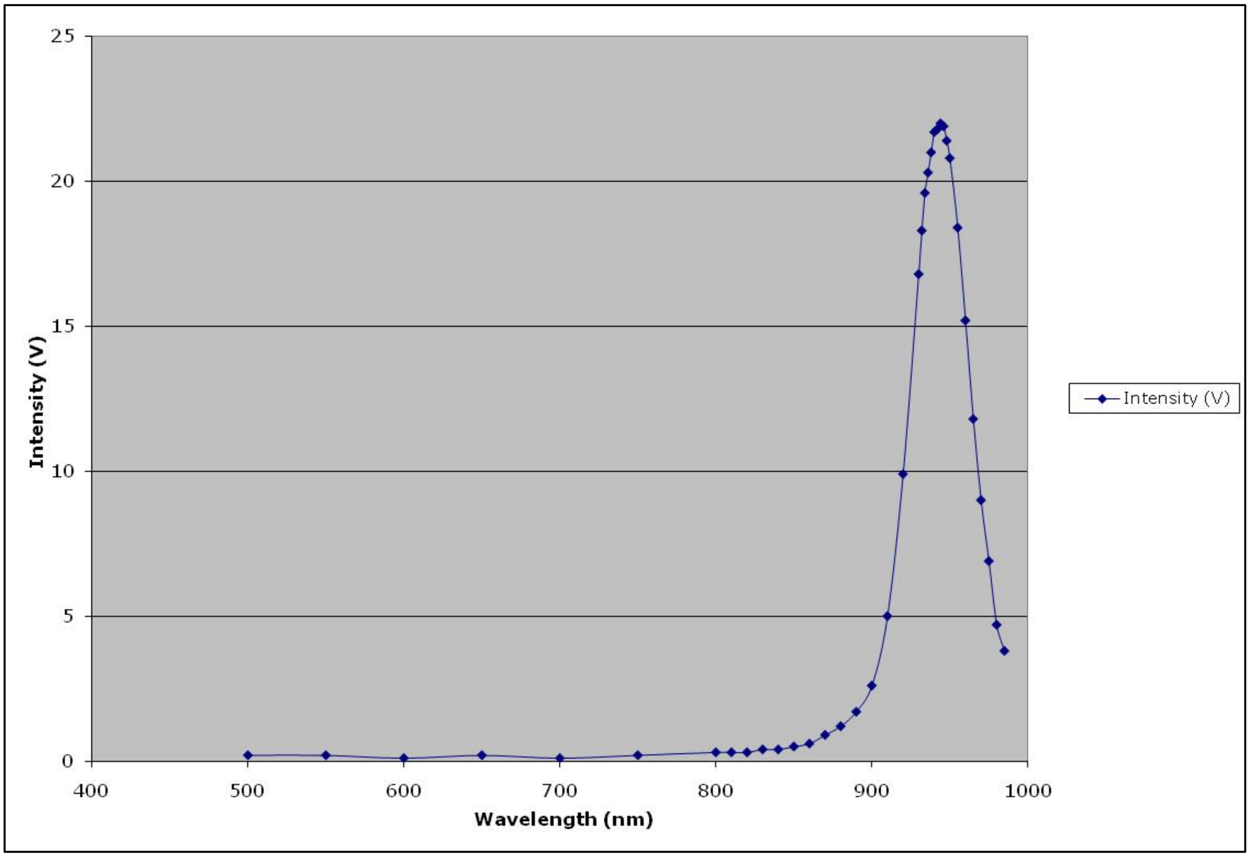


Figure 20. Radiation Output of the 140-LED IR Array as a Function of Wavelength

3. The third approach involved the concept of using two cameras on each side of the vehicle with additional visible illuminators placed nearby; that is, high on the trailer. The two cameras would then cover the entire side of the tractor-trailer and would allow higher levels of illumination because the illuminators would be above the normal view of a driver alongside (similar to streetlights). In addition, headlights would be substantially "off-angle" and would not create illumination directed at the cameras. However, as shown in Figure 21, the two cameras would require wide angle fields of view, there would be substantial image distortion, and two monitors would need to be integrated into the cab on each side of the vehicle. These various aspects suggested compromises in glare for the "other" driver, image distortion, and human factors in cab design. Consequently, the approach was not pursued further.

4. A fourth approach was to move the camera to the current mirror structure and use a field of view that was only slightly wide-angle, as shown in Figure 22. This approach was studied experimentally by temporarily moving the camera from the front fender to the mirror structure. In addition, both the camera and monitor were rotated 90 deg so that the long dimension of the image was vertical. All of this was done in anticipation of moving the illuminators upward so that they could be made brighter or more numerous. In addition, headlight illumination would again be off-angle with regard to the rear camera.

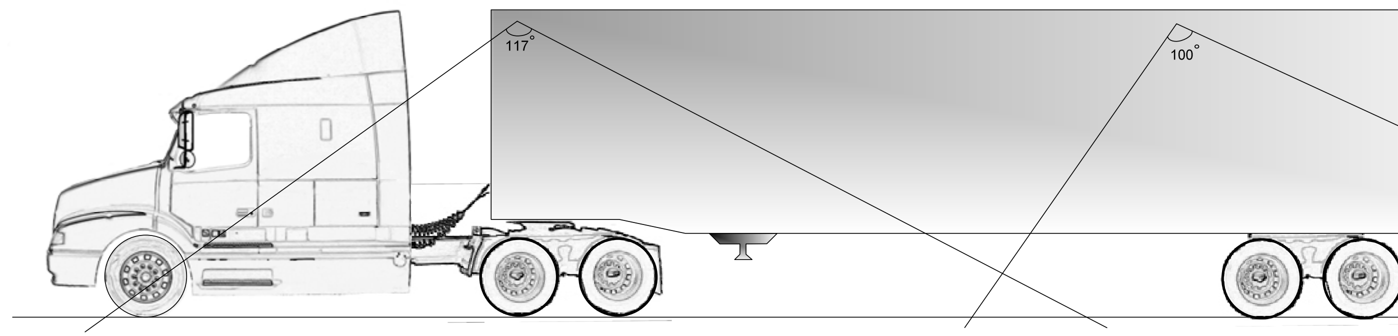


Figure 21. Potential Use of Dual Cameras with Additional Illuminators Placed High on the Trailer

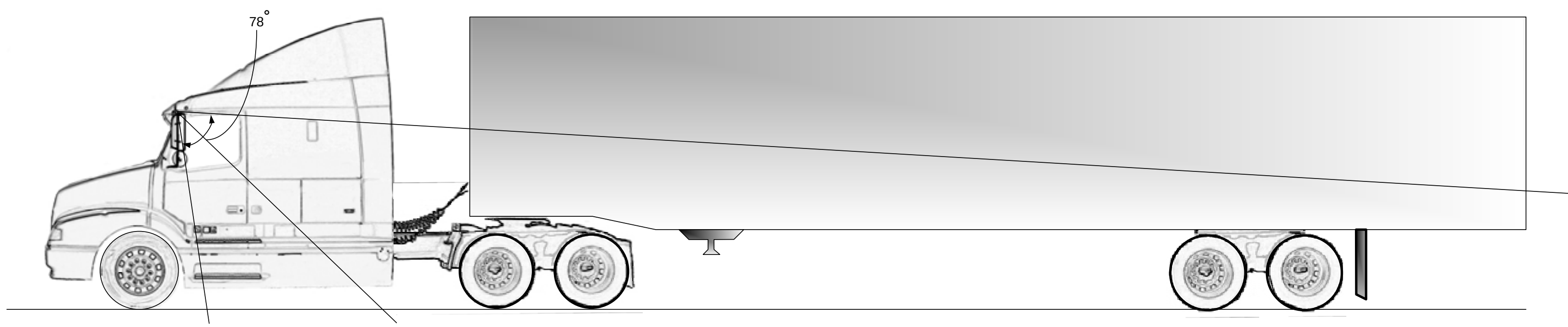


Figure 22. Potential Use of a Single Camera Mounted at the Mirror Structure

Unfortunately, the approach resulted in substantial image distortion with the trailer appearing to be only about 15 ft (4.6 m) long. In addition to this distortion, the approach did not provide blind spot coverage forward of the driver on the two sides of the vehicle, as the figure shows. Because of these substantial compromises, the approach was not pursued further.

5. The final approach was to rethink the entire problem. This approach involved changing objectives slightly. Originally, the goal that had been set was to provide the driver with information on the vehicle that might not be available from the side mirrors. Specifically, the video with its attendant processing was expected to provide an indication of the class of vehicle; that is, motorcycle, passenger car, light truck/SUV, or heavy vehicle. This identification was to have been obtained by outlining the vehicle using processing. However, such an objective, while helpful, is not always needed. The major problem is actually to evaluate whether there are objects alongside and to determine if sufficient clearance exists in case a lane change becomes desirable or necessary. In other words, improved situation awareness and clearance determination could be considered the main objectives of the Enhanced C/VIS.

Current side mirrors on heavy vehicles provide some information on the objects alongside, but they do not usually provide positive indications of clearance. Furthermore, they provide no information regarding objects directly behind the heavy vehicle. Driver experience and judgment are needed to assess clearance. If the Enhanced C/VIS trailer (rear) camera could be reconfigured to provide such information, then the heavy-vehicle driver's clearance estimation task should become easier and more accurate. The earlier project involving C/VISs examined this objective in detail (Wierwille, et al., 2007a).

Two approaches were developed in the earlier project: the so-called merge-remerge enhancement and the trailer rear wide-angle multipurpose look-down enhancement. The merge-remerge enhancement required two cameras and produced slightly better results than the trailer wide-angle look-down enhancement. However, the latter enhancement required only one camera and provided substantially improved driver estimation of clearance or overlap, compared with mirrors alone. This latter approach could be used in the Enhanced C/VIS to provide a rear view and to determine clearance in the adjacent lanes. It would only be necessary to replace the earlier concept of a rearview camera with the look-down wide angle alternative. This was, therefore, the approach used in the Enhanced C/VIS. By selecting this approach, no changes were required in the planned outdoor tests, which concentrated effort on the side camera, monitor, and processing.

Review of the Rear Wide-angle Multipurpose Look-down C/VIS

This C/VIS uses a camera mounted at the top rear of the trailer, aimed in such a way that the lower edge of the trailer appears in the video image as a reference. Figure 23 shows the camera, while Figures 24 and 25 show typical daytime views with an object vehicle directly behind and in the lane adjacent to the heavy vehicle. The figures show that the approach works well in assessing where an object vehicle is located.

The camera uses a horizontal (centerline) field of view of 102 deg, which covers the rear "same lane" and an adequate part of each adjacent lane. It should be mentioned that the horizontal field of view should not be made greater than is absolutely necessary because image distortion increases rapidly with field of view. Other specifications for this enhancement are provided in Appendix B which is taken directly from Wierwille, Schaudt, Gupta, Spaulding, and Hanowski (2007b).

Figure 23. Rear Wide-angle Multipurpose Look-down Camera at Back of Trailer

Figure 24. In-cab Monitor for the Trailer Rear Wide-angle Multipurpose Look-down Enhancement; Vehicle Directly Behind

Figure 25. In-cab Monitor for the Trailer Rear Wide-angle Multipurpose Look-down Enhancement; Vehicle in Adjacent Lane

Image Processing Subroutines

Originally, the research team planned to perform image processing following the stationary outdoor tests. However, because of the time required to develop the complex equipment for the outdoor setup and because processing was viewed as an important part of the experimentation, plans were changed. The image processing phase of the project was moved forward with the idea that it would be included in the stationary outdoor tests.

As mentioned, the fundamental idea was to take advantage of any changes in contrast in the raw video image and to use these changes for "outlining". It was believed that human (that is, driver) pattern recognition would be capable of identifying objects more easily if they contained outlines. The outlined processed video would then be superimposed over the original image, such that the original video would be seen with the outlines over the image. The amount of processing could be adjusted by a weighting scheme, which was specified at a given level (for the tests) by consensus of the developers.

An additional element of the processing was the concept of suppressing headlight bloom to the extent possible. Headlight bloom had been shown in both the indoor tests and in the preliminary outdoor tests to represent a problem. However, in spite of being a problem, the camera handled headlight bloom well and did not produce either vertical or horizontal streaks caused by bleed-through. The large white blooms, which were more-or-less elliptical, consumed a substantial portion of the vehicle image, but they were contained and did not streak. The combined image tended to suppress the white blooms somewhat because the processed image showed all but the edges of the bloom image as dark grey. When combined with the original image, the brightness of the bloom was reduced. A thin white perimeter line remained so that the driver could still identify the bloom and not mistake it for part of the vehicle.

Image processing after it was fully developed seemed to work well. It was included in all formal outdoor static tests. For daytime conditions, it used white outlines to show changes in contrast in the image. White outlines were, of course, also used for the B/W nighttime image.

In terms of hardware and software required, the image was first converted from NTSC (analog video) to digital form using a frame grabber. Thereafter, a custom program developed by VTTI personnel performed the processing operations, which involved use of Sobel filtering, additional processing as needed, and thresholding. The program was developed to run on a laptop computer, but could be easily converted to a dedicated processor. Once the processed image became available, it was superimposed over the unprocessed image in accordance with a specific weighting that had been selected experimentally. The composite image was then converted to VGA format and sent to the monitor. The use of this format was required in order to meet acceptable delay criteria. It was found that re-conversion to NTSC required excessive amounts of time, resulting in unacceptable image delays. The final program using the VGA output displayed on the screen was capable of delays not exceeding 85 ms, which was considered fully acceptable. Figures 26 through 29 show typical video results. Figure 26 shows the nighttime raw video, Figure 27 shows the corresponding processed image, and Figure 28 shows the corresponding combined images. All of these figures have the headlights on. Figure 29 shows the combined image with the headlights off. Daytime images placed white outlines around objects in color video, as previously mentioned.

Figure 26. Typical Nighttime Raw Video Image

Figure 27. Processing Applied to the Typical Nighttime Raw Video Image

Figure 28. Combined Nighttime Video Image

Figure 29. Combined Nighttime Video Image with Vehicle Headlights Off

Selection of Target Vehicle

It was recognized that the dark blue Saab 9-5 sedan that was originally scheduled for use in the outdoor static tests would not be suitable. This vehicle represented the extreme condition in that it became almost impossible to obtain a vehicle outline when the headlights were on during nighttime. While it might have been possible to double the size of the experiment by adding a light-colored vehicle, time and resources did not permit such an expansion. Therefore, a more typical vehicle had to be used.

The Virginia Tech motor pool had available a 2007 Chevrolet Malibu in what might best be described as olive green (Figure 30). This color was believed to represent an "average" in that it was neither very light nor very dark. The vehicle was also midsized, that is, average size for an automobile. It had the feature that the headlights or daytime running lights could be temporarily turned off by pushing a paddle switch on the turn signal stalk. Consequently, the vehicle was considered ideal for use as the object vehicle in the experiment. While it was possible to return to the Saab for the nighttime glare/discriminability tests, the decision was made to use the Malibu for these tests as well, making use of the fact that the Malibu was already warmed up. Thus, the Malibu was used for all formal testing. Tests were run in early 2008, but only when temperatures were at least several degrees above freezing.

Figure 30. Vehicle Used for All Tests (2007 Chevrolet Malibu)

CHAPTER 5. RESULTS OF THE FORMAL STATIONARY OUTDOOR TESTS

Once decisions were made regarding how to proceed, formal data gathering began. It took several weeks to obtain the data because the tests were run in January 2008 when freezing occurred on a regular basis. Data gathering could only occur on days when the temperature was at least several degrees above freezing. Of course, there was one major advantage to running during this time of year, namely, early darkness in the evening. This made it possible to obtain the nighttime data in the early evening hours.

As previously mentioned, all data gathering involved subjective evaluations of conditions using rating scales (Appendix C). Initially, the scale ratings were converted to numerical values. The left end of each scale was designated as 1, the center value as 5, and the right end value as 9. The remaining vertical delineators to the left of center were consecutively numbered as 2 through 4, and those to the right of center were consecutively numbered as 6 through 8. Although subjects were instructed that they could rate between vertical delineators, none did so. Had this occurred, such values would have been scored as the number to the left plus 0.5. For example, a rating on the line just to the right of center would have been assigned a value of 5.5. Once the ratings had been converted to numerical values, they were initially analyzed by appropriate ANOVAs (analyses of variance). Thereafter, significant results were plotted with post hoc test results included where appropriate.

After the ratings were converted to numerical values they were placed in an array and analyzed statistically. Five sets of analyses were performed, each initially involving an ANOVA and each having a different objective. The five are described under the following headings. In these analyses, post hoc SNK (Student-Newman-Keuls) tests were performed on main effects having three or more settings of the independent variable. Settings having a common letter do not differ significantly ($\alpha = 0.05$).

Nighttime Image Quality Assessment Analysis (Car Lights On)

In this assessment, the objective was to determine how satisfactory the video image in the cab of the tractor was to the subjects as a function of the nighttime condition. A 2 (Weather) x 4 (Illumination) x 3 (Position) within-subject ANOVA was performed on the data. These data were for the case in which the object vehicle (car) lights were on. The results demonstrated a significant Weather main effect $F(1,7) = 5.89$, $p = 0.0456$ and a significant Position main effect $F(2,14) = 17.63$, $p < 0.0001$. Neither the main effect of Illumination nor any of the interactions was significant. In regard to Illumination, the corresponding statistical results were $F(3,21) = 0.170$, $p = 0.9174$. More will be said about this lack of an Illumination main effect later.

Figure 31 shows the Weather main effect. This plot shows that subjects rated the clear condition higher than the rain condition. However, the rain condition was still considered to perform "moderately well", while the clear condition was rated near "quite well". Both of the ratings would be considered satisfactory or better.

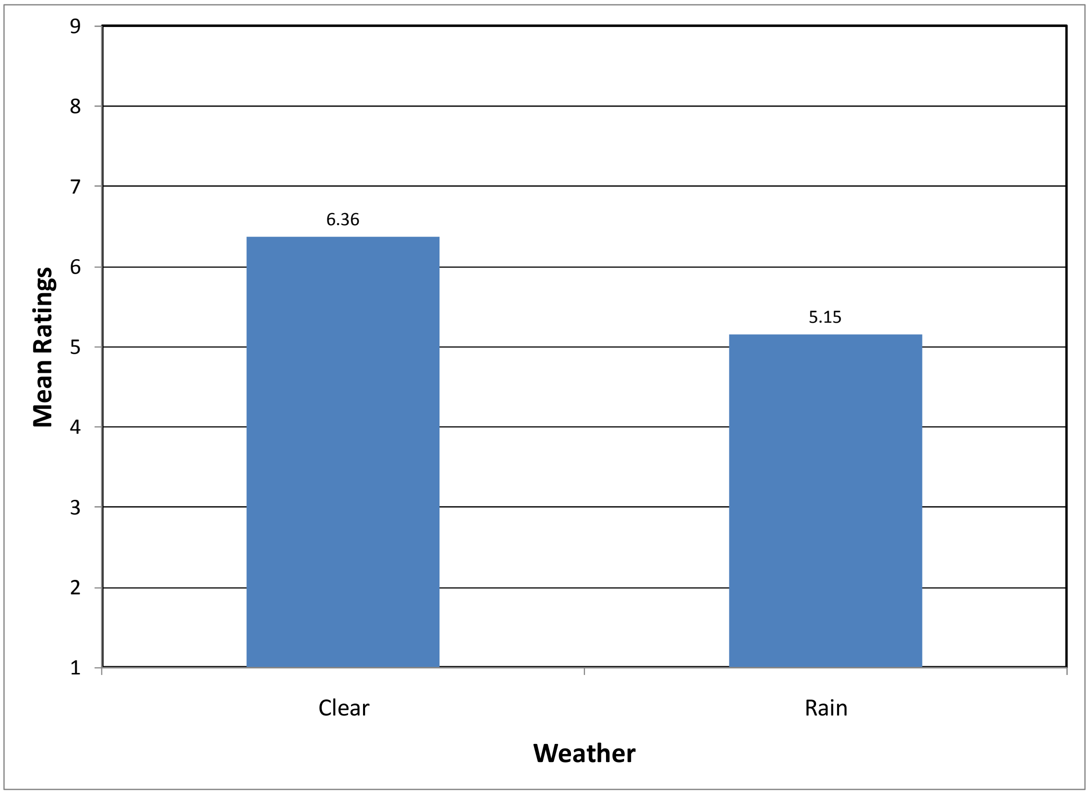


Figure 31. Weather Main Effect on Nighttime Image Quality Ratings; Car Lights On

Figure 32 shows the Position main effect, in which the near position provided significantly better ratings than the intermediate or rear positions. At the near position, the ratings indicate a value close to "quite well", whereas for the intermediate and rear positions the ratings correspond roughly to "moderately well". Again, these results suggest that the video system operates reasonably well. The results also suggest that the larger image appearing on the video screen at the near position produces better overall image quality ratings, a result that is not too surprising.

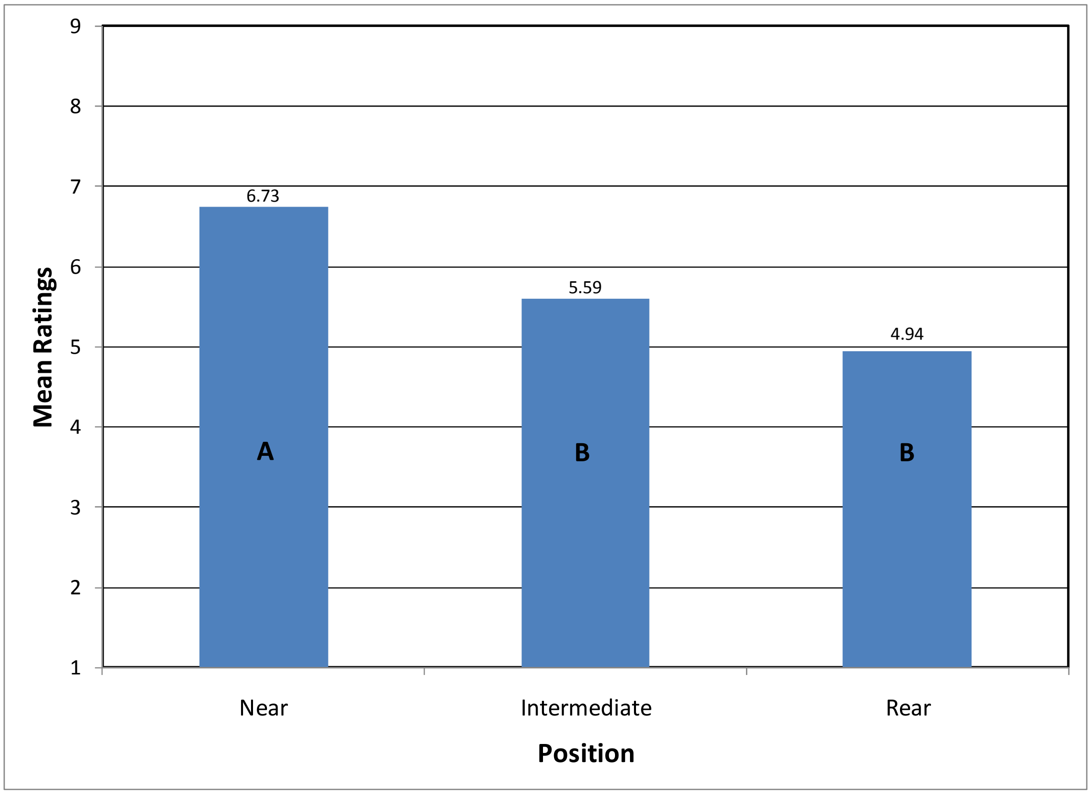


Figure 32. Position Main Effect on the Nighttime Image Quality Ratings; Car Lights On

A word of explanation is in order regarding the lack of an Illumination main effect. When the car lights were on, they tended to dominate the scene and cause any other illumination to be less effective or possibly ineffective. Therefore, it is not surprising that the Illumination main effect did not reach significance.

Nighttime Image Quality Assessment Analysis as a Function of Car Lights On/Off

At the intermediate position, subjects provided ratings with both the object vehicle (car) lights on and with the lights off. This made it possible to perform a comparison. A 2 (Weather) x 4 (Illumination) x 2 (Car lights On/Off) within-subject model was used for the ANOVA performed on the data. Results indicated a significant main effect of Weather, $F(1,7) = 8.25$, $p = 0.0239$ and a significant interaction of Illumination and Car lights On/Off, $F(3,21) = 5.01$, $p = 0.0089$. There were no other significant main effects or interactions. The Weather main effect is shown in Figure 33. Results are similar to those of Figure 31, but the mean values are slightly higher. This could be a result of the slightly better image quality occurring when the car lights are off (lack of blooming).

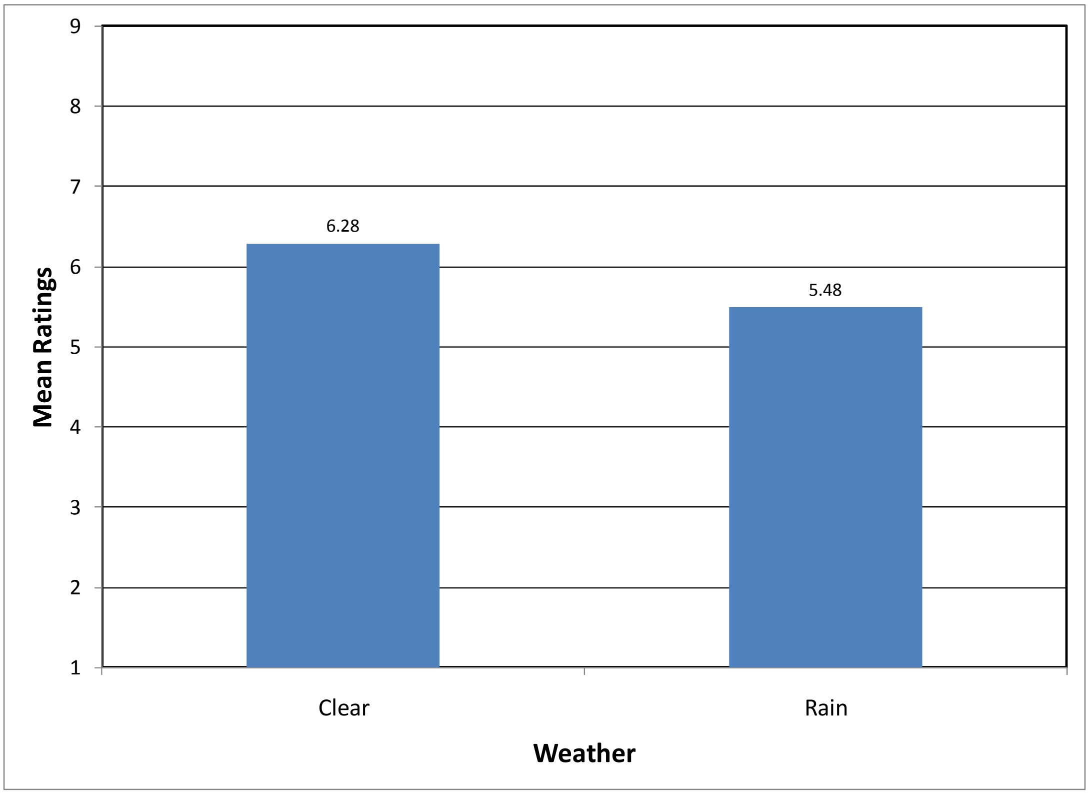


Figure 33. Weather Main Effect on Nighttime Image Quality Ratings; Car Lights both On and Off Included (at the Intermediate Position)

The interaction of Illumination and Car Lights On/Off is plotted in Figure 34. The plot shows that illumination improves the image quality ratings somewhat. In particular, with the car lights off, IR seems to improve the ratings. Visible illumination also has a slight beneficial effect, but the process of adding Visible and IR illumination does not produce an additive effect on the ratings. It should be noted in particular that, with illumination of either type, ratings approach the "quite well" performance level.

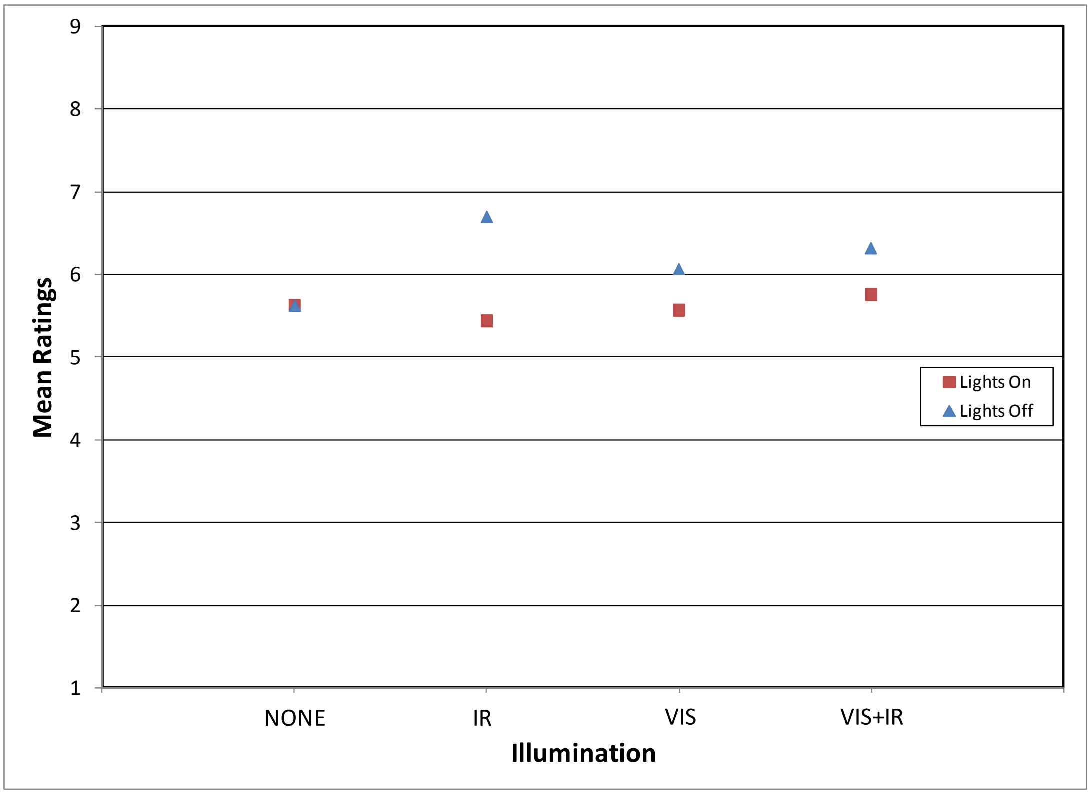


Figure 34. Interaction of Illumination Type with Car (Object Vehicle) Lights On/Off (at the Intermediate Position)

Daytime Image Quality Assessment Analysis (Car Lights both On and Off)

The daytime data for image quality of the in-cab video were analyzed using a 2 (Weather) x 3 (Position) x 2 (Car lights On/Off) within-subject ANOVA model. Here, as explained, it was assumed that drivers of object vehicles might have their lights on or off during the daytime. Consequently, data were taken at all three of the forward adjacent lane positions. Results exhibited a significant main effect of Position, $F(2,14) = 9.11$, $p = 0.0029$ and a significant main effect of Car lights On/Off, $F(1,7) = 7.47$, $p = 0.0292$. These main effects are plotted in Figures 35 and 36 respectively. There was also a significant Weather x Position interaction, $F(2,14) = 6.31$, $p = 0.0111$. This result is plotted in Figure 37. Neither the main effect of Weather nor the remaining interactions were significant.

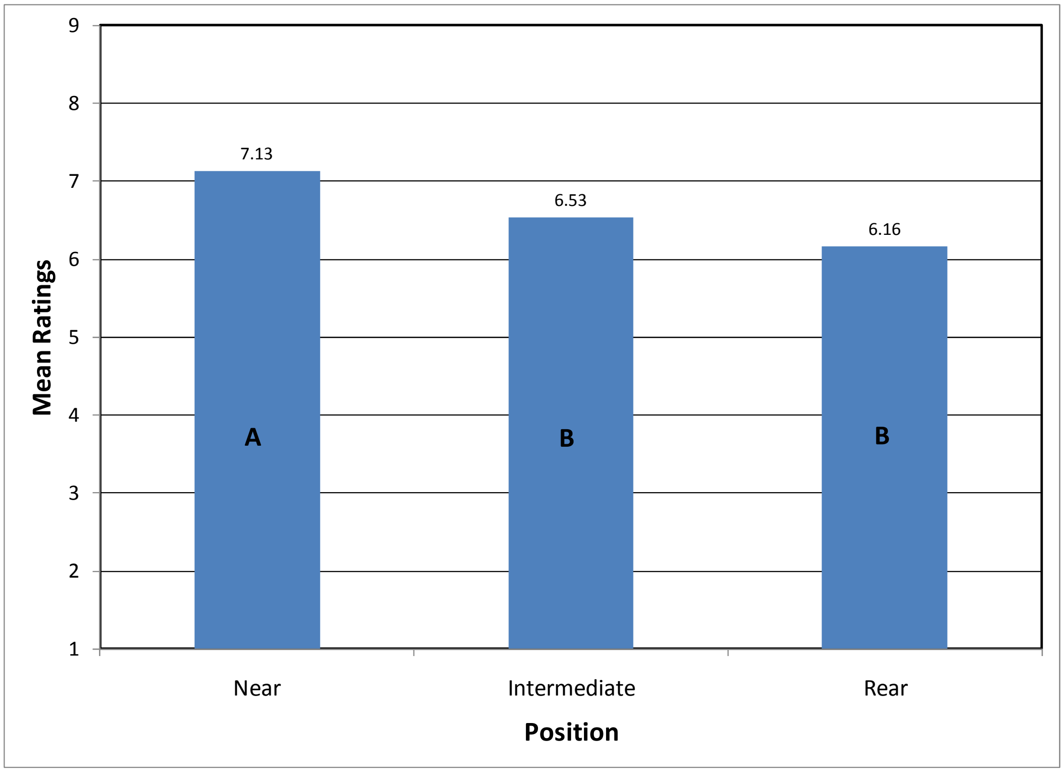


Figure 35. Daytime Main Effect of Position on Image Quality Ratings (Car lights both On and Off)

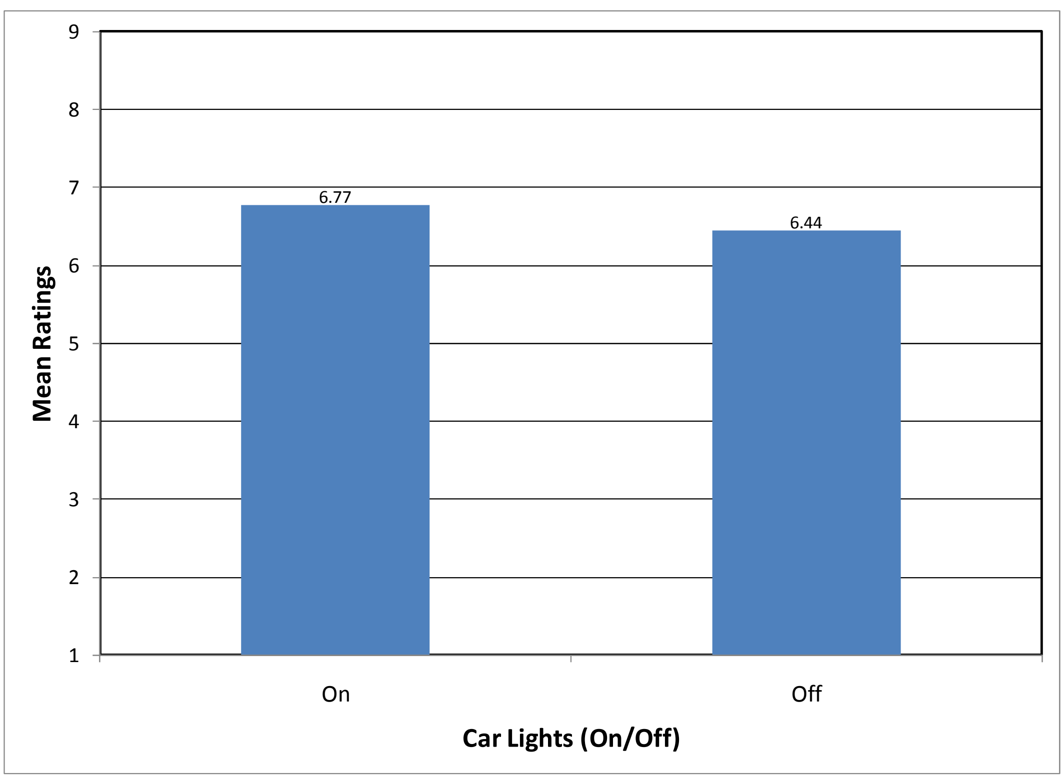


Figure 36. Daytime Main Effect of Car Lights On/Off on Image Quality Ratings

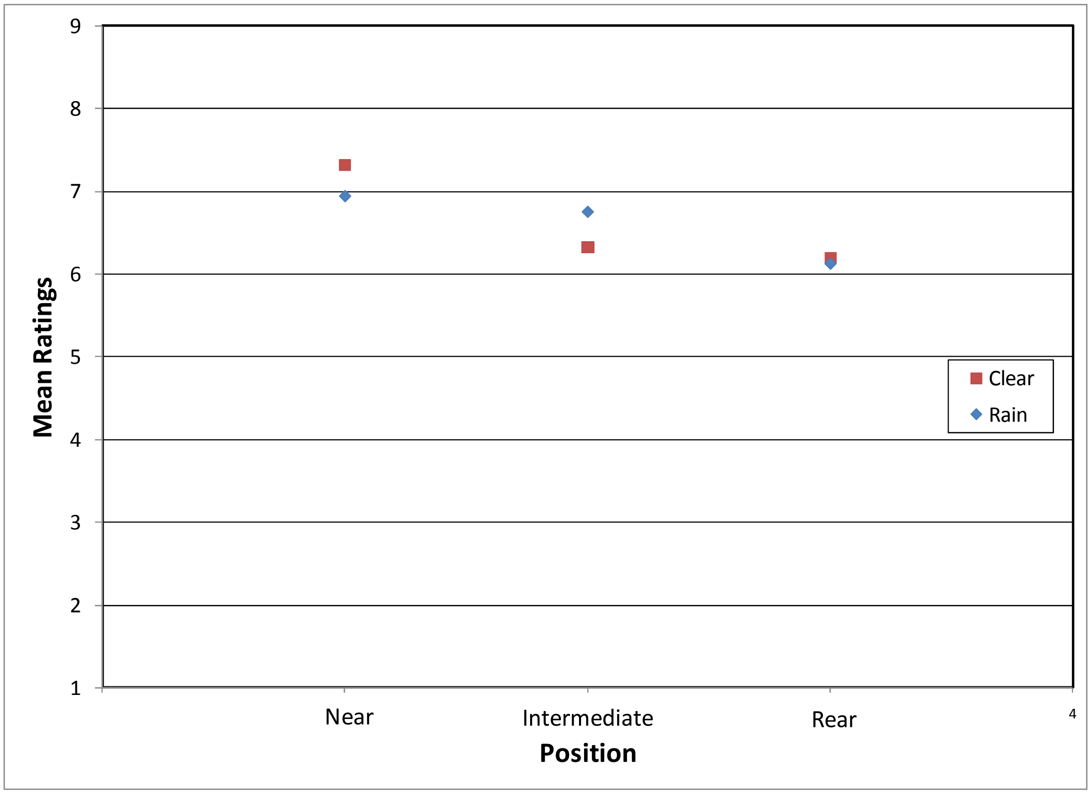


Figure 37. Daytime Interaction of Weather and Position on Image Quality Ratings

Figure 35 shows that in-cab daytime ratings were better as the object vehicle moved forward. A similar result was seen earlier for the nighttime tests. In particular, the near position produced significantly higher ratings than either the intermediate or rear positions, as demonstrated by the SNK tests. This result can once again be attributed simply to having a larger image of the vehicle and therefore having greater detail available. Figure 36 demonstrates that having the car lights on resulted in slightly, but nevertheless significantly, higher ratings than having the car lights off. Apparently, in daytime the lights contribute slightly to the definition of the object vehicle. Figure 37 indicates that the effect of rain on the ratings was dependent on object vehicle position. This result could certainly have been a result of the specific setup in which rain and wind would most likely not have been evenly distributed as a function of object vehicle positions. Actual highway conditions could be considered variable also. Still, interactive differences, though significant, are small.

It is important to point out that all of the daytime ratings are relatively good. They range from 6.0 to about 7.25. This range corresponds to "better than moderately well" to above "quite well". The specific camera used for the tests was, of course, the IK-64DNA. This camera was selected because it had both daytime color and nighttime B/W capabilities, and its sensitivity extended into the near IR range.

Nighttime Discomfort Glare Tests for the Visible Added Illumination

It will be recalled that relatively high-level visible illumination was used for some of the nighttime conditions. The illuminators used are shown in Figures 7, 12, 13, and 14; they are the oval-shaped illuminators. Because of their use, part of the nighttime experiment involved determining the level of discomfort glare they produced for the "other driver". The discomfort glare scale was set up so that higher values represented less discomfort glare (Appendix C). It is important to keep this in mind as the results are presented. Subjects moved the car from position to position with guidance from the experimenter.

The discomfort glare ratings were analyzed by means of a 2 (Weather) x 6 (Position) within-subject ANOVA. Results revealed only a significant main effect of Position, $F(5,35) = 5.88$, $p = 0.0005$. Neither the main effect of Weather nor the interaction of Position and Weather was significant. The Position main effect is plotted in Figure 38. Results are presented in descending order of mean ratings. Post hoc tests showed that the first three mean ratings values are associated with significantly less discomfort glare than the last two ratings values. The latter two correspond to the nearest positions in the same lane and the adjacent lane. However, the values range from 6.63 to 8.25. The 6.63 value is just below "slightly" uncomfortable and 8.25 is not too far from 9.00, corresponding to "not at all" uncomfortable. Consequently, it could be assumed that the discomfort glare is not a serious problem with the visible lighting used.

It is worth mentioning once again that the main effect of Weather was not significant $F(1,7) = 2.45$, $p = 0.1612$. Subjects were permitted and encouraged to use their windshield wipers. All did so for the rain conditions. All subjects used either the low- or high-speed continuous settings. They did not use the so-called "interval" settings. This indicates that during the rain conditions the amount of rain encountered was substantial. However, with the wipers operating, ratings for glare when the rain was present were not sufficient to overcome chance.

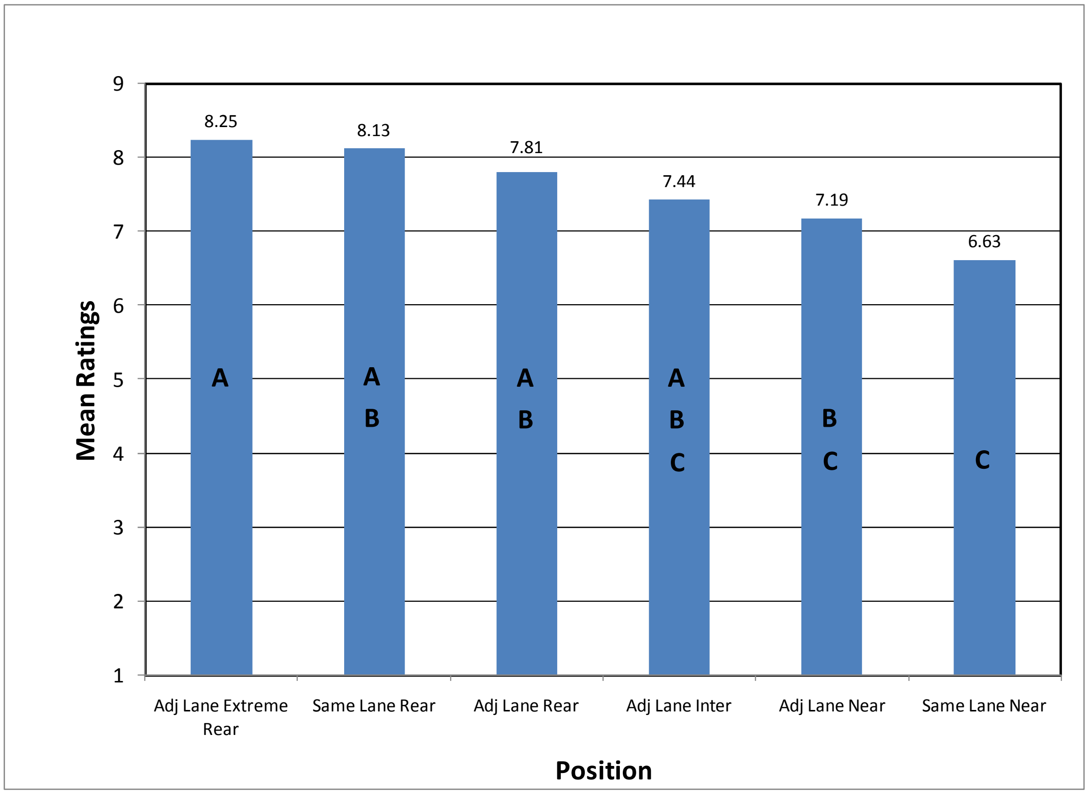


Figure 38. Discomfort Glare Ratings as a Function of Vehicle Position (Higher Values Indicate Less Discomfort Glare)

One source of concern with these tests was that the rain and wind were set up so that they would be authentic along the side of the tractor-trailer. They were not specifically set up to provide accurate simulation *behind* the trailer. Consequently, it was decided that a 2 (Weather) x 4 (Position) within-subject ANOVA using only the adjacent lane ratings should be performed. In other words, an alternative analysis without the trailer rear data was performed. Results similarly demonstrated a significant Position main effect $F(3,21) = 5.41$, $p = 0.0065$. Weather once again failed to reach significance $F(1,7) = 2.96$, $p = 0.1291$, and the interaction of weather and position was not significant. In examining the Weather main effect, it could be speculated that a substantially larger sample size would be necessary to achieve significance. If so, there is the implication that the effect is not of a large magnitude and that system operation with and without "Weather" is relatively similar.

Nighttime Discriminability Tests for the Visible Added Illumination

As mentioned, a lead vehicle with its taillights and license plate lights lit was included in the outdoor test setup. Subjects were asked to rate the reduction in discriminability created by the added visible illumination (Appendix C). Here again, subjects moved the car from position to position, as guided by the experimenter. However, only adjacent lane positions were used, because the trailer blocked the view to the lead vehicle when the car was in the same lane; that is, behind the trailer. The added visible illumination was turned on and off so that the subject could judge the loss in discriminability due to the added illumination.

A 2 (Weather) x 4 (Position) within-subject ANOVA was performed on the ratings. Results demonstrated a significant Weather main effect, $F(1,7) = 14.91$, $p = 0.0062$, and a significant Position main effect, $F(3,21) = 4.56$, $p = 0.0120$. The interaction of Weather and Position was not significant, but was not too far from significance $F(3,21) = 2.56$, $p = 0.0822$.

The main effect of weather is plotted in Figure 39. As the plot shows, the added nighttime visible lighting had very little effect on rated discriminability during the clear conditions and only a slightly greater effect during the rain conditions. For the rain conditions, discriminability loss falls midway between "not at all" and "slightly".

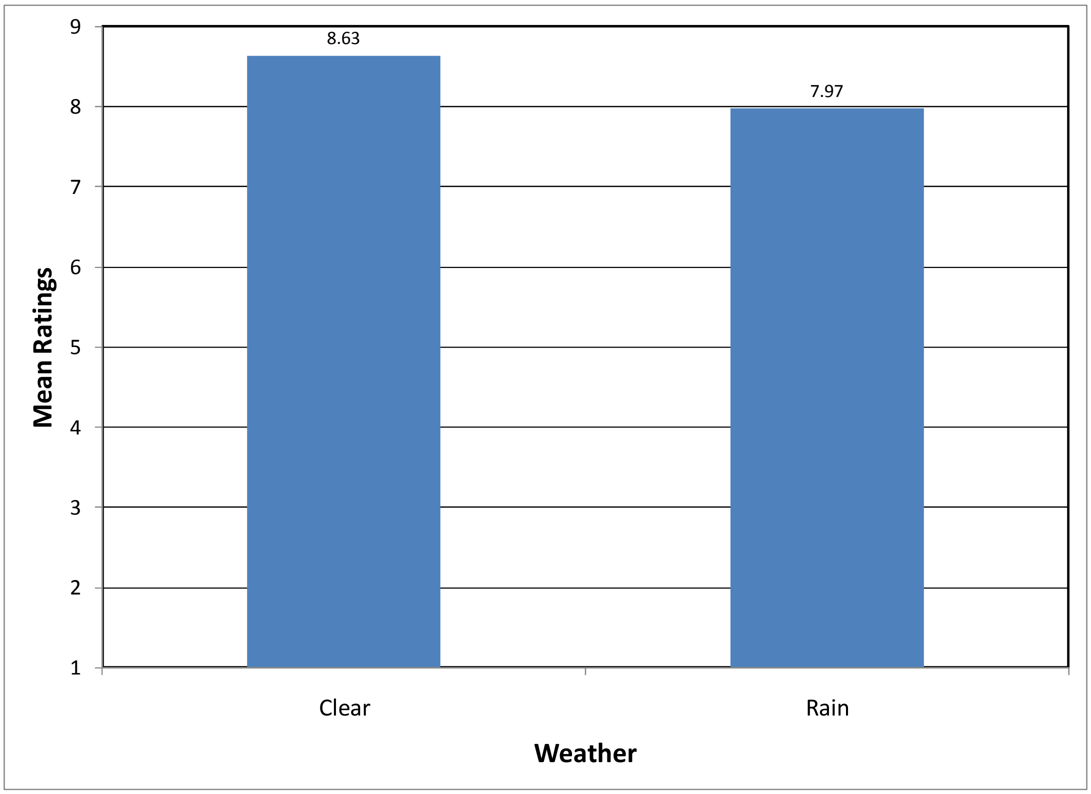


Figure 39. Discriminability Ratings as a Function of Weather (Higher Values Indicate Smaller Loss of Discriminability)

The main effect of Position is shown in Figure 40. As can be seen, the near position differed significantly from the rear and extreme rear positions according to the post hoc SNK tests. However the loss of discriminability at all positions was rated as quite low.

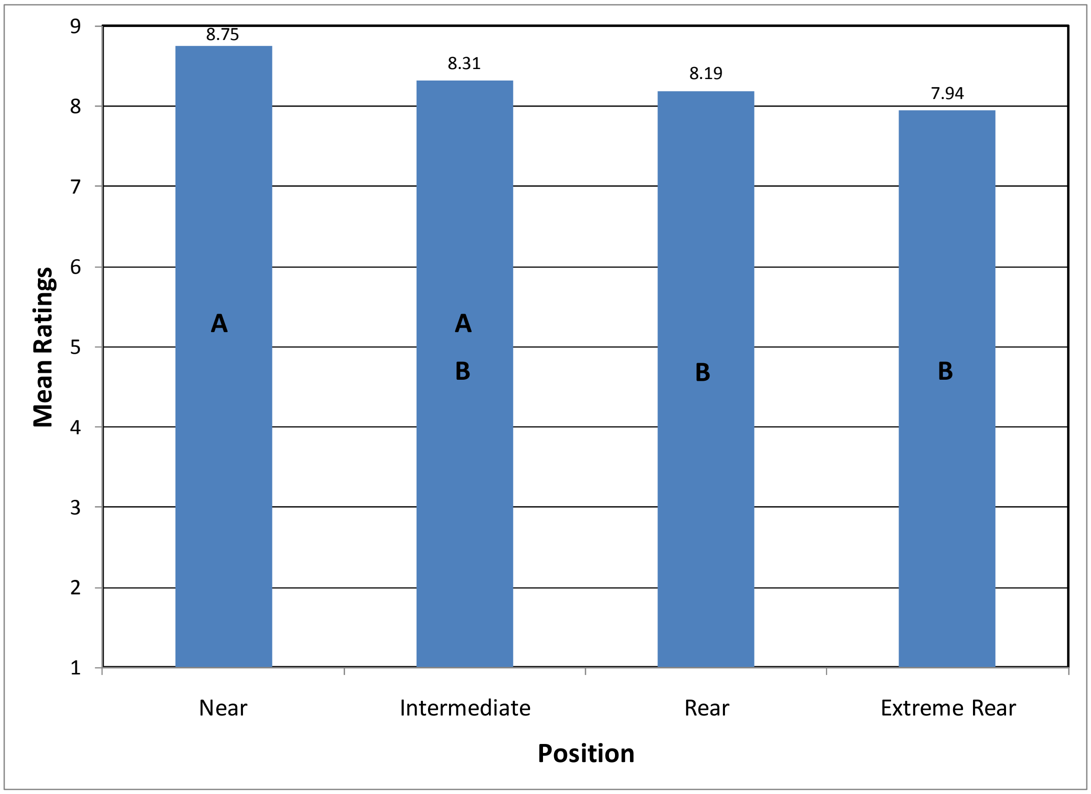


Figure 40. Discriminability Ratings as a Function of Vehicle Position (Higher Values Indicate Smaller Loss of Discriminability)

In general, the results show that losses in discriminability associated with the added visible lighting are quite small. These results suggest that added visible illumination does not interfere to any appreciable extent in ability to see or read details in a lead vehicle.

Perspective

Formal Results

Overall, the results of the outdoor formal experiments provided relatively positive evidence that the Enhanced C/VIS tested on the passenger side of the heavy vehicle worked quite well. This statement is true for both daytime color and nighttime B/W capability. The statement is also true for clear and rainy conditions. It should be remembered that processing was included in the tests, which may possibly have contributed to the satisfactory (or better) ratings. Clearly, the video equipment configuration provided satisfactory performance over a very wide range of conditions. These findings and others derived from the outdoor tests are as follows:

- The Enhanced C/VIS, as tested, performed well across all conditions tested and provided ratings that could be considered satisfactory or better. This is a major finding, suggesting that the developed equipment does (at least) a reasonably good job for all conditions tested. It also suggests that the full three-channel system should use similar equipment in its design.

- Rain generally had a small deleterious effect on the ratings, as expected, but the effect was sufficiently small that the ratings remained at the moderate level or higher. It should be recalled that the rain conditions were quite realistic and were reasonably representative of highway driving conditions.

- The *near* adjacent lane position received higher image quality ratings than the other positions. Owing to the larger size of object image, the near position image had greater equivalent resolution; that is, more pixels within the image.

- The addition of illumination at the side of the tractor and trailer for nighttime runs created higher image quality ratings, but only when the object vehicle lights were off (Figure 34). In particular, the use of IR seemed to provide the greatest improvement. This phenomenon was also observed by the experimenters, and is believed to be a result of an almost total lack of ambient illumination when the object vehicle lights are off. Therefore, it seems worthwhile to include IR in the final design, because some objects (such as trailers towed behind vehicles) may have limited or no lighting.

- The addition of visible additional illumination along the side of the tractor and trailer does not seem to provide any advantages over IR during the nighttime runs. Visible illumination does not provide results quite as good as IR, and it creates an unnecessary but low level of discomfort glare and reduction in discriminability. Therefore, IR is the recommended choice.

- Visible additional illumination used along the side of the tractor and trailer produced only the smallest increase in discomfort glare and only the smallest reduction in discriminability of a lead vehicle in terms of definition and ability to read details. Consequently, if for some reason IR is not or cannot be used, visible illumination (of the type tested) can be added without causing any substantial problems for other drivers.

Other Less-formal Findings

During the data gathering portion of the experiment, the experimenters noticed a few situations that were quite informative. These are primarily developmental issues that should eventually be addressed.

- The regular tractor-trailer side lights caused bright spots in the nighttime images. It was found that the side marker lights on the side of the tractor (at the sleeper berth location) and along the trailer (front, middle, and rear) could be seen in the video image at night as bright dots. These lights were simple marker lamps that were not too bright. However, they had great contrast at night because of the darkness and the direct view. A solution was to put a simple glare shield between the lamp and the camera. This could be done at or quite near the lamp. The material selected was slightly flexible so that should someone brush against it while walking past, they would not be injured. (Near the end of the project it was learned that drivers sometimes use the trailer rear marker lamps to judge clearance or overlap. If these markers are retained, there may be a brightness setting that would allow them to provide clearance judgments while not appearing too bright in the video image. On the other hand, clearance or overlap could be judged using the rear camera, as will be explained.)

- Reflections off the raindrops were found in sunlight. There were occasions when the sun reflected off raindrops, producing bright "speckles" in the video image. These were greatly exacerbated by the image processing, which was based largely on changes in contrast to emphasize image outlines. The experimenters noted this problem on one or two of the daytime runs. There were two possible solutions to this problem. One would be to modify the computer program to remove the speckles. (However, there may be desirable points of light in the scene that it would be best not to remove.) Another approach would be to temporarily reduce the weighting of the image processing, thus having the video heavily weighted toward the raw or unprocessed video image.

  The original concept of the interface for the driver included a "processing" rocker switch that could be used to increase or decrease the weighting of the processed image relative to the original image. It appears that this control would work extremely well to reduce the problem of reflection off raindrops. Therefore, the envisioned control for level of processing should be retained.

- The rain and wind increased the size of the bloom seen on the monitor. The experimenters noticed that the size of the headlight bloom on the monitor was increased under some conditions by the combination of wind and rain. This was apparently caused by reflections off raindrops caused by the headlight output. There appears to be little that can be done about this type of increase in bloom. However, once again, processing could be attenuated somewhat using the driver interface control. In addition, the original design of the Enhanced C/VIS was considered as an enhancement per se; that is, the side mirrors were to be retained. Consequently, the driver would have the option of looking into the mirrors under these unusual circumstances.

- Glare was found on the image surface of the monitor. The experimenters noticed that the monitor in the cab had reflections at various times, or in other words, stray light was reflected off the monitor screen. To minimize this occurrence, a glare shade should be used. This would eliminate the problem of glare created by light entering from any direction except nearly straight on. Straight on light would have to be handled by monitor aim, monitor position, and image surface treatment.

It should be mentioned in closing that all of the above less-formal findings were part of the data gathering; that is to say, the subject ratings included these problems to the extent that they occurred. Consequently, it could be argued that solving the problems might have resulted in slightly higher (that is, slightly better) average ratings.

Once again, it should be reiterated that in general the outdoor tests provided extremely valuable design and verification information. The outdoor tests were considered a success. The results set the stage for the three-channel system design.

CHAPTER 6. SYSTEM DESIGN FOR THE THREE-CHANNEL ENHANCED C/VIS

INTRODUCTION

This chapter describes all of the design information gathered during the indoor and outdoor tests for the design of the three-channel Enhanced C/VIS. Fortunately, the great majority of work was already completed, and it was primarily a matter of assembling it to achieve the design.

Several of the principles in the design are first reviewed. These can be outlined as follows:

- The design of the E-C/VISs for the two sides of the vehicle should be similar and should be closely patterned after the passenger-side E-C/VIS used for the outdoor tests.

- The rear E-C/VIS should be patterned after the rear wide-angle multipurpose look-down C/VIS developed during the original C/VIS project. Of course, the design for the rear Enhanced C/VIS should use the same type of camera (but with a wide-angle lens) as the side Enhanced C/VISs and should take advantage of the processing and all of the other updates needed to have the system function as an all-weather system.

- The additional illumination used should be IR and should use the IR illuminators pictured in Figures 12, 13, and 14 (white rectangular units). These are important for use at night when there is little other illumination.

- Processing should be included in each of the three channels of the E-C/VIS. The channels may use the same processor (providing that processing/throughput time in each channel is held to 100 ms or less) or different processors. These processors must operate reliably and should eventually be designed to initialize themselves.

- Monitors should have VGA inputs because reconversion to NTSC produces delays that are much too long. The monitors should be approximately Size 2 as defined in the original C/VIS project.

- The two side channels should use monitors located near the bases of the two A-pillars, with mirror image (that is, horizontal reverse) presentation. When installed at the A-pillars, any overlap should be toward the rear, so that the windshield is not blocked. The monitor for the rear system should be placed in the "equivalent" inside rearview mirror position, should also present a mirror image, and must not block any horizontal portion of the driver's forward view. All monitors should be turned toward the driver, so that his or her view is almost perpendicular to the monitor.

- The Enhanced C/VIS system is considered to be an enhancement (as defined earlier). Therefore, views of the side mirrors must not be blocked by the monitors installed at the A-pillars.

- Glare shades should be developed for the monitors. These should minimize off-axis incident light. The glare shades should be such that they do not present a hazard to the driver or front seat passenger when entering or exiting the vehicle or in case of a crash.

- The driver interface control should be similar to that developed conceptually during Task 1. It should include a brightness/contrast rocker control that allows this video parameter to be increased or decreased from its nominal setting. The interface control should also include a processing control that allows weighting of the processed image to be increased or decreased from the nominal setting. A reset button should return the system to nominal settings. The tests suggest that backlight compensation is not likely to add anything of value, because the processing already improves image outlines. Therefore, the interface should not include this control.

- The cameras should be installed in waterproof housings with sun shades. It was expected that closed course tests would include additional rain condition data gathering.

With these design principles in mind, it became relatively straightforward to complete the design. Figure 41 shows the revised coverage areas of the three cameras used in the system. It can be seen that there is some overlap between the side coverage and the rear coverage. This is desirable because of the need to locate objects accurately in adjacent lanes near the back end of the trailer. The overlap permits the driver to accurately determine where an object vehicle is in the adjacent lane, near the back of the trailer. Specifically, if the entire object vehicle can be seen in the rear video, then there is clearance. With a bit of additional space it would then be safe to merge into the adjacent lane in front of the object vehicle.

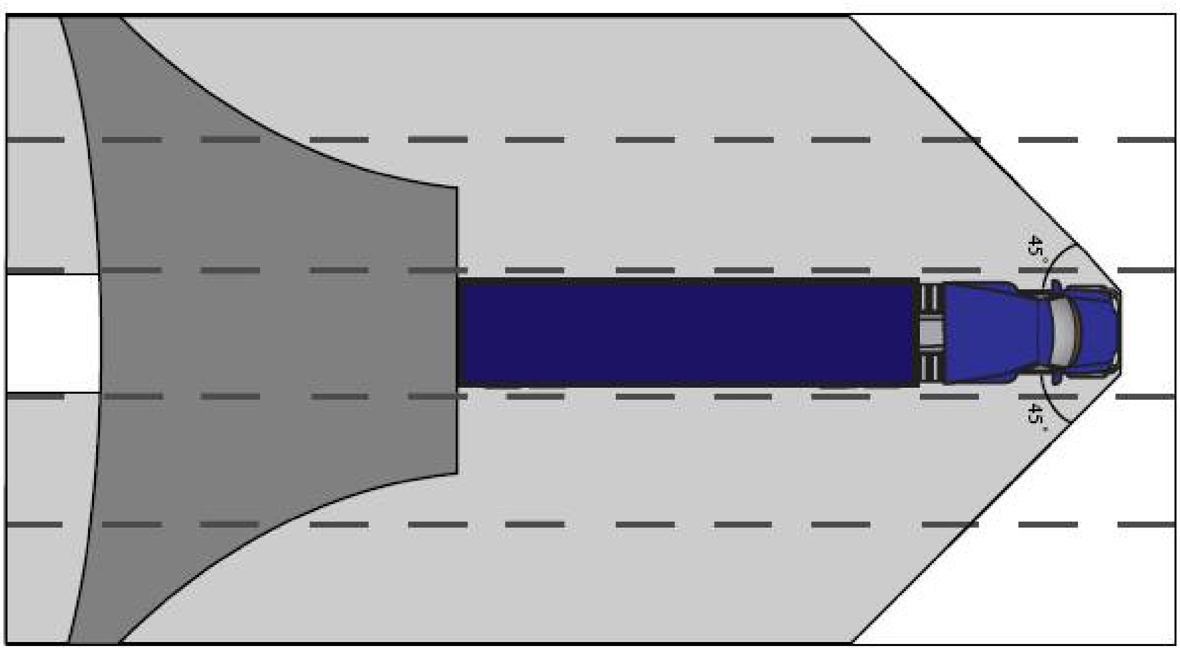


Figure 41. Coverage of the Three Cameras in the Final Design

In regard to the IR illuminators, only small changes in illuminators were necessary. Figure 10 shows the original locations and aims of the IR illuminators. Because the illuminators did a satisfactory job along the side of the tractor-trailer, no changes were contemplated in that region. However, in changing the position and angle of coverage of the rear video channel, aiming the rear illuminators straight back did not appear to be optimally appropriate, for two reasons. First, if the illuminators were aimed straight rearward, the adjacent lanes would receive some of the illumination, but they would not receive the center of the beam. Secondly, objects directly behind do not need to be distinguished in great detail. Presence or absence information should suffice. On the other hand, with the objective of providing the driver with definitive information regarding objects in the adjacent lane near the rear of the trailer, it seemed prudent to aim the corresponding rear IR source into that lane. Figure 42 shows the modified aiming design for the two rear illuminators. It should be noted that the beam widths of the IR sources are at least 45 deg. Therefore, there will still be illumination directly to the rear, even though the beam centerlines are now directed into the adjacent lanes somewhat. Moreover, a vehicle directly behind will be illuminated by its own headlight reflections off the rear of the trailer.

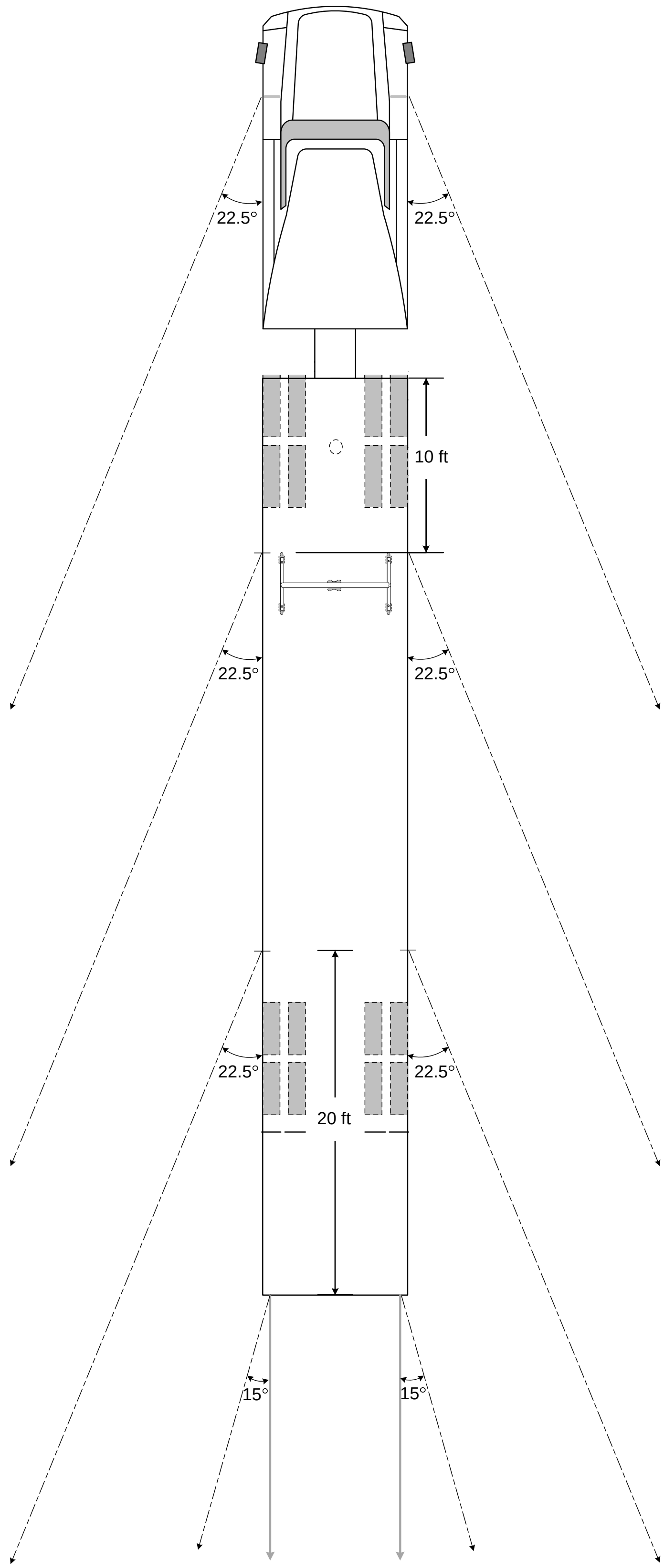


Figure 42. Diagram Showing the Revised Aiming of the Rear IR Illuminators

As stated earlier, the DVI should also be revised from that envisioned and presented in the Task 1 report. In particular, it appeared that the backlight compensation control would be ineffective because the IK-64DNA camera generally provides optimum compensation for varying conditions. Accordingly, this control can be eliminated. Figure 43 shows the envisioned revised control. In the way of review, note that for purposes of reducing driver distraction, all three channels would operate in parallel. Consequently, control of an individual video image can only be accomplished by having similar changes in the other two video images. This simplifies the interface by reducing the number of controls by a factor of three or, alternatively, avoiding a specific-monitor access menu.

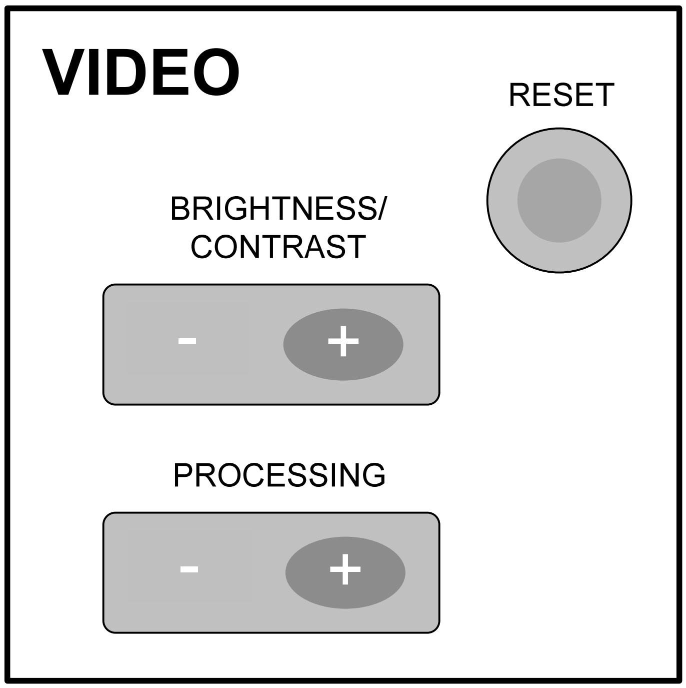


Figure 43. Revised Driver Vehicle Control Interface

The day/night filters and corresponding daytime color/nighttime B/W switching of the three cameras should be done simultaneously so that the cameras do not bounce arbitrarily between daylight and nighttime conditions independent of one another. Therefore, a system should be designed that determines when dark conditions occur and switches all three cameras accordingly and simultaneously. There are several possibilities for accomplishing this changeover. One approach would be to use a light sensor that could be placed on the dash and aimed upward through the windshield. The output of this photosensitive device would then be amplified, smoothed, thresholded, and used to drive complementary metal oxide semiconductor (CMOS) switches controlling the changeover. It is important to make the default position the daytime filter position so that the cameras are protected from high light levels. The system should initially be adjustable, so that the appropriate level of ambient lighting is selected for the changeover. In addition, there should be a bit of hysteresis in the design so that "hunting" does not occur when the threshold is approached. This will require two comparators with spaced thresholds in the design. The lower one would be associated with going from daylight to darkness and the upper threshold would be associated with going from darkness to daylight, thereby eliminating hunting. Figure 44 depicts this process.

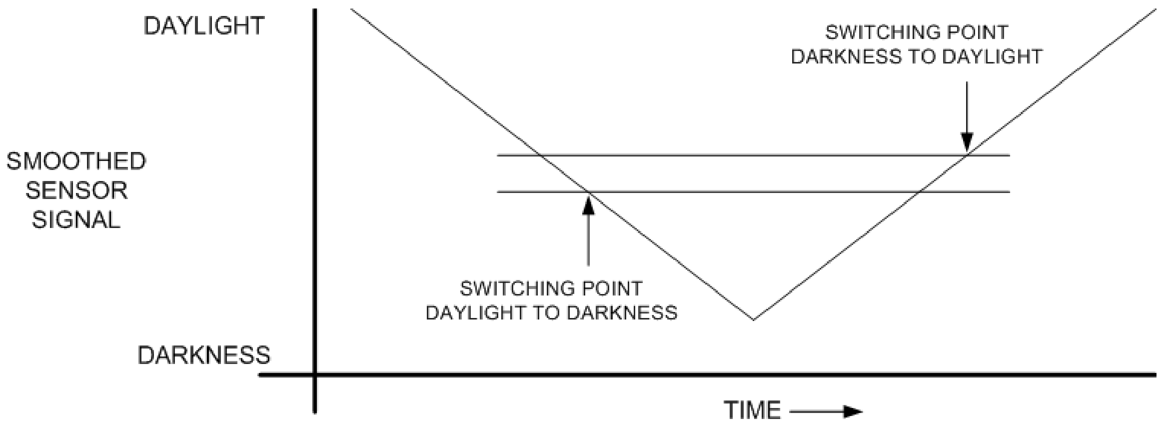


Figure 44. Depiction of the Crossover Threshold Between Daytime Color and Nighttime B/W

CHAPTER 7. SMART ROAD AND OBJECT DETECTION TESTING OF THE REVISED ENHANCED C/VIS; EXPERIMENT DESIGN AND EQUIPMENT

The purpose of this additional testing was to verify the extended environmental range of the Enhanced C/VIS, which was composed of three video channels with coverage as shown in Figure 41 of the previous chapter. It was decided that testing would be limited to nighttime conditions. The reason for this was that the daytime conditions were believed to have been studied sufficiently to demonstrate feasibility for such conditions. Both the stationary outdoor tests and the previous work with the original C/VIS project suggested that there would not be a problem with the Enhanced C/VIS operating in daylight conditions. In addition, resources could then be placed where additional experimental results were needed.

Main Independent Variables

The Virginia Smart Road was considered to be an ideal test bed for the testing because it provided a controlled environment in which the effects of rain and highway lighting could be studied under dynamic (that is, moving vehicle) conditions. Rain was considered important in that it is one of the most frequently occurring inclement weather conditions. For comparison purposes, it was considered important to test not only with rain, but also without rain; that is, under clear conditions. Roadway lighting was also considered to be important because it was a different condition from any that had been studied previously. In addition, it was considered likely that the luminaires might cause reduction in image quality for the side cameras, once the vehicle had passed them. The main problem was believed to be the fact that the luminaires might appear in the field of view of the side cameras and, therefore, might cause glare problems. This situation, as indicated, had not been studied previously in any of the indoor or outdoor tests.

Also, to get an idea of how much improvement (if any) might be expected with the Enhanced C/VIS, it was considered necessary to test with the system operating and with the system not operating; that is, Baseline. Without the Baseline system (Enhanced C/VIS not operating) it would be difficult to determine the degree of improvement (if any) that the Enhanced C/VIS would provide.

Yet another aspect of the testing considered was object location and identification. This represented a particularly vexing problem because of the need to maneuver objects into position in a dynamic environment. Eventually a compromise was reached which will be explained later.

Finally, it was considered important to run the tests with naïve CDL drivers, for two reasons: first, these individuals were typical of the ones who would eventually determine whether or not the system would be helpful and acceptable, and second, because these individuals were qualified to drive the equipped heavy vehicle. Furthermore, all previous tests (in the Enhanced C/VIS project) had been run with VTTI personnel. It was therefore considered important to obtain actual user performance and opinion data. Drivers were recruited from a volunteer database. Recruiting was carried out without regard to gender, but drivers had to have at least two years of full time experience as a heavy vehicle driver. As it turned out all of the eight qualified participants were males.

The experiment had three main independent variables, as follows:

- Weather: rain or clear
- Lighting: presence or absence of street lighting
- Enhanced C/VIS: system operating or not operating (Baseline).

These independent variables were considered important for the Smart Road tests.

It was considered desirable to deal with the object detection problem and to determine if the Enhanced C/VIS would provide improved object detection. However, the investigators were not able to devise an object detection testing methodology that was considered authentic, safe, effective, and efficient in the dynamic situation. Therefore, the Smart Road tests themselves did not include this type of testing. Instead, it was decided that additional tests should be performed in a blacktopped area at VTTI. This area is the same area where earlier stationary tests had been performed. The object detection tests preceded the Smart Road tests and thus had the added benefit of familiarizing drivers with the tractor-trailer and the Enhanced C/VIS. The tests were performed statically, which removed the danger of a collision. Although these tests were performed before the Smart Road tests, they will be described in this chapter after the Smart Road tests are described, because the Smart Road tests were directed more toward the main objectives.

Experimental Design of the Smart Road Tests

There were, as previously mentioned, three independent variables with two levels each, resulting in a total of eight factorial combinations of conditions. Tests were planned so that all eight conditions (not counting practice) could be examined in eight loops of the Smart Road for each driver. In four of the eight loops (for each driver), the rain towers were activated, producing the rain conditions, whereas in the remaining four loops the rain towers were deactivated (or not activated). Similarly, in four of the eight runs, the roadway lighting was activated and in the other four the roadway lighting was deactivated. Finally, on four loops, the Enhanced C/VIS was activated and on the other four it was deactivated; that is, Baseline.

Rain simulation had certain constraints. The most important for the current research was the time required to initiate steady-state rain, and the time to "clear" the rain once it was turned off. Activation required close to 30 minutes, while clearing required about 15 minutes. Because of these lags, runs were planned so that turning on or off was performed only once for a given subject. This meant that once rain was activated, it was not turned off until all rain-related runs were completed. Similarly, once the sequence of clear runs was started, the clear runs were all completed.

In terms of Smart Road overhead lighting, that lighting could be turned on or off in a relatively short time. However, some of the lighting had a warm-up period estimated to be not more than 3 minutes. Consequently, switching to lighting from no lighting entailed a short delay. On the other hand, turning the Enhanced C/VIS system on and off was relatively easy, in that it was possible to simply blank or un-blank the monitors, leaving the video and all processing running. This had the effect of turning off the displays so that the driver was forced to use the standard side mirrors (only) for determining the situation around the heavy vehicle. As previously indicated, the plan called for the use of eight subjects (drivers) in the experiment, with each subject experiencing all eight factorial conditions. The sequence used for each subject is shown in Table 4. Note that the conditions were counterbalanced at the same time that the rain required only one turn-on and one turn-off. The overhead lighting required two turn-ons and two turn offs, and the Enhanced C/VIS system required four turn-ons and four turn-offs. Thus the scheme offered an efficient design, while retaining desired counterbalancing of conditions. With this design, data gathered for each dependent variable could be analyzed statistically with an ANOVA using a within-subject model, as follows: 2 (Weather: Rain versus Clear) by 2 (Lighting: Street Lighting On versus Dark) by 2 (E-C/VIS: system operating or Baseline).

Table 4. Counterbalancing Scheme for the Smart Road Experiments

Order of Condition Presentation

→

Subject	**Rain**					**Clear**			
	OH Lights On		OH Lights Off			OH Lights On		OH Lights Off	
S1	E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off		E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off
S2	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On	**Break**	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On
	OH Lights Off		OH Lights On			OH Lights Off		OH Lights On	
S3	E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off		E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off
S4	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On		E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On

	Clear					**Rain**			
	OH Lights On		OH Lights Off			OH Lights On		OH Lights Off	
S5	E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off		E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off
S6	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On	**Break**	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On
	OH Lights Off		OH Lights On			OH Lights Off		OH Lights On	
S7	E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off		E-C/VIS On	E-C/VIS Off	E-C/VIS On	E-C/VIS Off
S8	E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On		E-C/VIS Off	E-C/VIS On	E-C/VIS Off	E-C/VIS On

The preliminary experiment which will be described later in this chapter provided a good deal of practice in using the E-C/VIS (as well as Baseline) while in a static condition. However, it was deemed necessary to provide some additional practice in a dynamic situation as well, prior to data gathering. This was considered necessary to increase familiarity with the heavy-vehicle baseline operating condition as well as the E-C/VIS operating condition. Consequently, each driver performed the first two runs in his or her sequence twice: the first time for practice and the second time for data gathering. This plan assured equal practice across the eight conditions and eight drivers while at the same time allowing each driver to obtain exposure under dynamic conditions to an E-C/VIS condition and a corresponding baseline condition, prior to data gathering. Thus, each driver actually performed ten loops of the Smart Road, but only the last eight were data gathering runs.

Dependent Measures

Performance

Both performance and opinion data were gathered in the Smart Road tests. The main aspect of the performance testing was determining how well subjects could ascertain the position of an object vehicle at night under various conditions. This test was used previously for daytime runs in the original C/VIS project (Wierwille et al., 2007a). It was found to be an effective indicator of how well subjects could locate the position of the object vehicle when it was located in an adjacent lane near the rear end of the trailer. This indicator is believed to be valuable in assessing the potential for reduction in sideswipe crashes. Two measures were previously used: whether there was longitudinal clearance or longitudinal overlap, and how much there was in terms of distance. Clearance/overlap was scored as correct or incorrect. How much clearance or overlap in feet was scored in terms of the amount of error. If the clearance/overlap decision was correct, then the estimated distance was subtracted from the actual distance to get the error. If the clearance/overlap decision was incorrect, the estimated distance was added to the actual distance. Thereafter, the absolute value was used as the measure of accuracy in estimation. Consequently, in the current experiment, the plan was to use two dependent measures, as follows:

- Number of correct responses (or percent correct) in the clearance/overlap determination, and
- Absolute error in the clearance/overlap estimate.

A measure not previously used was the total response time. It could be hypothesized that response time might be faster, the same, or slower with the Enhanced C/VIS, because of the greater, but more precise, information it provides. In any case, the idea of using this measure seemed reasonable in that it might shed light on how the subject used the Enhanced C/VIS and whether or not it compromised response time. Therefore, the following measure was determined:

- The amount of time required to determine clearance/overlap added to the amount of time required to estimate distance.

A final measure, taken for exploratory purposes, was glance position as a function of time. The directions of glances used were: forward, E-CVIS (right/left/center), mirrors (left/right), and dash/IP (instrument panel). Occasionally the driver would glance elsewhere, which was counted as a valid sample in calculating the glance probability. However, there were so few of these that they were not included in any of the graphs. The interval over which data were gathered was specified to be from the beginning of the instruction to determine clearance/overlap to the end of the driver's response regarding how much clearance or overlap there was in feet. The measure associated with this analysis was:

- Eye glance probability to specific locations.

This measure was calculated by pooling data across the eight subjects for the given condition, thereby allowing eye glance differences to be presented as a function of the condition under test.

It was determined ahead of time that, for each loop of the rain generating and lighted area of the Smart Road, two replications could be accomplished during the outbound leg and two more replications could be accomplished during the inbound leg at an instructed speed of 25 mph (40.2 km/h). By performing one clearance/overlap determination and one corresponding longitudinal distance determination *on each side* of the heavy vehicle *in each direction*, there were a total of four replications per driver and condition. Note that Side could be treated as an additional independent variable in these tests. It is important to realize that all conditions were tested using the same stretch of the Smart Road; that is, the stretch which had both rain and lighting capability. Of course, for some of the runs, these capabilities were deactivated.

During these tests an automobile driven by a confederate experimenter approached rapidly from the rear and then matched speed at a specified position relative to the rear of the trailer. The position was selected differently for each driver and each replication, but all values fell within 16 ft (4.88 m) of overlap and 23 ft (7.01 m) of clearance using the longitudinal distance between the rear of the trailer and the front of the automobile. Once the automobile reached position, the subject performed the estimation task (clearance/overlap and longitudinal distance estimation). The automobile then dropped back and approached again on the opposite side for the second replication of the task. Note that since the Smart Road has two lanes in the rain-producing area, it was necessary for the *subject* in the heavy vehicle to change lanes while the automobile was dropping back. The automobile then once again accelerated, approached, and positioned itself at a new specified distance for the second estimation task.

It should be noted that this test did not require the automobile to be in exactly the specified position at the time of the estimation (as long as speed was matched) because the actual distance was measured by video using cameras located at the rear of the trailer (but not seen by the driver). These cameras were identical to the merge/re-merge cameras described in the original C/VIS project. These cameras were calibrated so that distance could be determined to the nearest 6 in (15.2 cm). Thus, the "ground truth" value was used in calculating correctness of the decisions by the subject and amount of error in the estimates, not the confederate vehicle driver’s ability to get to and maintain the correct position.

To summarize, each subject (heavy-vehicle driver) experienced all factorial combinations of Weather, Lighting, and Enhanced C/VIS, as specified. The subject provided four decisions regarding clearance/overlap and four estimates of distance of clearance or overlap for each of the eight different factorial combinations. In addition, the total time to perform these tasks was measured, as were the eye glance patterns. The data provided objective evidence of the degree of the relative performance of the E-C/VIS as compared with Baseline for a variety of nighttime conditions.

Opinion

Driver opinion is important because it is likely to be one of the major factors that trucking concerns might use to decide whether or not they should equip their fleets with Enhanced

C/VISs. Clearly, if drivers do not accept these systems as useful, the systems are not likely to be implemented. It seemed therefore that some form of opinion data should be taken.

In Table 4, note that for each condition, subjects performed tests in pairs in which one condition was Baseline and the other condition was the Enhanced C/VIS condition. This suggested that after every two loops of the Smart Road, the driver should be queried in comparing the two previously experienced conditions. Obtaining this opinion data at four different, two-loop intervals allowed comparison of the Enhanced C/VIS to Baseline for all four factorial combinations of Weather and Lighting. Rating scales for performing these tasks appear in Appendix D.

A final set of rating scales was also provided, following all runs on the Smart Road. These scales were intended to determine whether or not subjects were receptive to the Enhanced C/VIS, as determined by responses on several scales (as shown in Appendix D). After rating scale data were gathered, ratings were converted to numerical values and were then analyzed.

A final question solicited any additional information the subject wanted the investigators to have, using a simple ruled space for the subject to reply. This gave the subject a chance to provide any additional opinion regarding the Enhanced C/VIS and its comparison with Baseline.

Object Detection/Recognition Task

As stated earlier, the decision was made to perform an object detection/recognition task, but to do so using a stationary situation. It was believed that this would make a good "warm-up" task and would help the subjects become familiar with the vehicle both in the Enhanced C/VIS and the Baseline conditions prior to driving on the Smart Road. At the same time, object detection would become a safe exercise, while useful information regarding ability to detect targets would be obtained. Tests were performed in a large blacktopped area at VTTI using a variation of the paradigm developed by Jenness, Llaneras, and Huey (2005) under subcontract in the first phase of the original C/VIS project.

Procedure

After preliminary qualifications were completed in one of the buildings at VTTI (including signing the informed consent, performing simple hearing and vision tests, and filling out necessary payment forms) the subject was taken to the parked, equipped tractor-trailer. There the subject was seated in the driver’s seat and instructed to look down (noise cancelling headphones were used to shield the subject from sounds of the exterior maneuvering of objects). On command, the subject looked up and searched for the object. Once found, the subject so indicated, identified the object, and gave an approximate location.

The experimental design used is shown in Table 5. Half of the subjects performed with Baseline (Enhanced C/VIS not operating) for the first 15 objects/locations while these same subjects performed with the Enhanced C/VIS operating for the second set of 15 objects/locations. Actually, the two sets of objects/locations were identical, but were presented in two pseudo-random orders; that is, one order for the first 15 objects and the other order for the second 15 objects. The orders were changed in such a way that the driver was unable to predict where the next object might be, what type of object it might be, and what its location was. On the other hand, because every object was presented twice, once in Baseline and once with the Enhanced C/VIS, within-subject comparisons could be made as a function of object/location and Enhanced C/VIS operating or Baseline.

This type of experimental design in and of itself does not control for gradual learning and fatigue effects. To account for these effects, the other half of the subjects performed the first 15 object detection/recognition tasks with the Enhanced C/VIS operating and the second 15 object detection/recognition tasks in Baseline. These subjects used exactly the same pseudo-random sequences in exactly the same order. Such a design controls for gradual learning and fatigue insofar as it might affect the comparison of Baseline and Enhanced C/VIS performance. Thus, the experiment was set up so that the data could initially be analyzed as an E-C/VIS versus Baseline, by First presentation versus Second presentation, by Object type/Location within-subject ANOVA, with eight data values per cell.

Subjects were instructed that on a few of the tasks there might not be an object present. This helped to prevent guessing. As an example of guessing, a subject who knew that an object was present that could not be seen in the Baseline condition would most likely assume the object was directly behind the trailer. However, if the subject were given the option of saying the object was undetectable, the response would not involve guessing. Therefore, "undetectable" was considered the appropriate response, and subjects were discouraged from guessing. This allowed comparison of the number of undetectable responses with and without the Enhanced C/VIS.

Results were scored in terms of correctness of object location, correctness of object location *and* identification (combined), and response time. A maximum time was selected as 50 s because objects were not always detectable regardless of time allowed. However, there were no cases where response time exceeded 50 s. Drivers who could not find an object simply said it was undetectable. This always occurred in less than 50 s, so selection of the value became moot.

Table 5. Object Presentation Scheme for the Object Detection Task

Order of Presentation →		
Subjects	Object/Location 1 through 15	Object/Location 16 through 30
1, 2, 7, 8	Baseline	Enhanced C/VIS
3, 4, 5, 6	Enhanced C/VIS	Baseline

Figure 45 shows the layout for the object detection/recognition static experiment. Five lanes on the asphalt pad were used, with the tractor-trailer in the center lane. The figure shows the approximate planar coverage of the three video cameras from a bird’s eye view. Four objects were used for the tests: an orange barrel with two horizontal silver stripes (shown in the figure as a circle), a pedestrian (shown as a small circle with a surrounding ellipse), a yellow adult tricycle (shown as a pair of handlebars with a line segment connected to the representation of the two rear wheels), and a red stop sign placed on a standard that could be moved from position to position (shown as a hexagon surrounding an x in the figure). Objects were placed at various positions along the sides and to the rear of the heavy vehicle, in a pseudo-random order that was the same for all subjects, as previously described. The 30 test conditions were ordered as shown by the numbers just to the left of the object in the figure. For example, the tenth presentation was the adult tricycle located in the D1 (driver's side adjacent) lane at distance position 3. This object and location also corresponded to the thirtieth presentation. Once again, note that the presentation sequence was selected in such a way that subjects could not predict the next object or location.

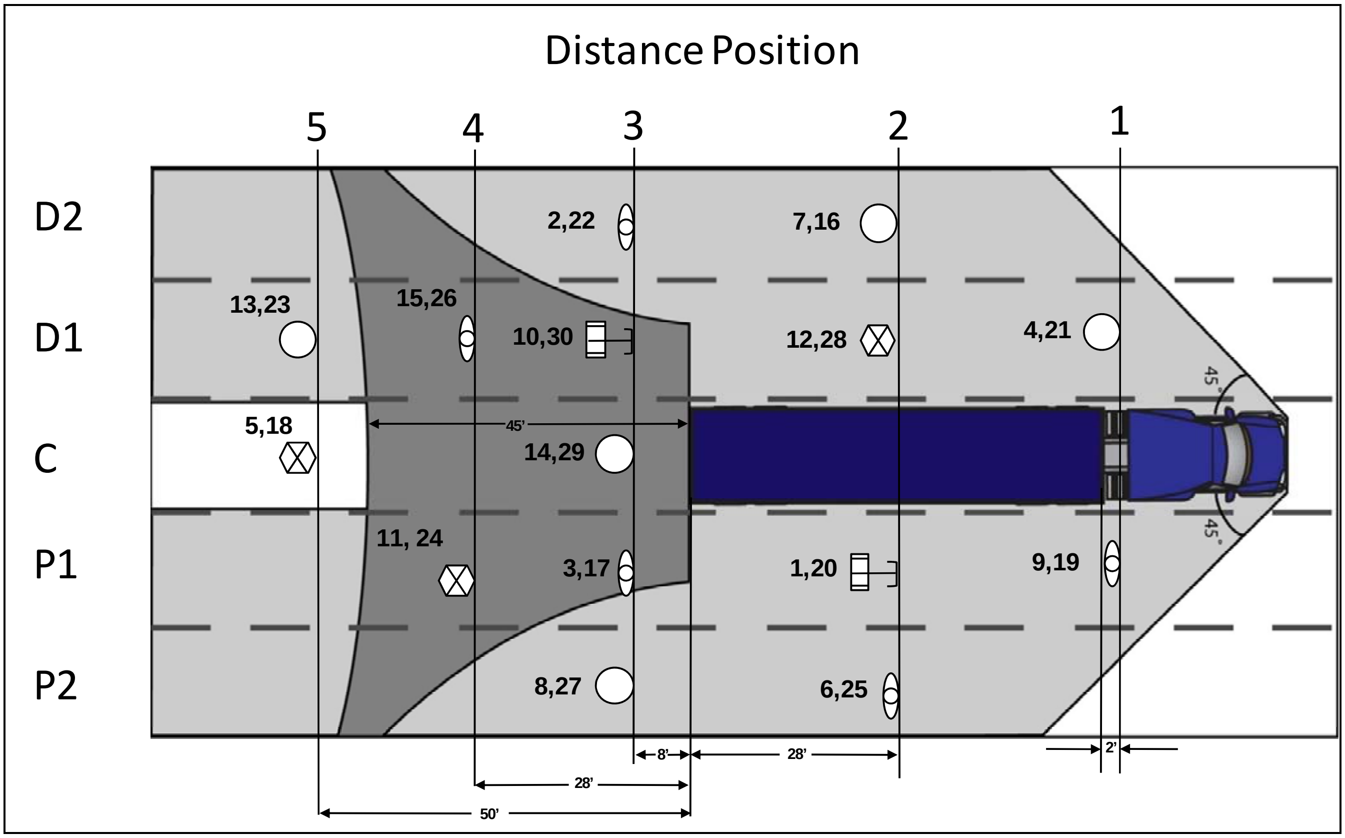


Figure 45. Layout for the Preliminary Object Detection/Recognition Task

This experiment was performed with the IR illumination on at all times. The reason for this was that the IR illumination was not helpful to the subject in Baseline, because it could not be detected visually. It was only helpful when viewed with the Enhanced C/VIS (and also in the data gathering videos).

As stated, this object detection experiment preceded the Smart Road tests. Consequently, the experiment had the added benefit of serving as a means of familiarizing subjects with the Enhanced C/VIS and with the tractor-trailer in general. Yet another advantage was that, for four of the eight subjects, the Smart Road preparations for rain could be performed while the subject was involved in the object detection/recognition experiment. This allowed the rain-related runs to begin very shortly after the subject entered the Smart Road with the tractor-trailer for the tests described earlier (Subjects 1 through 4). Figure 46 depicts the overall layout of the experiment, including the Smart Road preparations by VTTI personnel.

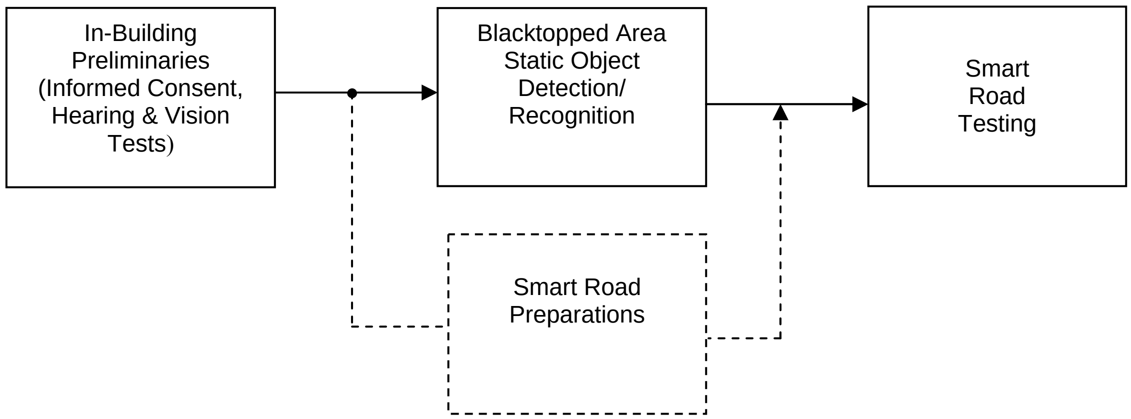


Figure 46. Overall Layout of the Enhanced C/VIS Road Tests including Preliminaries and Object Detection and Recognition

Instrumentation

The tractor-trailer was equipped with the three-channel E-C/VIS, as previously described. This system was composed of the three cameras in weatherproof housings and three monitors, one at each A-pillar and one at the equivalent center rearview mirror position. Three laptop computers were on board to perform the image processing that produced outlines of objects in each video view. Also included were the DVI and a light sensor system to switch the cameras from daytime to nighttime operation and vice versa. Note that the latter was not actually needed for the tests described in this chapter (all of which were performed at night); however, the system was designed, developed, and installed so that the tractor-trailer could demonstrate daytime operation if necessary.

Data gathering instrumentation for the Smart Road testing was handled totally separately from the E-C/VIS instrumentation. Four cameras were added to the tractor-trailer. Two of these were used to determine the driver's eye glance position, and two were used to evaluate the clearance and overlap positions. The four camera outputs were recorded digitally as a quad-split image. This image contained a time stamp and an audio track with two microphones as inputs. The experimenter had one microphone attached near his position and the driver (subject) had a similar microphone mounted to the header. The microphones were aimed to pick up the voices of both the experimenter and the driver for recording on the audio track.

Eye glance position was determined by the use of two small cameras, one just above each A-pillar monitor. Lenses were selected so that the two images of the driver's head were approximately the same size even though the distances from camera to driver differed for each A-pillar. If the driver looked directly at a monitor on one of the A-pillars, that could be detected from the corresponding video image. On the other hand, if the driver looked at the side mirrors, that could also be detected. This was considered an important distinction and was the reason for using two cameras; that is, one on each side. Each camera included its own IR illumination, which of course could not be seen by the driver. This illumination was necessary because of the need to record video at night.

As described earlier, the equivalent of two merge/re-merge cameras were used to determine actual clearance or overlap and actual longitudinal distance of clearance or overlap. These values were used as ground truth values, as previously described. Optical measurement techniques were employed using standard, stationary video recordings (taken earlier) with the trailer and the confederate vehicle at measured longitudinal distance differences. It is important to note that the merge/re-merge cameras did not have their own IR illumination sources. They used the same IR illumination around the back of the trailer as was used by the two E-C/VIS side cameras.

The experimenter sat behind the driver, but in a centered position. The experimenter could look over the driver's right shoulder. The experimenter could also view a separate data gathering monitor on which the quad-split image was shown. (This ensured that the image was being recorded correctly.) The monitor was placed in front of the experimenter in a position that was unobservable by the driver. On the other hand, the experimenter could see all three E-C/VIS images directly to ensure that all elements of the E-C/VIS were operating properly.

For the object detection/recognition task on the asphalt pad, exactly the same video recording system was used. Because of the audio track, search times could be measured and correctness of identifications could be checked after the experiment was run.

Final Instructions for Drivers (Subjects)

It is important to note that drivers were instructed on how to compare videos in the E-C/VIS to help determine position of objects and to assess clearance or overlap. If an object could be seen alongside near the rear end of the trailer, the driver could then look at the rear wide-angle look-down camera monitor (in the typical rearview mirror position). If the object could be fully seen in that view, then there was clearance. If the object could not be seen or could not be fully seen, there was overlap. This cross comparison was considered an important instruction and might not have otherwise been obvious.

Equipment and Facilities

The equipment and facilities used for the Smart Road and Object Detection Testing were extensive. This section contains photographs which show the equipment and facilities so that the reader can gain a better understanding of the experiments that were performed. The photos are grouped starting with daytime pictures of the equipment, followed by nighttime pictures taken on the Smart Road at the completion of the data gathering runs.

Figures 47, 48, and 49 show the cameras used at the rear of the trailer. Figure 47 shows the wide-angle look-down camera at the top and the two "merge/re-merge" cameras down toward the sides. The wide-angle look-down camera was mounted in a weatherproof, nitrogen-filled enclosure, as shown in Figure 48. It should be noted that this camera was set up for research purposes and would have to be lowered somewhat and made more compact for commercial use. Figure 47 also shows the two rear IR LED illuminators, one below each set of red taillights. Figure 49 shows the merge/re-merge camera on the passenger side of the trailer. It was used (only by the experimenter and later data reduction) for clearance determination on the driver side of the vehicle and was housed in a cylindrical weatherproof enclosure. The merge/re-merge camera on the opposite side was symmetrically identical.

Figure 47. Rear of the Equipped Trailer Showing the Three Cameras Used

Figure 48. Close-up View of the Rear Wide-angle, Look-down Camera and its Mounting

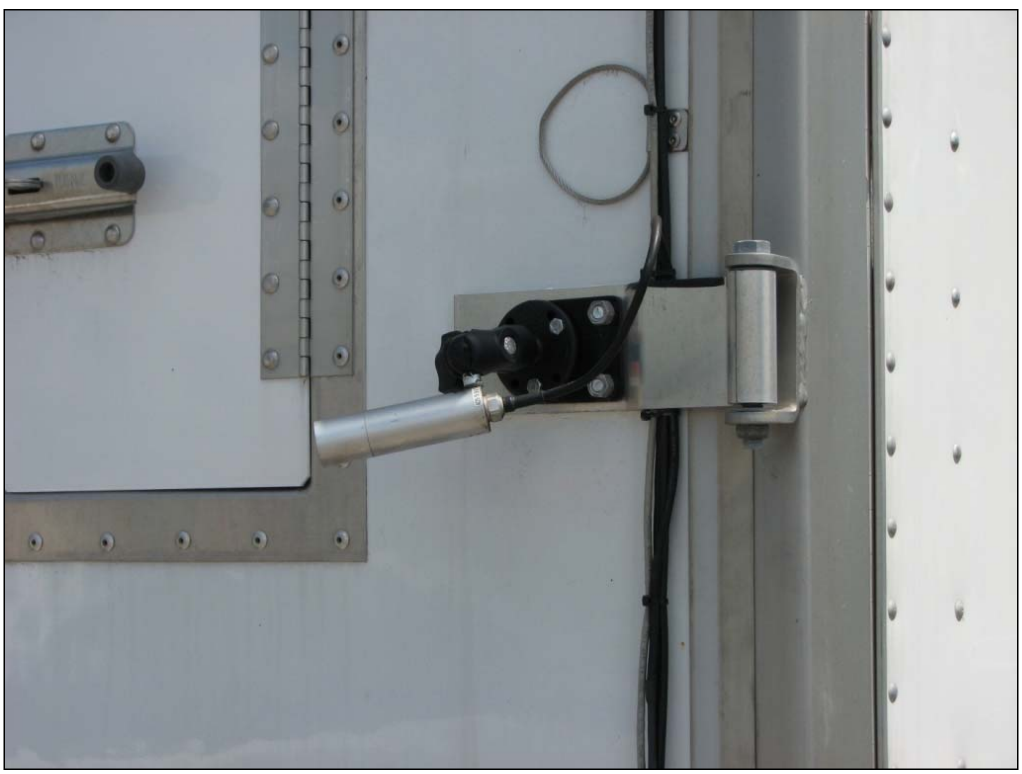


Figure 49. Close-up View of the Merge/re-merge Camera at the Right Rear of the Trailer

Figures 50 and 51 show additional daytime pictures. Figure 50 shows a typical IR LED illuminator mounted under the side of the trailer, while Figure 51 shows the “objects” used in the object detection/identification experiment.

Figure 50. Typical IR LED Illuminator Mounted under the Side of the Trailer

Figure 51. The Four "Objects" Used in the Object Detection/identification Experiment

Facilities in the cab of the equipped tractor are shown in Figures 52 through 57. Figure 52 shows the experimenter's position behind the driver, looking forward. Figure 53 shows an experimenter in position, with the photo taken from the passenger seat, looking back into the rear area of the cab. Figure 54 shows the three laptop computers used to perform image processing. One computer was used for each of the three Enhanced C/VIS channels. The three computers were located behind the passenger seat against the passenger-side wall of the cab.

In Figure 55, the driver-side monitor can be seen directly above the steering wheel. The left face camera with IR LED illuminators is shown above the monitor in a small rectangular enclosure. Figure 56 shows the three monitors in their locations for the experiment. The right face camera with IR LED illuminators is shown just above the passenger-side monitor in its small rectangular enclosure.

The driver interface for the Enhanced C/VIS is shown in Figure 57. This interface was mounted at the wing panel. Its location on the wing panel can be seen in Figure 52.

Figure 52. Experimenter's Position Relative to the Driver's Position in the Cab (Camera Aimed Forward)

Figure 53. Experimenter in Position Behind the Driver (Camera Aimed Rearward)

Figure 54. Laptop Computers Used for Image Processing

Figure 55. Driver-side Monitor Located at the A-pillar (Note face camera above monitor.)

Figure 56. Cab Interior Showing the Three Enhanced-C/VIS Monitors (Note second face camera above passenger-side monitor.)

Figure 57. Driver Interface for the Enhanced C/VIS

Nighttime pictures were also taken, as mentioned earlier. Figure 58 shows the tractor-trailer and the confederate vehicle on the Smart Road during clear conditions with road lighting. Similarly, Figure 59 shows the tractor-trailer and confederate vehicle emerging from the artificial rain section with street lighting.

Figure 58. The Tractor-trailer and Confederate Vehicle under Street Lighting on the Smart Road

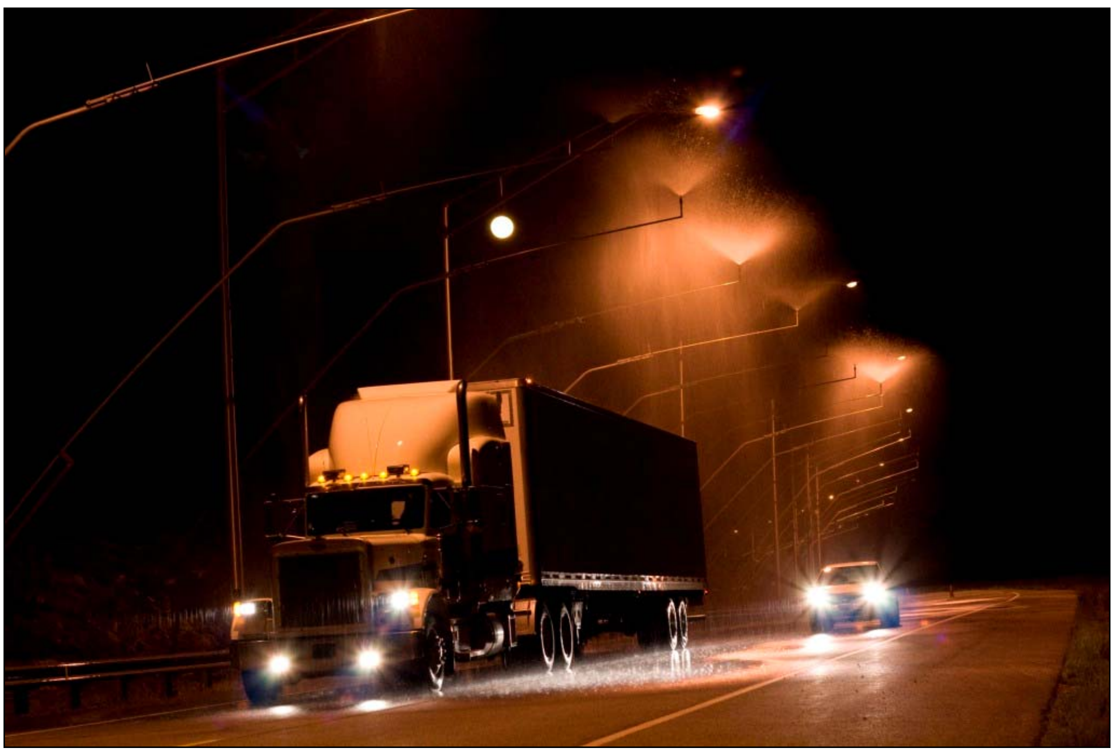


Figure 59. The Tractor-trailer and Confederate Vehicle Emerging from the Artificial Rain Portion of the Smart Road with Street Lights On

Several photos were taken of the cab interior displays (monitors) under typical test conditions. These are shown in Figures 60 through 71. Figure 60 shows the driver-side monitor under street lighting and artificial rain. The left portion of the photo also shows the image of the confederate vehicle in the west coast mirror, while the bottom left shows the image in the convex mirror as just a pair of dots. Figure 61 shows the same type of image under street lighting without artificial rain, but with wet pavement. Once again the image in the driver-side mirrors is plainly visible. Figures 62 and 63 show worst-case situations in which there is darkness and headlight bloom. In Figure 62 the pavement is dry and in Figure 63 it is wet. Figure 64 shows wet pavement under street lighting. This figure shows how outlining using post-processing works well in this situation by bringing out the outline of the confederate vehicle.

Figure 65 shows the passenger-side monitor in total darkness, but without a target vehicle. The effects of IR illumination can be seen on the pavement. This photo also shows the IR LEDs above the monitor in the housing of the passenger-side face camera. These LEDs were not visible to the drivers, but were picked up by the camera used to shoot this photo. Figure 66 shows a similar photo under street lighting. The effects of outlining are clearly visible. Figure 67 shows the same scene, but with both artificial rain and street lighting. Once again, the effects of outlining are clearly visible.

Figure 60. Driver-side Monitor under Artificial Rain with Street Lighting (Note images in mirrors to the left in the photo.)

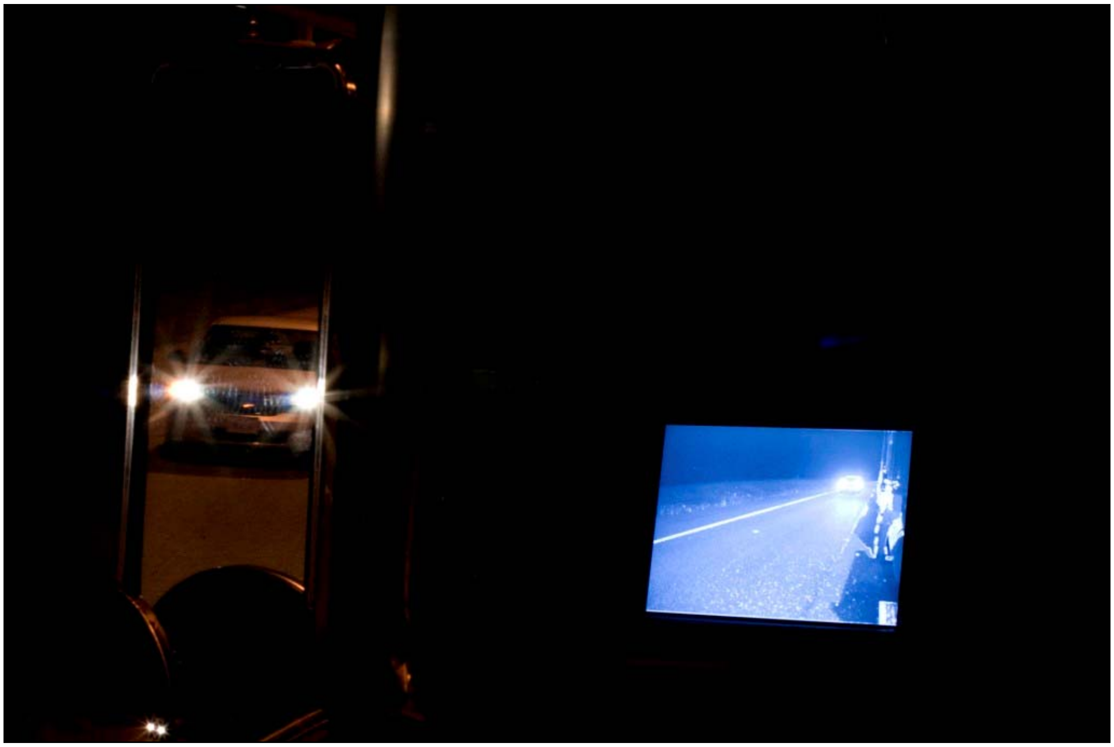


Figure 61. Driver-side Monitor with Street Lighting and with Wet Pavement (Note images in mirrors to the left in the photo.)

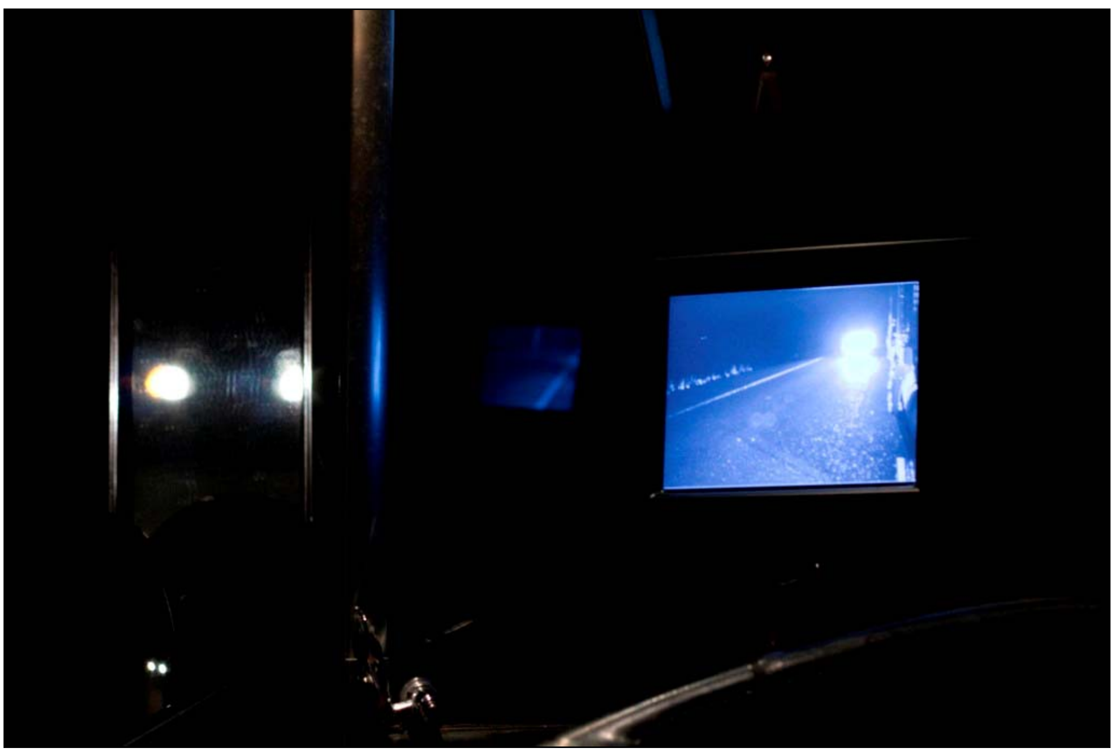


Figure 62. Worst-case Situation with Total Environmental Darkness and Headlight Bloom on Dry Pavement

Figure 63. Worst-case Situation with Total Environmental Darkness and Headlight Bloom on Wet Pavement (IR Illuminators in use)

Figure 64. Image with Street Lighting and Wet Pavement (Note the effects of post-processing on the confederate vehicle image.)

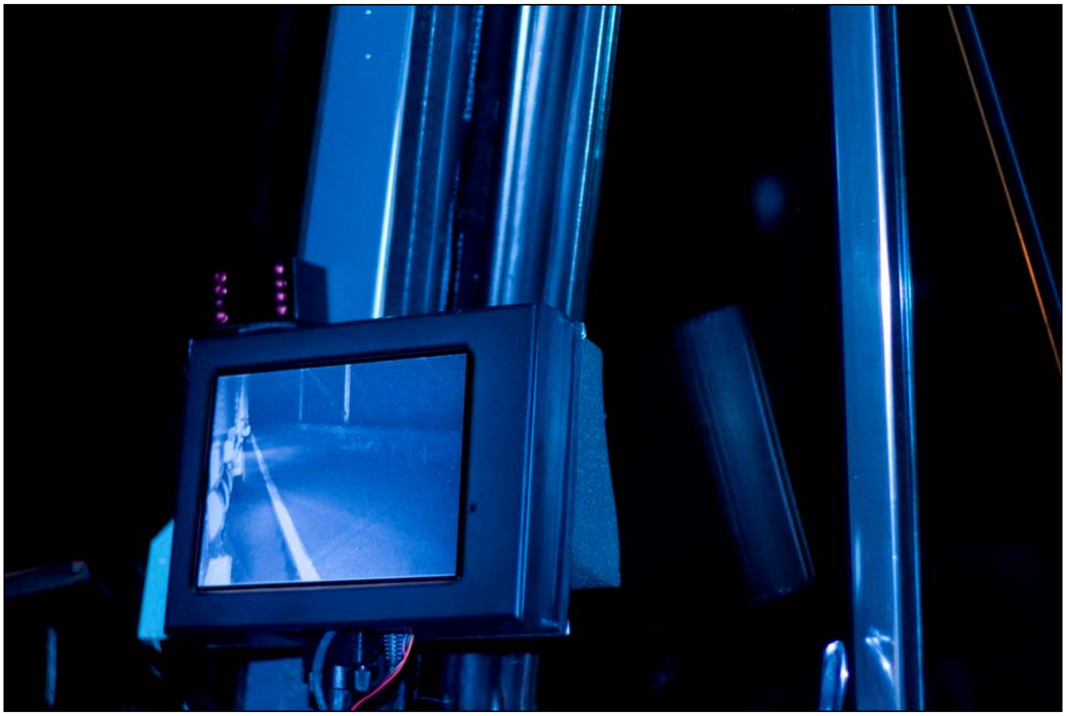


Figure 65. Passenger-side Monitor Showing Street Scene in Total Environmental Darkness, Dry Conditions (IR illuminators in use)

Figure 66. Passenger-side Monitor Showing Street Scene with Street Lighting, Dry Conditions

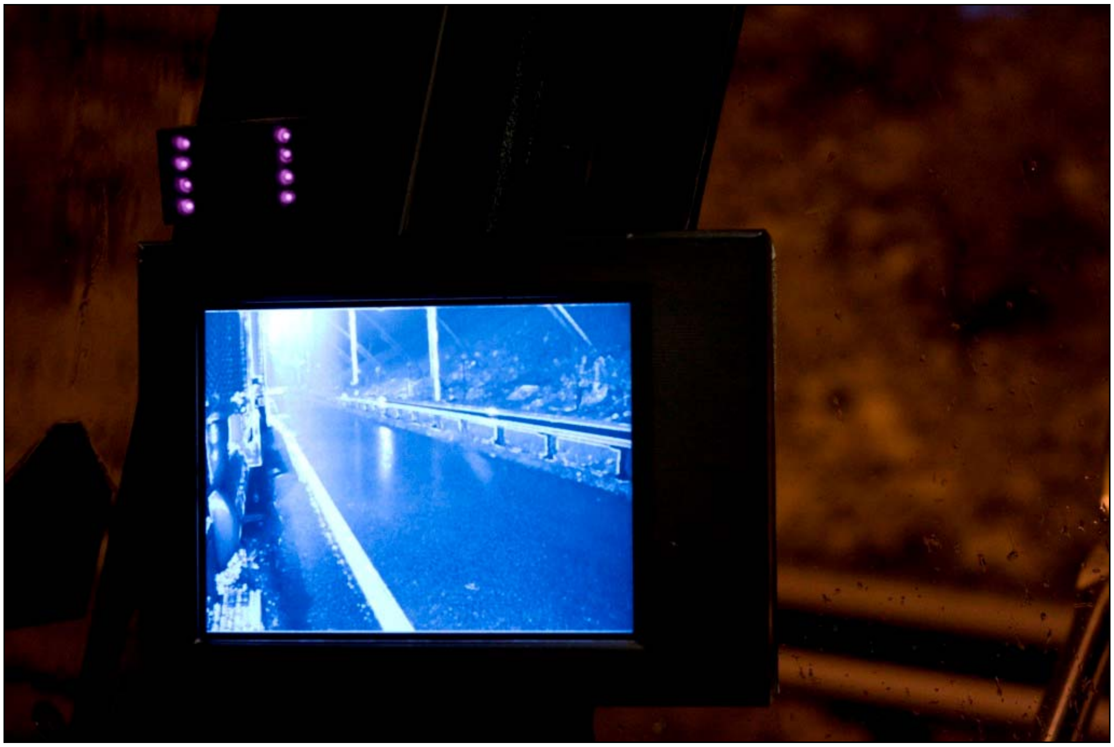


Figure 67. Passenger-side Monitor Showing Street Scene with Street Lighting and Artificial Rain

The remaining pictures show aspects of the trailer wide-angle, look-down monitor. Figure 68 shows the monitor in the cab under street lighting and dry pavement conditions. The confederate vehicle is seen approaching in the left adjacent lane. Note the lower edge of the back of the trailer in the video scene. Figure 69 shows a closer view of the monitor for the same scene. Figure 70 shows another worst-case situation in which there are dark conditions with headlight bloom. The pavement is dry in this picture. Finally, Figure 71 shows a similar scene but with artificial rain and street lighting. In this case, the reflections of the luminaires are seen directly behind the trailer.

Figure 68. Rear Wide-angle Look-down Monitor as Viewed Looking out the Windshield

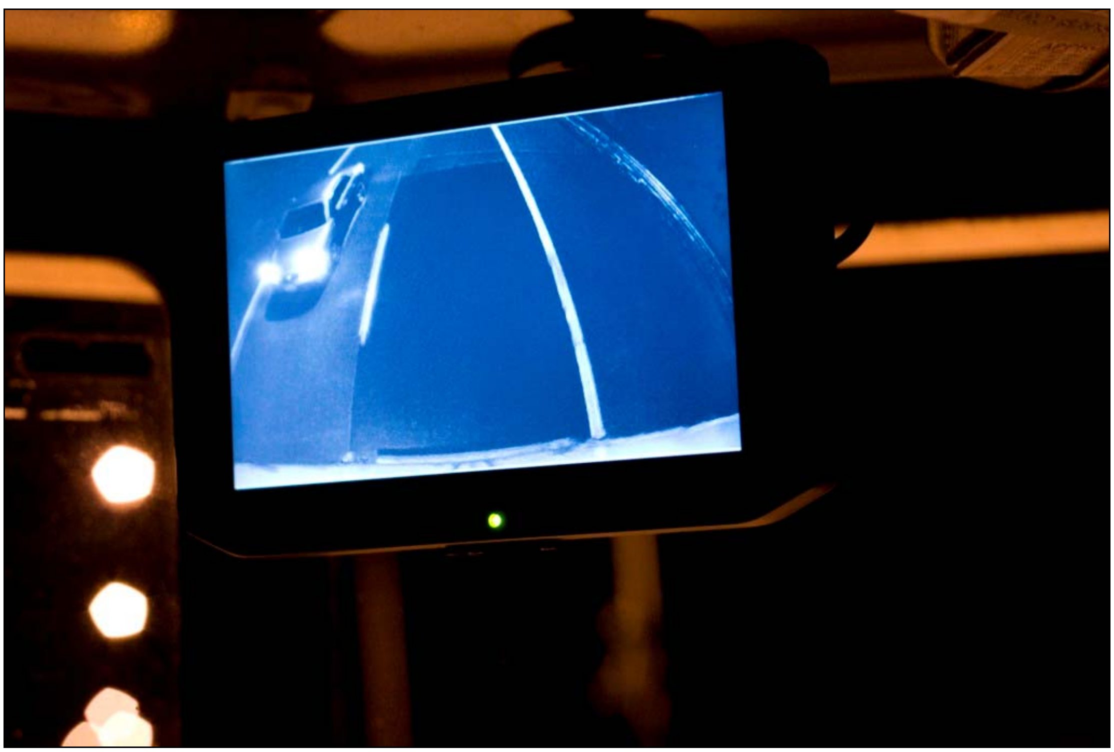


Figure 69. Close-up View of the Rear Wide-angle Look-down Monitor

Figure 70. Rear Wide-angle Look-down Monitor Worst-case Situation: Dark Conditions with Headlight Bloom

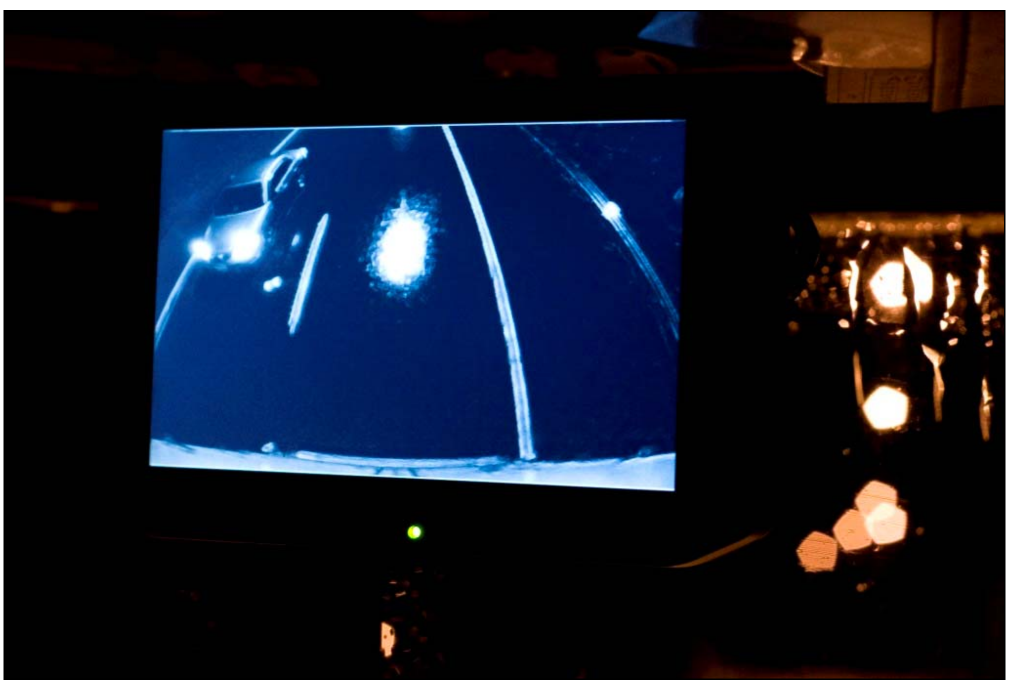


Figure 71. Rear Wide-angle Look-down Monitor with Street Lighting and Artificial Rain

CHAPTER 8. SMART ROAD AND OBJECT DETECTION TESTING OF THE REVISED ENHANCED C/VIS; EXPERIMENT RESULTS

The previous chapter showed how the Smart Road and Object Detection Testing of the Revised Enhanced C/VIS was planned and carried out. This chapter provides the results and conclusions associated with the testing. The results are presented roughly in the order in which data were gathered; that is, the object detection results are presented first, followed by the Smart Road testing results.

Object Detection/Recognition Results

Pair (14, 29). To begin the analysis, two pairs of objects/locations were removed from the larger data set because they represented special conditions. Referring back to Figure 45, note that one pair (14, 29) could only be seen in the center monitor of the E-C/VIS. It could not be seen in the other E-C/VIS monitors or with the mirrors. Consequently, the correct response for this pair would be "undetectable" for the Baseline condition, but detectable for the E-C/VIS condition with the subject indicating that the object (a barrel) was directly behind the trailer. This pair was included to demonstrate the possible greater coverage afforded by the E-C/VIS.

Results for this pair showed that, indeed, all eight subjects found the target to be "undetectable" in Baseline and seven of the eight subjects correctly located the target and identified it when the E-C/VIS condition was presented. It was observed that the one subject who considered the target to be undetectable in the E-C/VIS condition actually failed to glance at the center monitor. The results were tested using a Fisher Exact test and were found to be significant in the two-sided test ($p = 0.0014$). These results indicate that the E-C/VIS condition resulted in better coverage behind the trailer.

Pair (5, 18). Another pair (5, 18) was also separated from the main data set. In this case, the stop sign could not be seen in either the Baseline mirrors or in the E-C/VIS monitors. This stop sign was behind the trailer, but sufficiently far back that it was out of the field of view of the rear wide-angle look-down camera. Consequently, all responses should have been found "undetectable" to be correct. Indeed, results showed that all eight drivers responded with "undetectable" in both cases and, of course, there was then no statistically significant difference. In regard to response time, differences between the E-C/VIS and Baseline conditions were tested, with the result that response times were found not to be significantly different using a t-test: $t(7) = -0.59$, $p = 0.57$.

Remaining Data. Thirteen pairs remained after (14, 29) and (5, 18) were removed. In these remaining pairs, as Figure 45 shows, all objects should have been detectable in both Baseline and in E-C/VIS conditions, neglecting the fact that data were gathered at night without added *visible* light from the heavy vehicle. This represents a nighttime comparison, which is where the E-C/VIS was intended to extend the range of vision. The first analysis was directed at correctness of object location. Table 6 shows the results. There were 13 pairs for each of eight subjects, resulting in a total of 104 trials for Baseline and 104 trials for E-C/VIS. A Chi-Square analysis demonstrated a significant difference between the Baseline and E-C/VIS conditions: $\chi^2(1) = 22.5$, $p < 0.0001$. This result shows that object location determination was significantly better with the

E-C/VIS than with Baseline. In terms of comparison, subjects provided the correct location of objects 96 percent of the time with the E-C/VIS operating, and 72 percent of the time with Baseline.

Table 6. Correctness of Location as a Function of Baseline versus E-C/VIS

	Incorrect	Correct
Baseline	29	75
E – C/VIS	4	100

The data were also subjected to a correctness of location *and* correctness of object identification analysis. In a few cases, objects were correctly located and then incorrectly identified. Table 7 shows the results. Once again there were 13 pairs for each of the eight subjects, again resulting in a total of 104 trials for Baseline and 104 trials for E-C/VIS. A Chi-Square analysis again demonstrated a significant difference between Baseline and E-C/VIS conditions: $\chi^2(1) = 15.0$, $p = 0.0001$. Subjects provided correct location *and* correct identification of objects 91 percent of the time with the E-C/VIS and 70 percent of the time with Baseline.

Table 7. Correctness of Location *and* Identification as a Function of Baseline versus E-C/VIS

	Incorrect	Correct
Baseline	31	73
E – C/VIS	9	95

Driver Side Analysis. Subsets of the data were also examined by side of vehicle and by rear of vehicle. These data were intended to determine if the E-C/VIS was helpful, depending on the general location of the object; that is, to the sides or to the rear. In regard to the driver side, all pairs appearing in rows D1 and D2 in Figure 45 were included. There were seven pairs on the driver side, as the figure shows. Data for these seven pairs were extracted and analyzed. Initially, data were analyzed for location correctness and found not to be significantly different when comparing Baseline to E-C/VIS using a Chi-Square test: $\chi^2(1) = 0.439$, $p = 0.51$. For information purposes, subjects responded with the correct location 93 percent of the time with the E-C/VIS, and 89 percent of the time with Baseline.

As with the full set of 13 pairs, the data for the seven pairs on the driver side were also subjected to a correctness of location *and* correctness of object identification analysis. Once again, results did not reach significance: $\chi^2(1) = 0.087$, $p = 0.77$. In fact, the results were quite similar with correctness 89 percent of the time for Baseline and 88 percent of the time with E-C/VIS. It should be noted that mirrors on the driver side are relatively close to the driver and therefore provide reasonably good coverage of objects, even though such objects may be quite dark.

Passenger Side Analysis. This analysis was carried out in a manner similar to the driver side analysis, except that pairs in rows P1 and P2 were used. In this case there were six pairs. The data were again analyzed statistically and were found to result in significance using a Chi-Square test: $\chi^2(1) = 30.25$, $p < 0.0001$. Table 8 shows that the subjects correctly located all objects on the passenger side with the E-C/VIS and a bit more than half with Baseline. This result shows clearly that the E-C/VIS monitor on the passenger side (possibly with the help of the rear monitor and the side mirrors) was effective. It should be noted that in Baseline, the passenger-side mirrors are quite far from the driver's position and the angles of coverage, particularly for the west coast mirror, are small.

Table 8. Correctness of Location as a Function of Baseline versus E-C/VIS; Passenger Side

	Incorrect	**Correct**
Baseline	23	25
E – C/VIS	0	48

Data for the six pairs on the passenger side were then subjected to a correctness of location *and* correctness of object identification analysis. In this case (passenger side) results again reached significance: $\chi^2(1) = 25.3$, $p < 0.0001$. Table 9 shows the results, with the E-C/VIS demonstrating superiority over Baseline. Subjects correctly located and identified objects 96 percent of the time with E-C/VIS and only 48 percent of the time with Baseline.

Table 9. Correctness of Location *and* Identification as a Function of Baseline versus E-C/VIS; Passenger Side

	Incorrect	**Correct**
Baseline	25	23
E – C/VIS	2	46

Trailer Rear Analysis. This analysis involved objects in columns (distance positions) 3, 4, and 5 and also in rows D1, D2, P1, and P2 (as shown in Figure 45). Note that for an object to be included, the object had to be in one of the three columns *and* one of the four rows. Thus, seven object locations were included. It should be mentioned that three of these seven pairs could not be seen in the rearview monitor because they were outside the coverage of the rearview camera. Subject responses in terms of location correctness were analyzed using a Chi-Square analysis, with the result that the difference was found not to be statistically significant: $\chi^2(1) = 2.18$, $p = 0.14$. For information purposes only, it was found that subjects responded with the correct location 84 percent of the time for Baseline and 93 percent of the time with E-C/VIS. Subject responses were also analyzed in terms of location correctness *and* identification correctness. Once again results did not reach statistical significance: $\chi^2(1) = 0.292$, $p = 0.59$. Subjects were correct 84 percent of the time with Baseline and 88 percent of the time with E-C/VIS. In regard to the trailer rear analysis, it should be remembered that pair (5,18) was removed prior to the analysis. This pair specifically demonstrated improved viewing for objects directly behind the trailer when the E-C/VIS was present.

Response Time Analysis for the Thirteen Pairs of Data. Subject response times were analyzed for the 13 pairs of locations/objects. Two types of analyses were performed in an attempt to handle incorrect location responses. In the first of these analyses, incorrect location responses were handled by adding 1 s to the longest correct response time for each given subject. Here, the reasoning was that the subject would very likely take at least that long to provide the correct response. This type of analysis allowed completion of the data matrix of values so that an equal-N's analysis could be carried out. In the second of these analyses, response times were analyzed regardless of correctness. In other words, this analysis was simply response time from the cue to begin the search until the subject responded with a location, whether correct or incorrect. This approach also resulted in a complete data set.

In each case, a 2 (Baseline versus E-C/VIS) by 13 (Object location-Type) within-subject ANOVA was performed, using the data from the eight subjects. For the first analysis, the Baseline versus E-C/VIS main effect was not significant, but wasn't far from it $F(1, 7) = 4.59$, $p = 0.0694$. The main effect of Object location-Type was significant: $F(12, 84) = 6.82$, $p < 0.0001$, and so was the interaction of Baseline versus E-C/VIS with Object location-Type $F(12, 84) = 5.53$, $p < 0.0001$. Results for the second analysis in which responses were included regardless of correctness provided similar results. The Baseline versus E-C/VIS main effect was not significant, but was quite close: $F(1,7) = 5.12$, $p = 0.0582$. The main effect of location type was significant with $F(12, 84) = 9.17$, $p < 0.0001$, and the interaction was significant with $F(12, 84) = 5.94$, $p < 0.0001$.

For information purposes, the main effect of Baseline versus E-C/VIS with "corrections" made for incorrect responses is plotted in Figure 72. The main effect of Baseline versus E-C/VIS on response time, regardless of correctness, is shown in Figure 73. Surprisingly, the results show that times to find objects were faster for the E-C/VIS condition than for the Baseline condition, even though there were more sources to scan with the E-C/VIS condition. In any case, it can be said that E-C/VIS did not add to response time, an important finding.

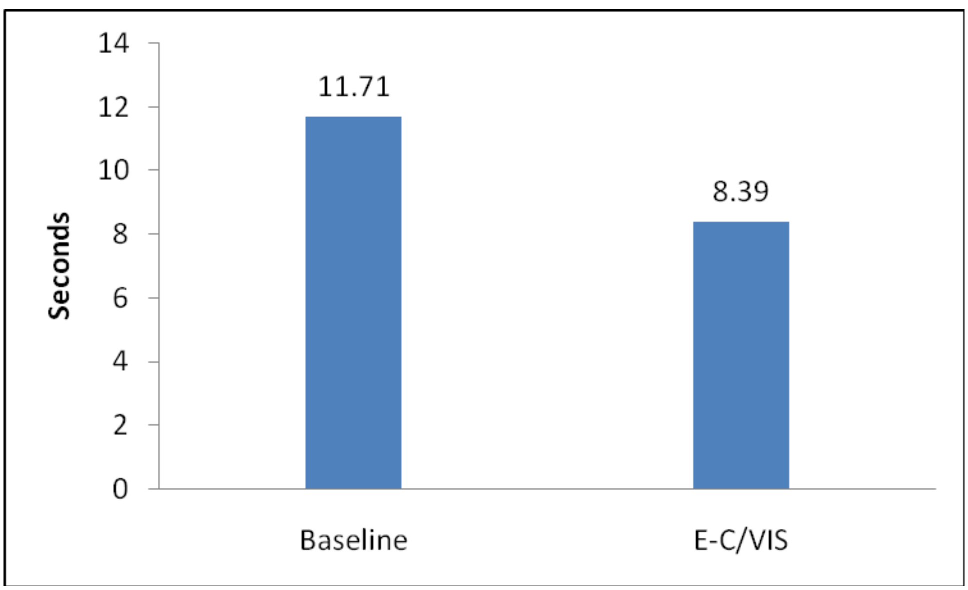


Figure 72. Response Times as a Function of Baseline versus E-C/VIS, with Corrections Made for Incorrect Responses (note that *p* = 0.0694)

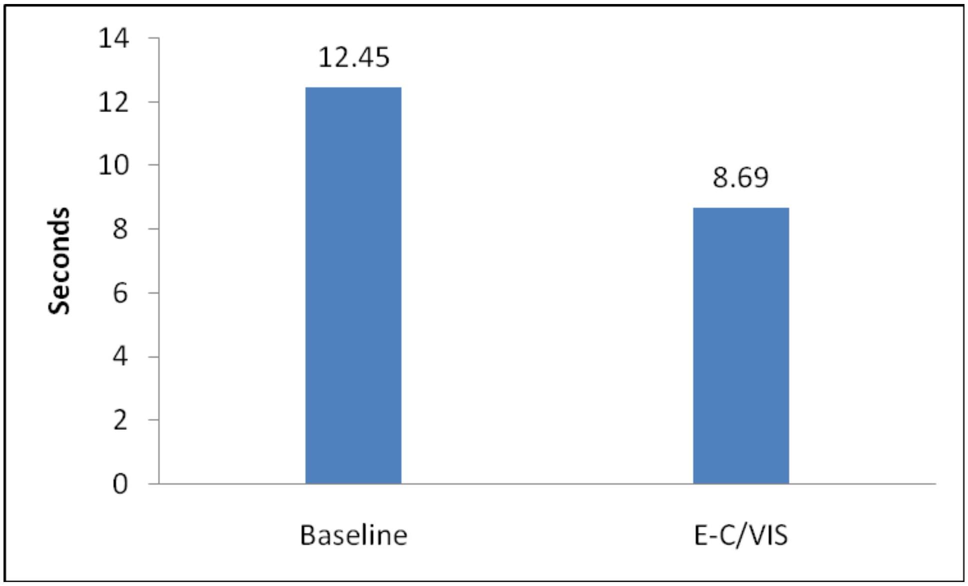


Figure 73. Response Times as a Function of Baseline versus E-C/VIS Regardless of Correctness (note that *p* = 0.0582)

The main effect of Object location-Type for responses regardless of correctness is shown in Figure 74. Here the response times regardless of correctness have been put in ascending order. Post hoc Tukey HSD analysis showed that the outward objects (Figure 45), by and large, took longer to detect. In Figure 74, means with a common underline do not differ significantly (α = 0.05). The interactive effect is shown in Figure 75 (the same order is used as that in Figure 74). Figure 75 shows that several of the very long response time pairs were substantially improved (shortened) by the presence of the E-C/VIS condition.

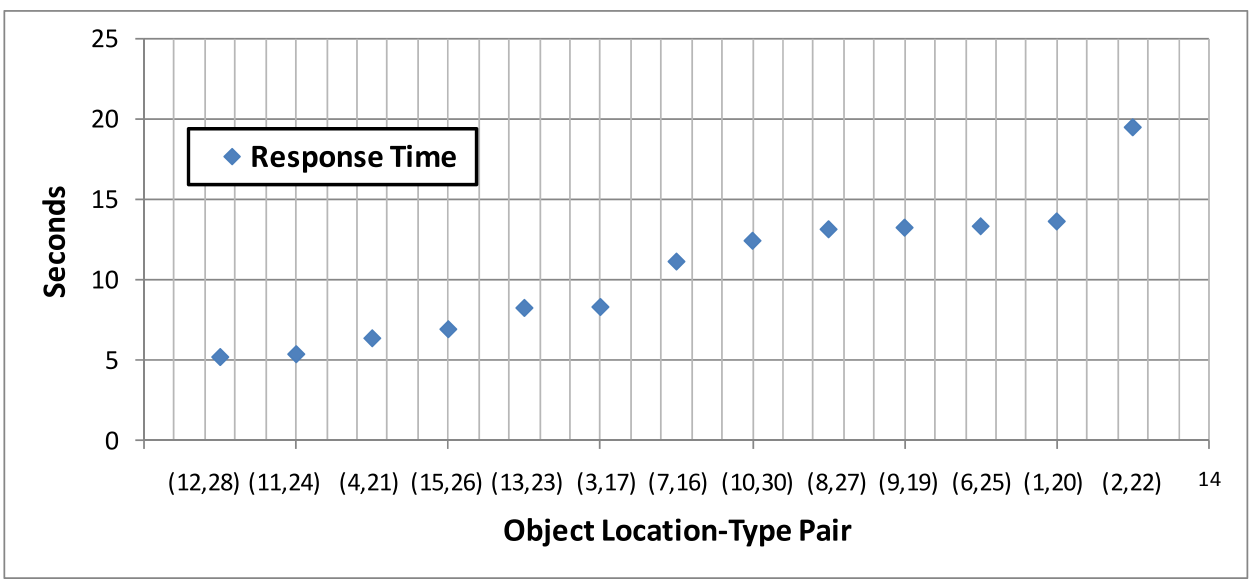


Figure 74. Main Effect of Object Location-Type Pair on Response Time (Note that object location-types having a common underline are not significantly different.)

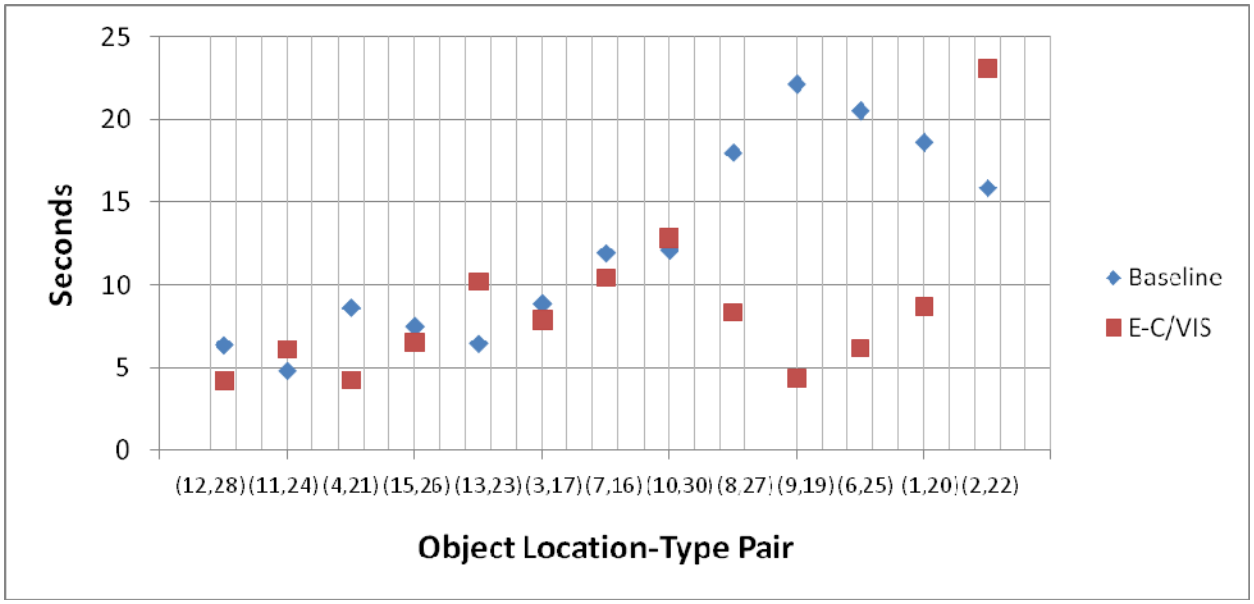


Figure 75. Interaction of Baseline versus E-C/VIS with Object Location-Type Pair on Response Time

Taken together, the results suggest that the E-C/VIS is effective in reducing the search times and also in improving the accuracy of object location and type detection. Results demonstrate statistically significant improvements on the passenger side as well as improvements in general. It should be noted that some of the objects were difficult to see. As Figure 51 shows, the tricycle is rather thin (outline in form) in terms of area covered in any image, whether in one of the mirrors or on one of the video monitors. Similarly, results show that the pedestrian in gray clothing (again shown in Figure 51) is also difficult to detect. These results can be seen in Figures 74 and 75.

When the E-C/VIS covers a blind area and the object is relatively close, as in pair (5, 18), the results show that detection scores are greatly improved. It should be remembered that infrared illumination was used during the tests and that tests were carried out at night. These are conditions where the E-C/VIS offers advantages over the mirrors combined with normal vision (meaning, without added visible illumination).

Smart Road Test Results

The Smart Road Tests had the objective of serving as a means of determining operational qualities of the E-C/VIS when compared to Baseline. There were three major independent variables in this study: Condition (Baseline versus E-C/VIS), Lighting (Street Lighting versus Dark), and Weather (Rain versus Clear). The study was carried out at night because of the need to determine the degree of usefulness of the extended range of the E-C/VIS. It is important to understand that the tests were intended to examine the most critical aspect of situation awareness, namely, the amount of clearance or overlap when another vehicle is alongside but near the back of the trailer. This situation is critical to lane changing or merging while avoiding a sideswipe crash. There are other aspects of general situation awareness, but they are not as important as assessing clearance or overlap and their approximate magnitude.

Clearance/Overlap. Data for the clearance overlap tests were first examined using a within-subject 2 by 2 by 2 model for the ANOVA. Because of the small number of trials, Side was not examined as an independent variable. A given subject then would have four possibilities for each set of independent variables. He or she could be correct on 0, 25, 50, 75, or 100 percent of responses because there were four trials per factorial combination of Baseline versus E-C/VIS, Street Lighting versus Dark, and Rain versus Clear. Results indicated that only the main effect of Baseline versus. E-C/VIS was significant: $F(1,7) = 11.67$, $p = 0.0112$. None of the other main effects or interactions was significant. Figure 76 shows the significant main effect of Baseline versus E-C/VIS. Clearly, the E-C/VIS condition provided superior results in regard to clearance/overlap correctness, with almost all responses correct.

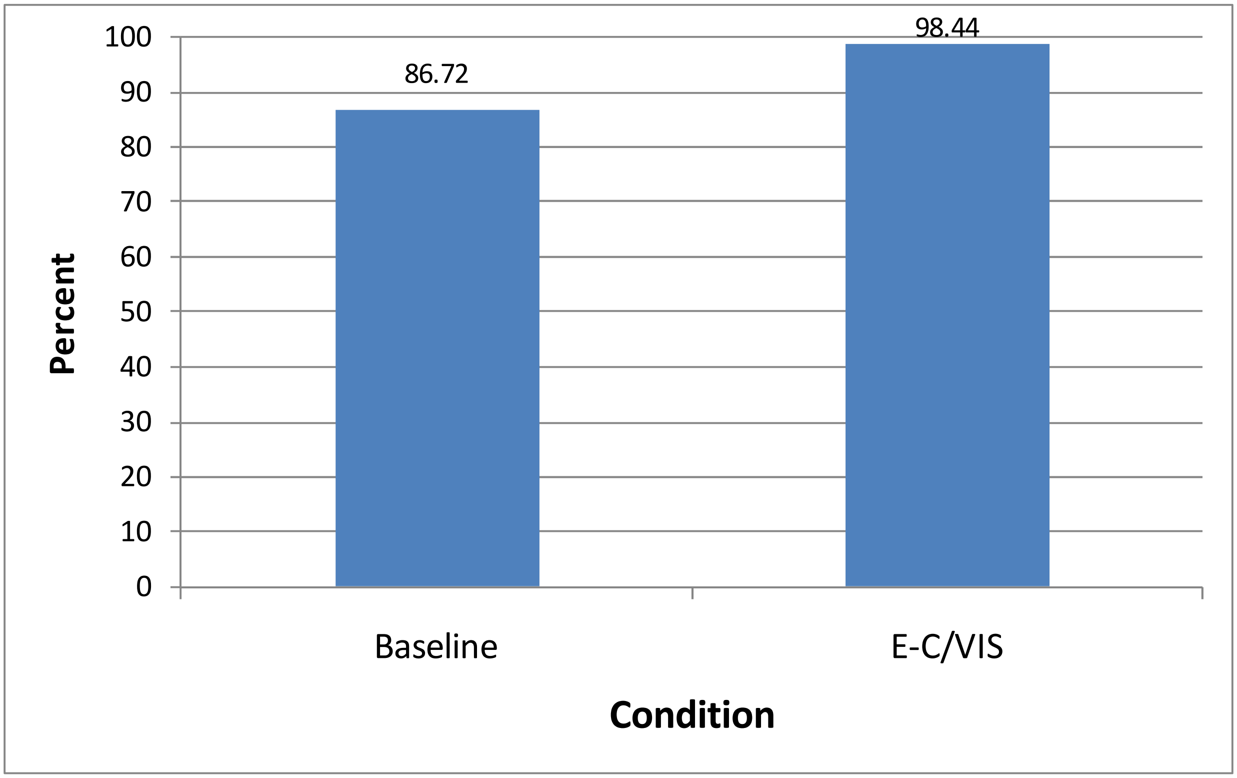


Figure 76. Clearance/Overlap Correctness as a Function of Condition

Another way of looking at these data would be by subject scores. As indicated, each given subject could be correct on 0, 25, 50, 75, or 100 percent of responses for a given condition. Therefore, there would be 64 total scores (or in other words, 8 by 8 scores). These have been plotted in terms of distribution in Figure 77. Clearly, the great majority of runs resulted in either 100 percent or 75 percent correctness, but results with the E-C/VIS provided superior overall scores.

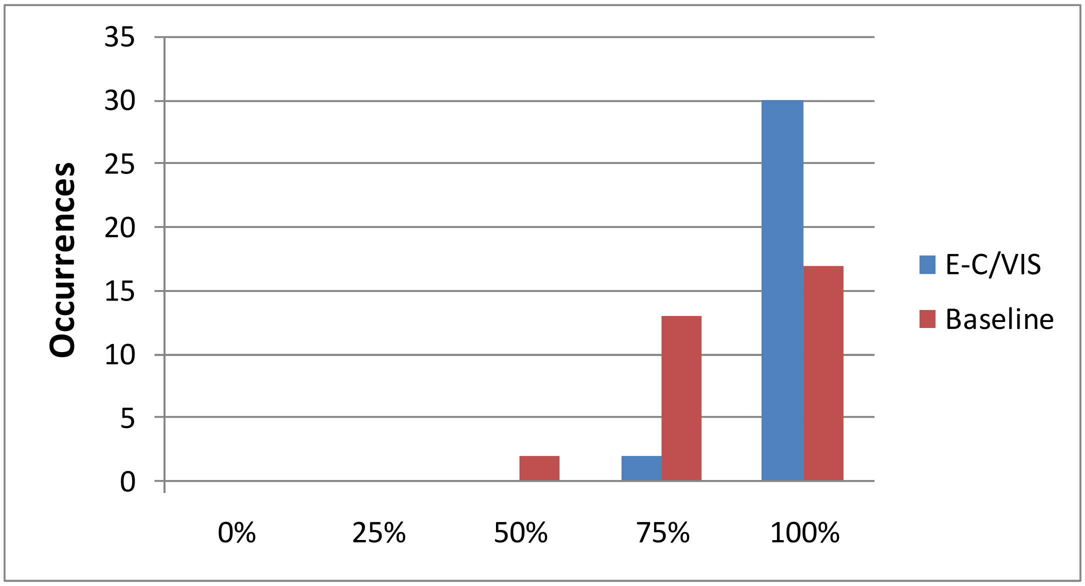


Figure 77. Distribution of Correctness Scores by Subjects and Runs

It will be recalled that subjects also provided an estimate of the amount of clearance or overlap in feet. If a given subject provided the correct answer in terms of clearance or overlap, then the subject's distance estimate was subtracted from the actual amount of clearance or overlap. Thereafter, the absolute value was obtained and was considered to be the error in feet. On the other hand, if the subject answered incorrectly on the query regarding clearance or overlap, the subject's distance estimate was added (algebraically) to the actual distance. Thereafter, the absolute value was obtained and was likewise considered to be the error in feet.

Absolute error values were analyzed by a four-way within-subject ANOVA. The independent variables were Condition (Baseline versus C-VIS), Side (Driver or Passenger), Lighting (Street Lighting versus Dark), and Weather (Rain versus Clear). Results of the analysis demonstrated significant main effects of Condition with $F(1,7) = 32.03$, $p = 0.0008$; and Side with $F(1,7) = 32.04$, $p = 0.0008$. There were two significant two-way interactions: Condition by Side with $F(1,7) = 11.29$, $p = 0.0121$ and Lighting by Side with $F(1,7) = 5.41$, $p = 0.0529$ (this latter condition was treated as significant). For completeness, two additional non-significant interactions are noted: Lighting by Condition with $F(1,7) = 3.77$, $p = 0.0934$; and Lighting by Condition by Side with $F(1,7) = 3.75$, $p = 0.0938$.

Figure 78 shows the Condition main effect. Clearly, the size of the error in estimates is cut drastically using the E-C/VIS. This is an important finding and was also noted in the C/VIS daytime tests performed in the previous project. Figure 79 shows the Side main effect. Here the absolute error was found to be much larger on the passenger side than on the driver side. The reason for this is believed to be that the mirrors on the passenger side are much farther away from the driver and therefore have a smaller field of view, particularly the west coast mirror. It is believed that this narrow view makes distance estimation substantially more inaccurate. In Figure 80, the interaction of Condition and Side shows very clearly that large errors occur on the passenger side when the E-C/VIS is not used.

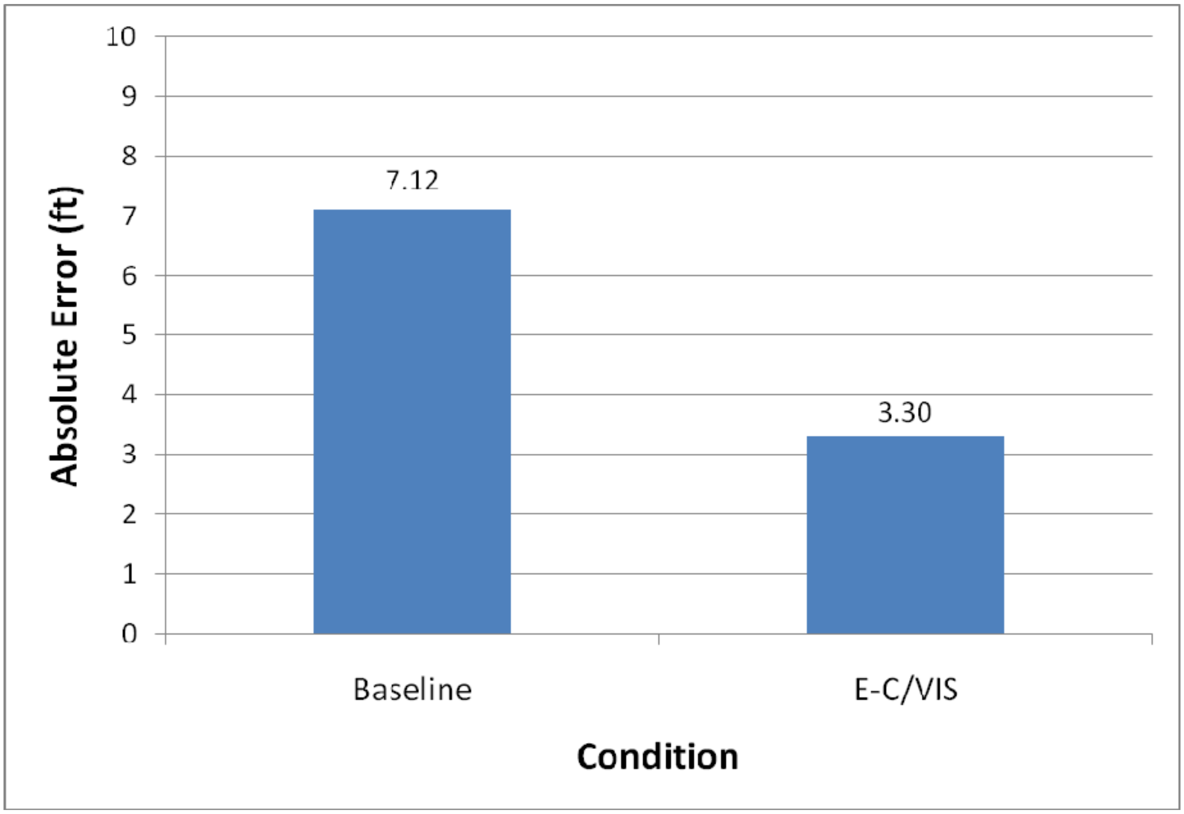


Figure 78. Effect of Baseline versus E-C/VIS on Distance Estimation Errors

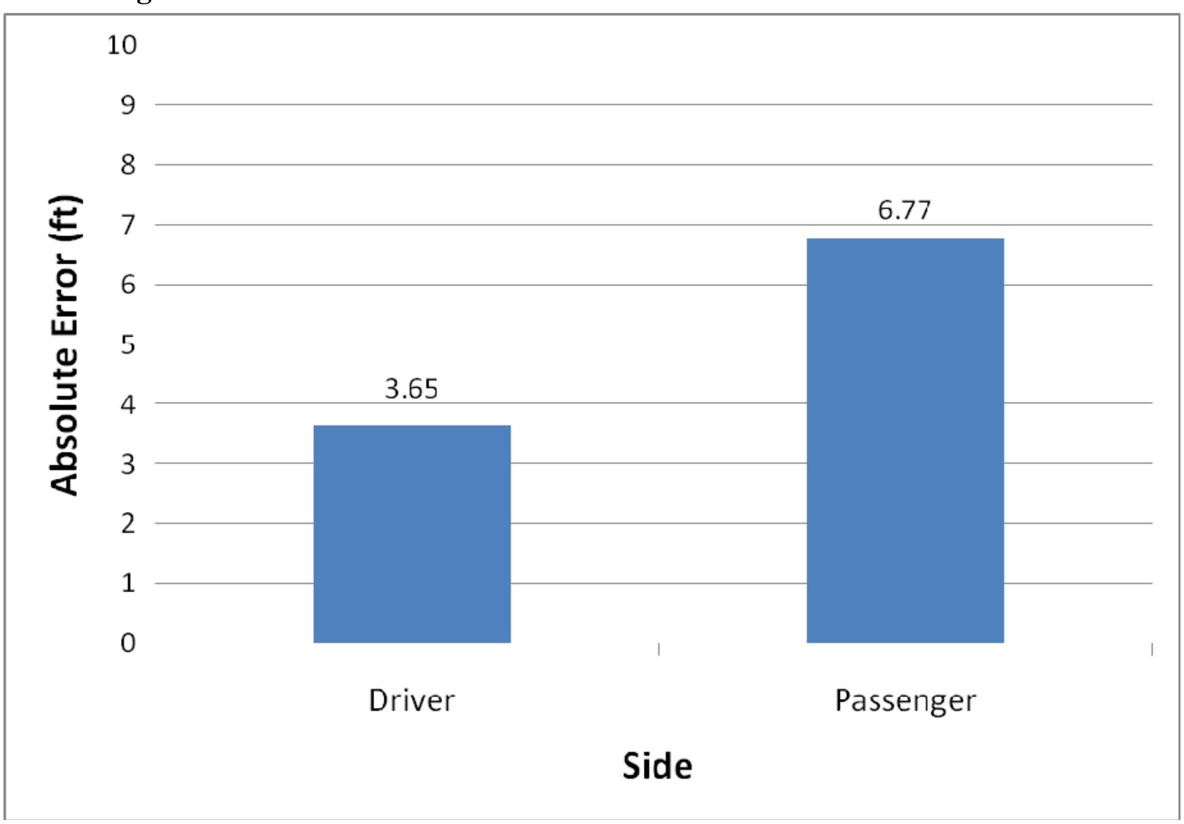


Figure 79. Effect of Side on Distance Estimation Errors

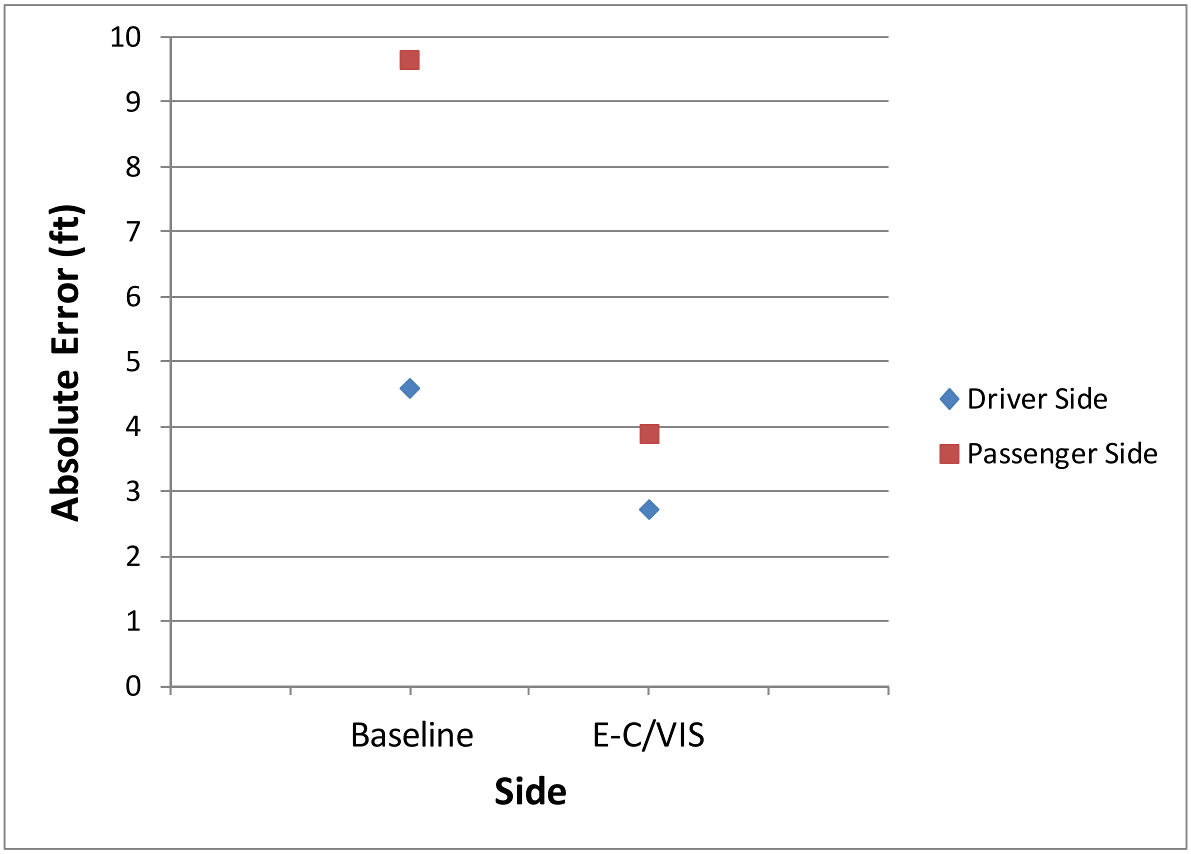


Figure 80. Interaction of Condition and Side on Distance Estimation Errors

Street lighting seemed to have an effect on the error estimates as well, although the effect was not as strong. Figure 81 shows the interactive effect of Lighting on Condition (Baseline versus E-C/VIS). Strictly speaking this interaction was not significant ($p = 0.0934$), but there is a reversal that takes place when Lighting is used. Note specifically the reduction in absolute error when the E-C/VIS is in use. Figure 82 also shows a street lighting effect, but this effect is very close to significance ($p = 0.0529$). In this case, errors are seen to increase in the dark condition on the passenger side, probably because of large errors when the E-C/VIS was not in use. This latter effect is more easily seen in the triple interaction shown in Figure 83. This interaction is also not significant ($p = 0.0938$), strictly speaking. Nevertheless, the impression is that Lighting has an effect on the data with regard to error magnitude.

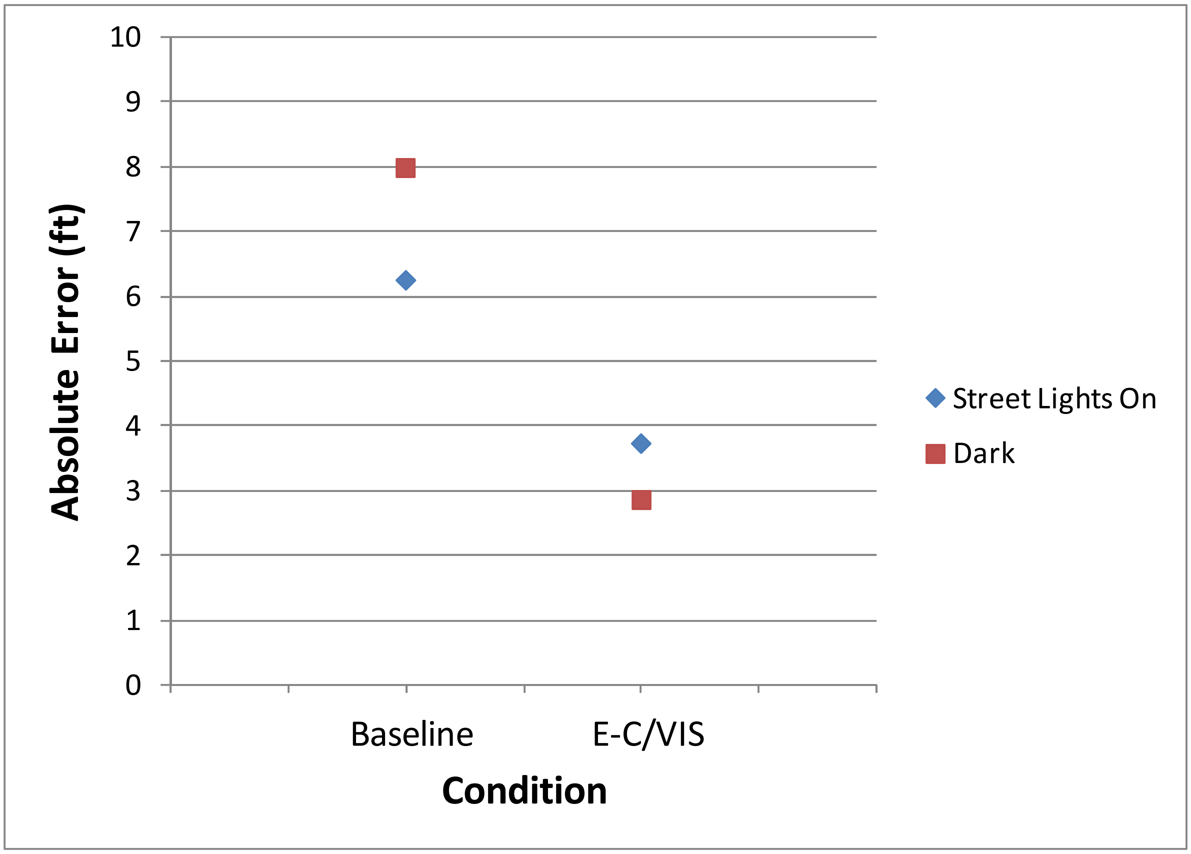


Figure 81. Interaction of Lighting with Condition (Baseline versus E-C/VIS); (note that *p* = 0.0934)

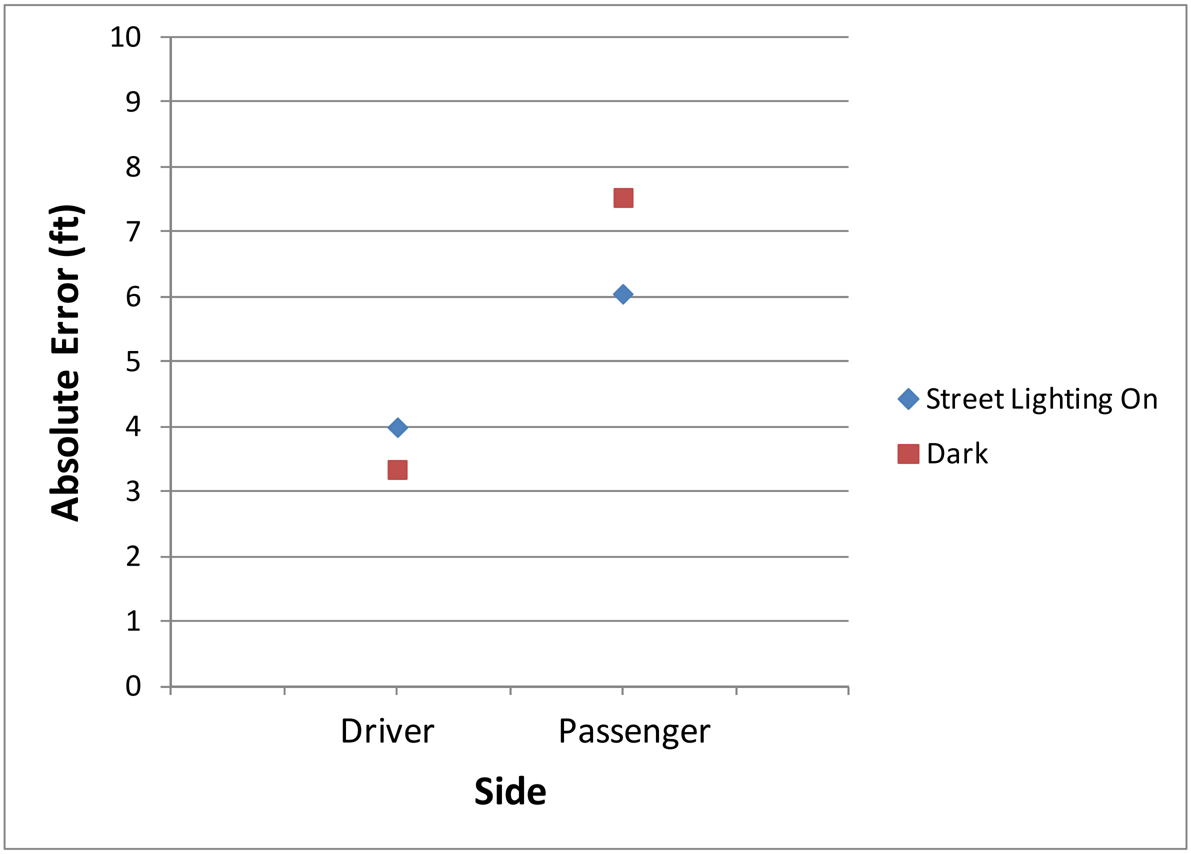


Figure 82. Interaction of Lighting with Side (Driver versus Passenger); (note that *p* = 0.0529)

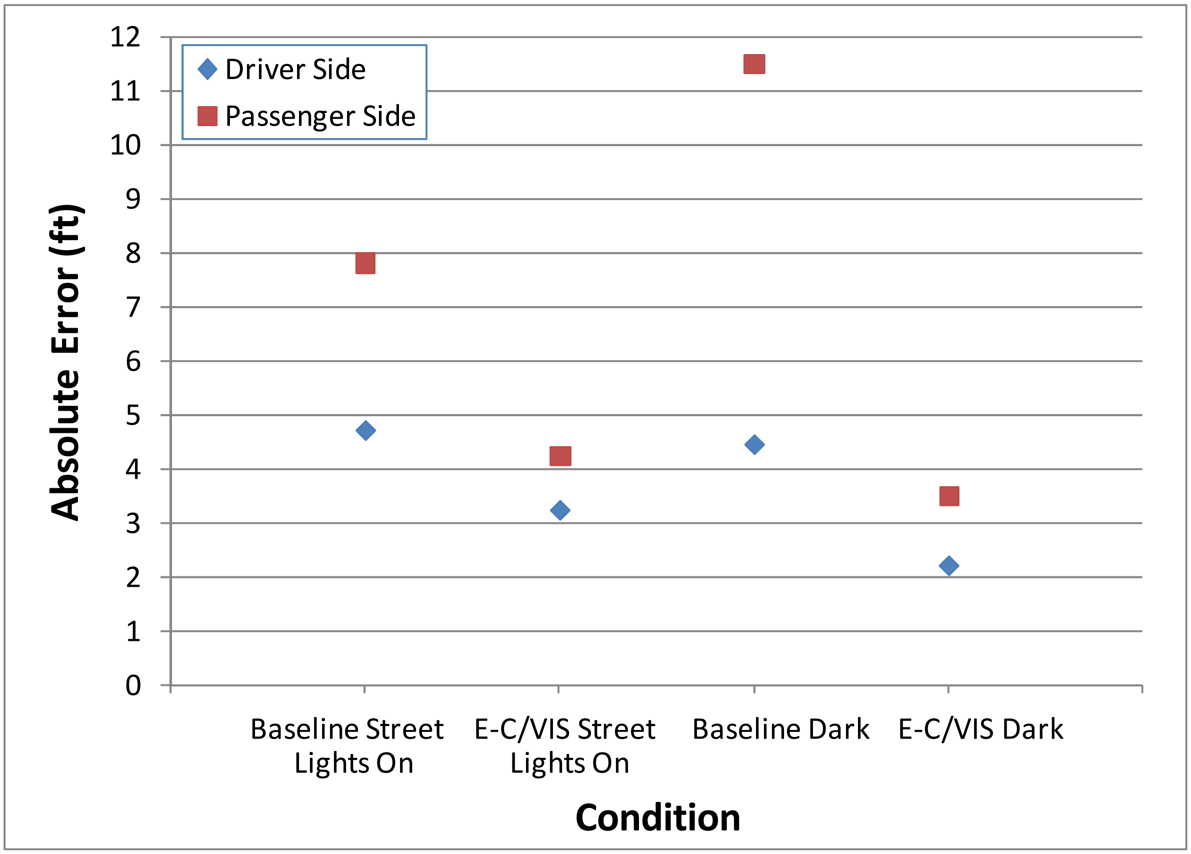


Figure 83. Three-way Interaction of Lighting, Condition (Baseline versus E-C/VIS), and Side (Driver versus Passenger); (note that *p* = 0.0938)

Eye Glance Analysis. While performance results show substantial improvement for the E-C/VIS condition, there is a question regarding the degree to which drivers (subjects) are using these added displays. Therefore, eye glance analyses were carried out for the Smart Road tests. These tests provide an indication of sources from which subjects gathered their information during decision making. Data were gathered and analyzed from the time that the experimenter completed the query regarding clearance or overlap, and ended when the subject provided an estimate of distance of clearance or overlap. Thus, the interval during which data were gathered was that associated with the two queries: clearance or overlap, and how much clearance or overlap in feet. There was no break (in the data gathering interval) during the experimenter's query regarding amount of clearance or overlap in feet.

It is important to understand that the Smart Road tests were limited to passing/merging conditions; namely, determination of clearance or overlap, and corresponding amount of clearance or overlap in terms of distance. These conditions were chosen because they reflected realistic situations in which sideswipe accidents might occur. It would be expected that eye glance behavior would be strongly influenced by the conditions selected, but these conditions were believed to be the most critical and were therefore used for testing.

Probabilities were calculated by careful examination and reduction of video files associated with the two face cameras mounted just above the two E-C/VIS side monitors. The probability of looking at a given object or area was defined as the number of video frame samples to that object or area divided by the total number of readable video frame samples in the measurement interval.

Figure 84 shows the overall eye glance behavior for the Smart Road experiments. This figure is quite revealing. It shows that during Baseline runs (that is, runs without the E-C/VIS operating) drivers relied heavily on their side mirrors with glances to the forward view. There is also an occasional short glance to the instrument panel (believed to be primarily the speedometer). On the other hand, when the E-C/VIS was operating, drivers relied heavily on the rear wide-angle look-down monitor (center E-C/VIS) with glances to the forward view. In this condition, they also looked occasionally at the mirrors, the two side monitors, and the instrument panel. It can be said that driver information gathering was very different when the E-C/VIS was operating. Specifically, drivers relied very heavily on the rear wide-angle look-down monitor when it was available. The reason appears to be that this monitor contained precise information regarding the longitudinal clearance or overlap between the rear of the trailer and the light vehicle in the adjacent lane.

Also worth mentioning in Figure 84 is the fact that the drivers had slightly higher probabilities of looking at the forward view when the E-C/VIS was operating. This occurred even though there were more sources for the drivers to view and also drivers had less experience with the E-C/VIS. Glance probability to the forward view represents a safety factor, in that a given driver can maintain better control of his/her heavy vehicle while assessing the location of the vehicle alongside.

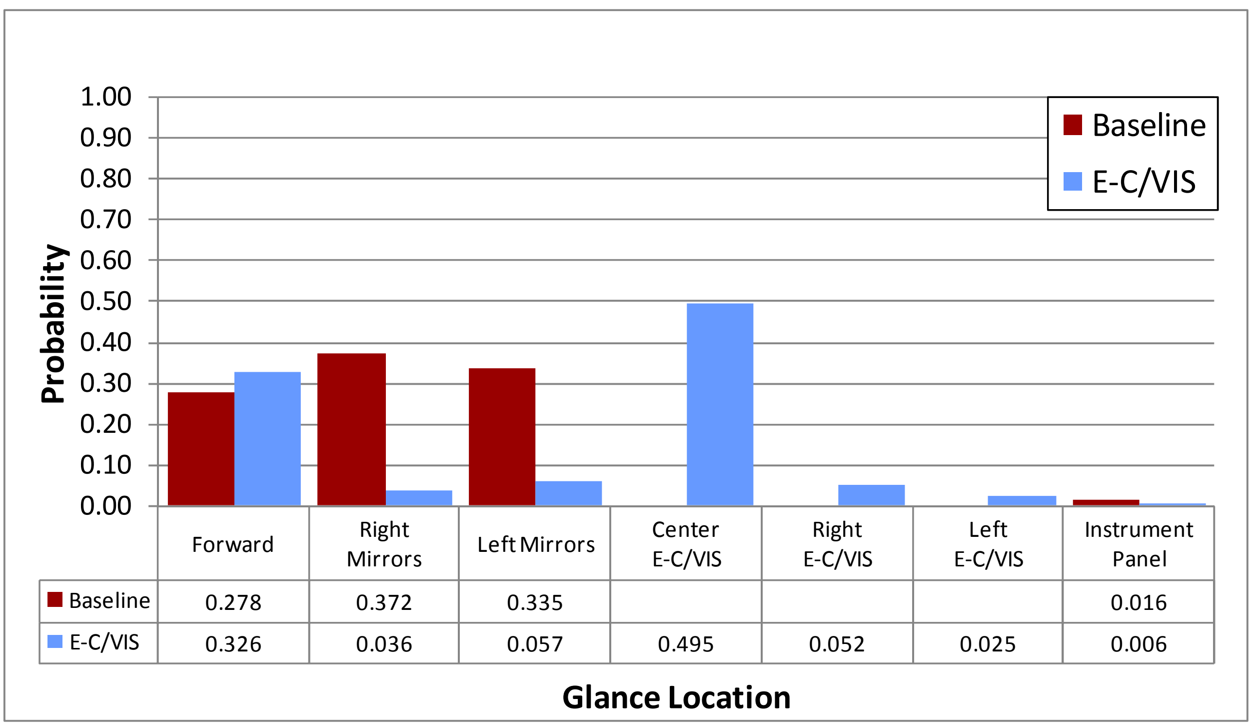
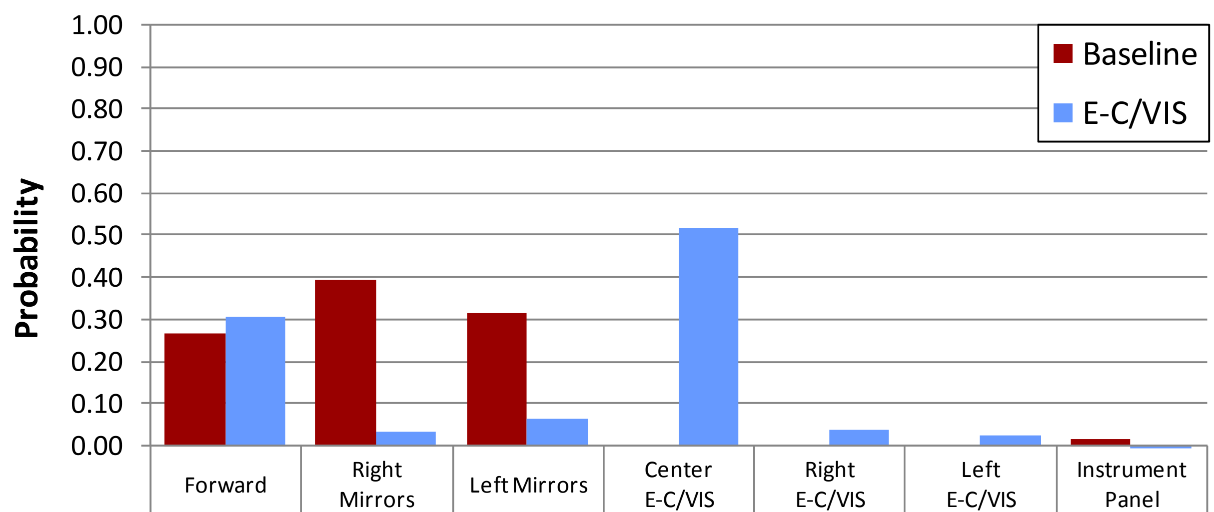


Figure 84. Glance Probabilities (as a function of Baseline versus E-C/VIS) for all Conditions Tested in the Smart Road Experiments

Analyses were also conducted for specific independent variables to determine if the variables had any major effects on driver eye glance behavior. Figures 85 through 98 show these plots. Figures 85 and 86 allow the comparison of Streetlight and Dark conditions. As can be seen, any differences are small. This can be considered as a positive situation, in that the E-C/VIS continued to operate and to be used whether or not there was overhead lighting. Figures 87 and 88 show that drivers relied heavily on the rear wide-angle look-down channel of the E-C/VIS when it was available. They relied to a much lesser degree on the corresponding side channel and mirrors during the clearance/overlap and distance estimation tasks. Figures 89 and 90 show no major differences as a function of Rain or Clear conditions, indicating that there was no change in driver strategy. Figures 91 through 98 similarly show no major differences as a function of Side for Street Lighting/Dark conditions and for Rain/Clear conditions.

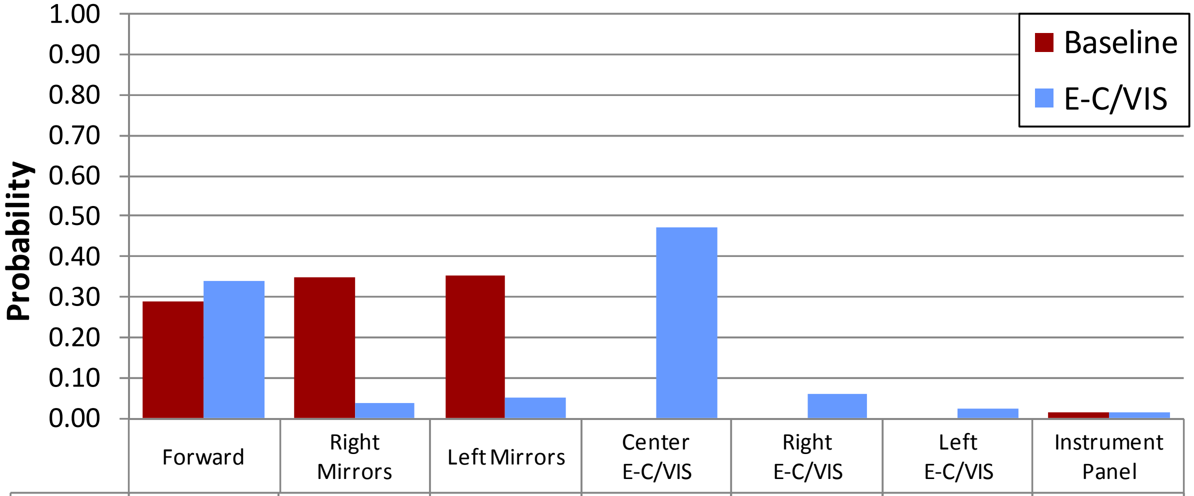
The results generally show that the E-C/VIS worked reasonably well under all conditions tested in regard to information gathering. Drivers apparently did not change strategy of information gathering except for Baseline versus E-C/VIS conditions, which was expected. As previously mentioned, drivers used the rear wide-angle look-down channel of the E-C/VIS when it was available. This was believed to be due to the accurate information it could provide in regard to clearance or overlap and amount of clearance or overlap. Without the E-C/VIS, drivers were forced to rely on their side mirrors to estimate the clearance or overlap and the amount of clearance or overlap. Thus, drivers used the E-C/VIS when it was available.



	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.267	0.398	0.316				0.019
E-C/VIS	0.311	0.035	0.065	0.519	0.041	0.027	0.001

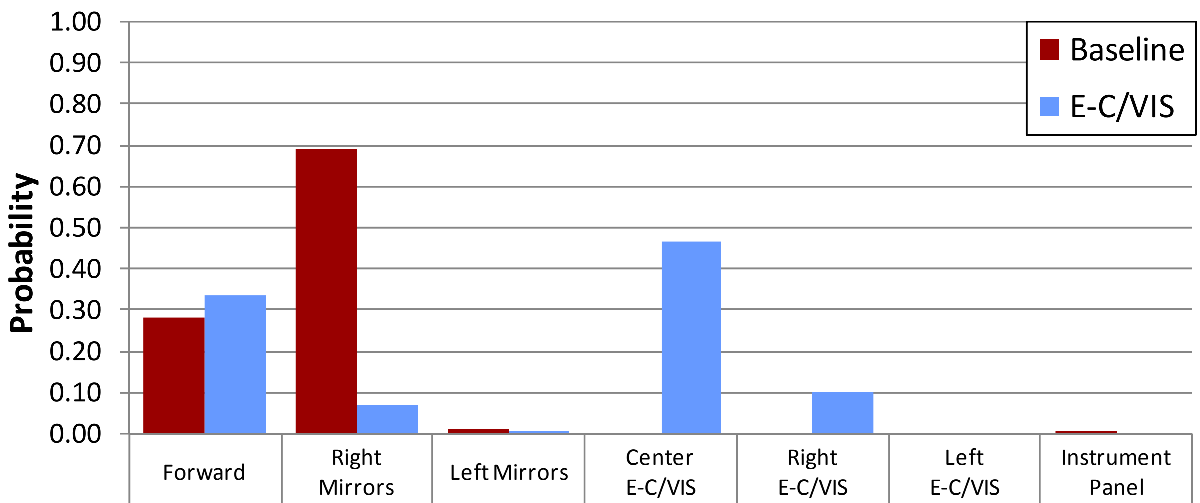
Glance Location

Figure 85. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Streetlights On Conditions in the Smart Road Experiments



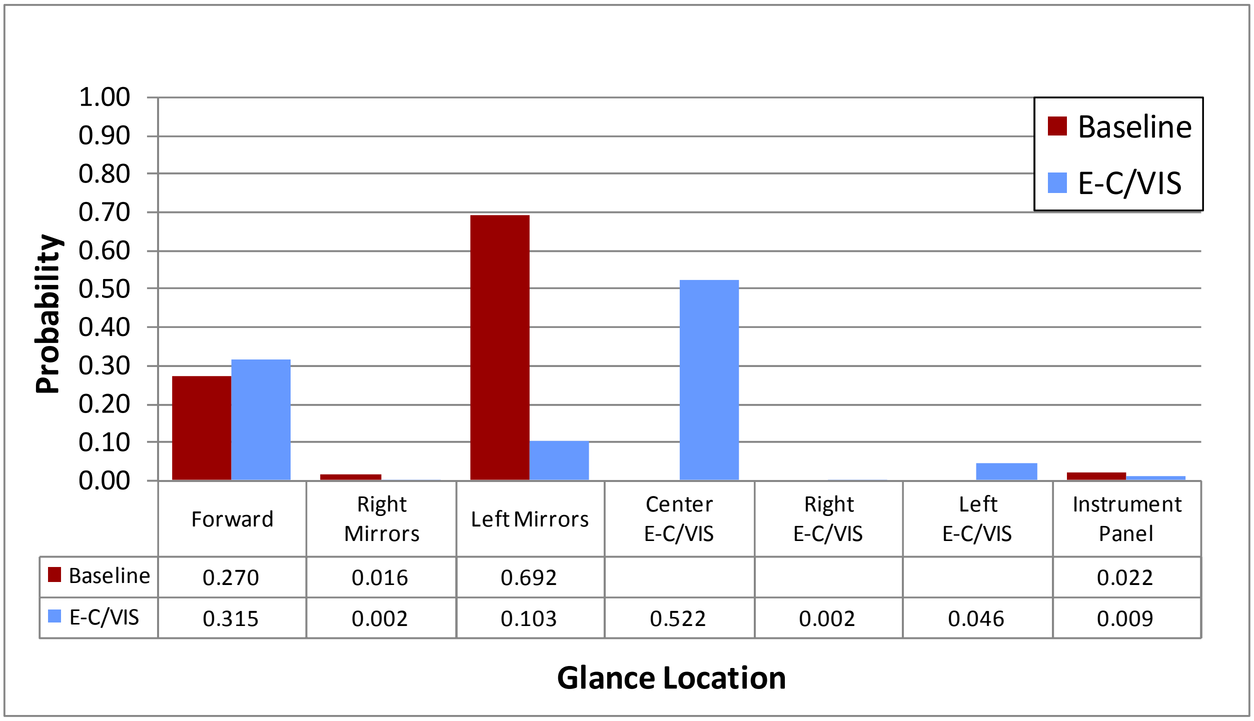
	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.288	0.347	0.353				0.012
E-C/VIS	0.340	0.037	0.048	0.472	0.062	0.023	0.012

Figure 86. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Dark Conditions in the Smart Road Experiments



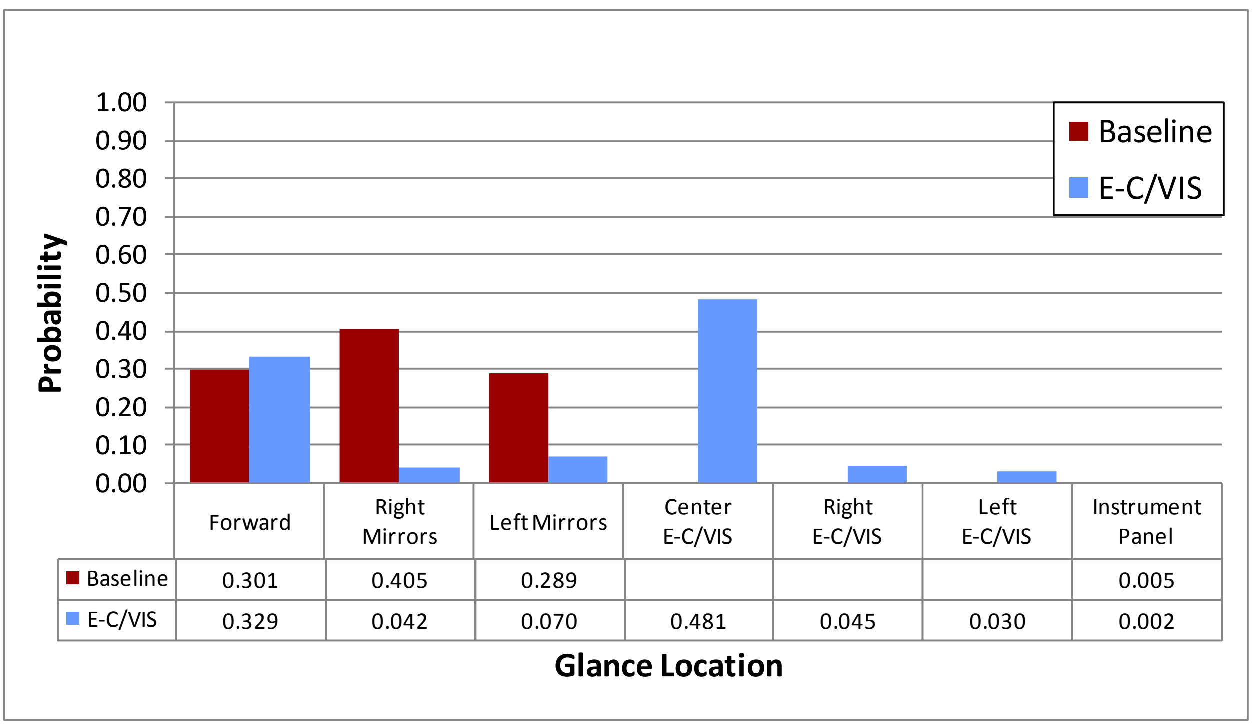
	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.284	0.693	0.012				0.010
E-C/VIS	0.337	0.072	0.009	0.467	0.102	0.003	0.003

Figure 87. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Passenger-side Assessments in the Smart Road Experiments



	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.270	0.016	0.692				0.022
E-C/VIS	0.315	0.002	0.103	0.522	0.002	0.046	0.009

Figure 88. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Driver-side Assessments in the Smart Road Experiments



	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.301	0.405	0.289				0.005
E-C/VIS	0.329	0.042	0.070	0.481	0.045	0.030	0.002

Figure 89. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Rain Conditions in the Smart Road Experiments

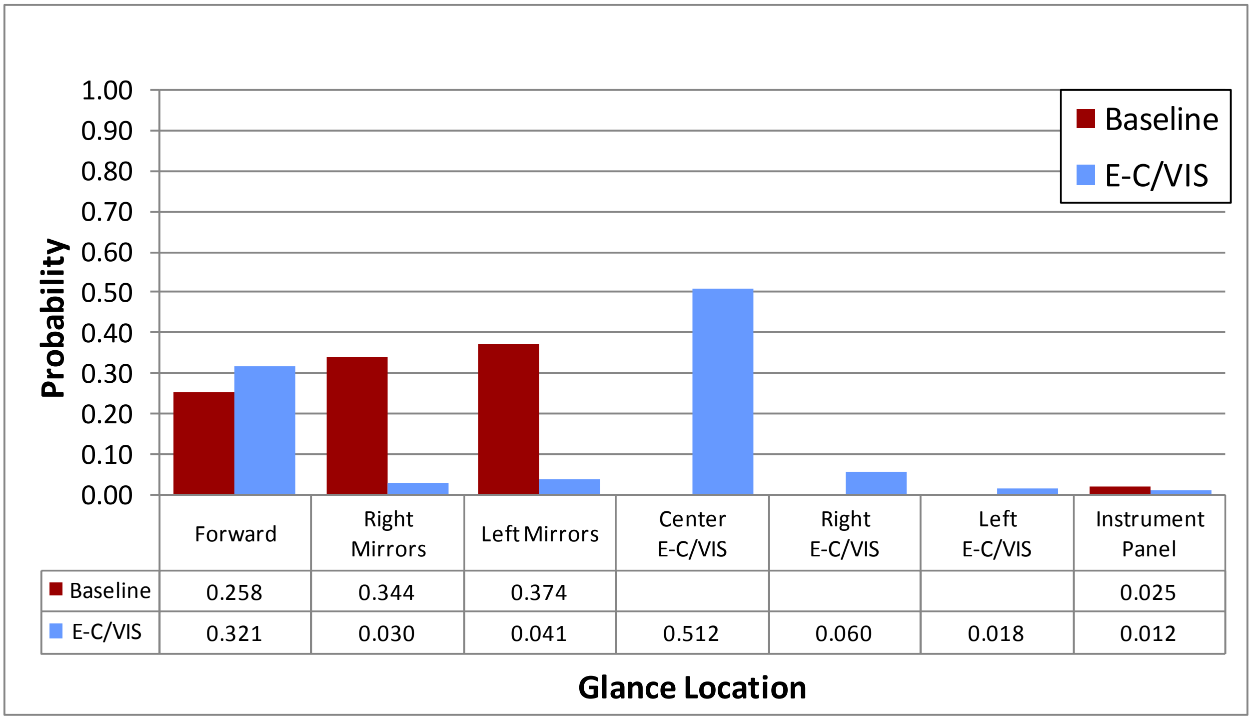


Figure 90. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for all Clear Conditions in the Smart Road Experiments

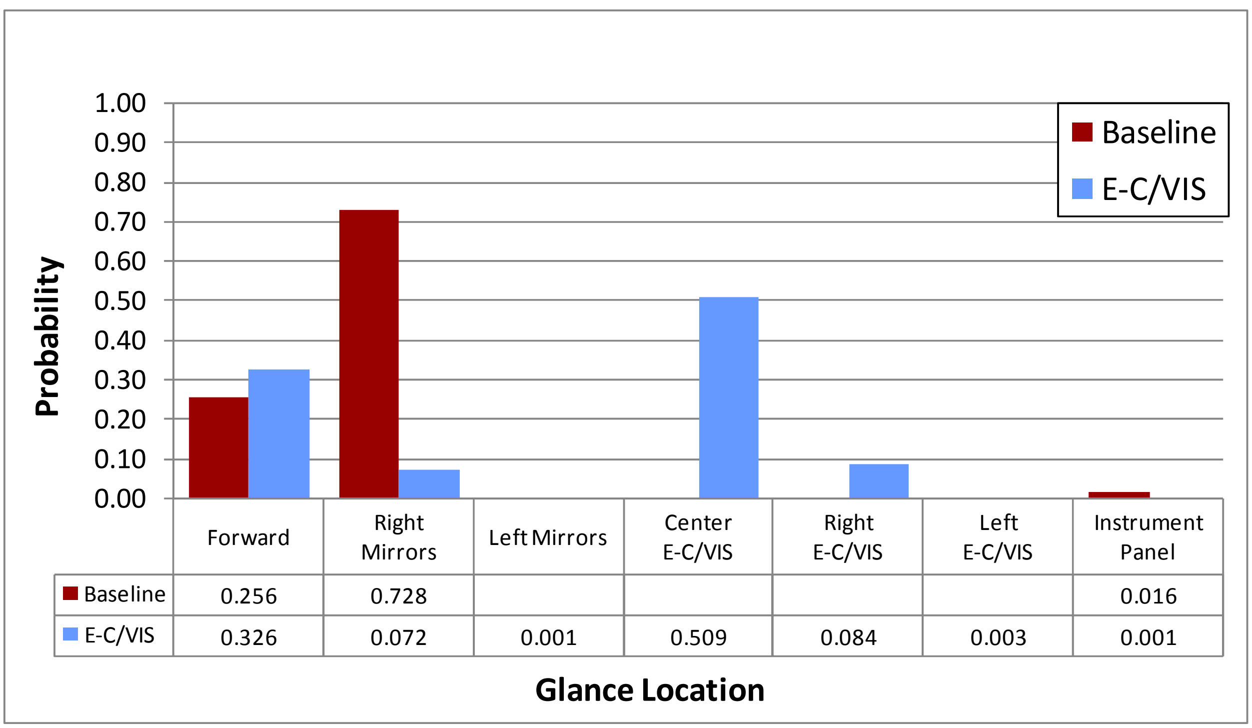


Figure 91. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Passenger-side Assessments with the Streetlights On in the Smart Road Experiments

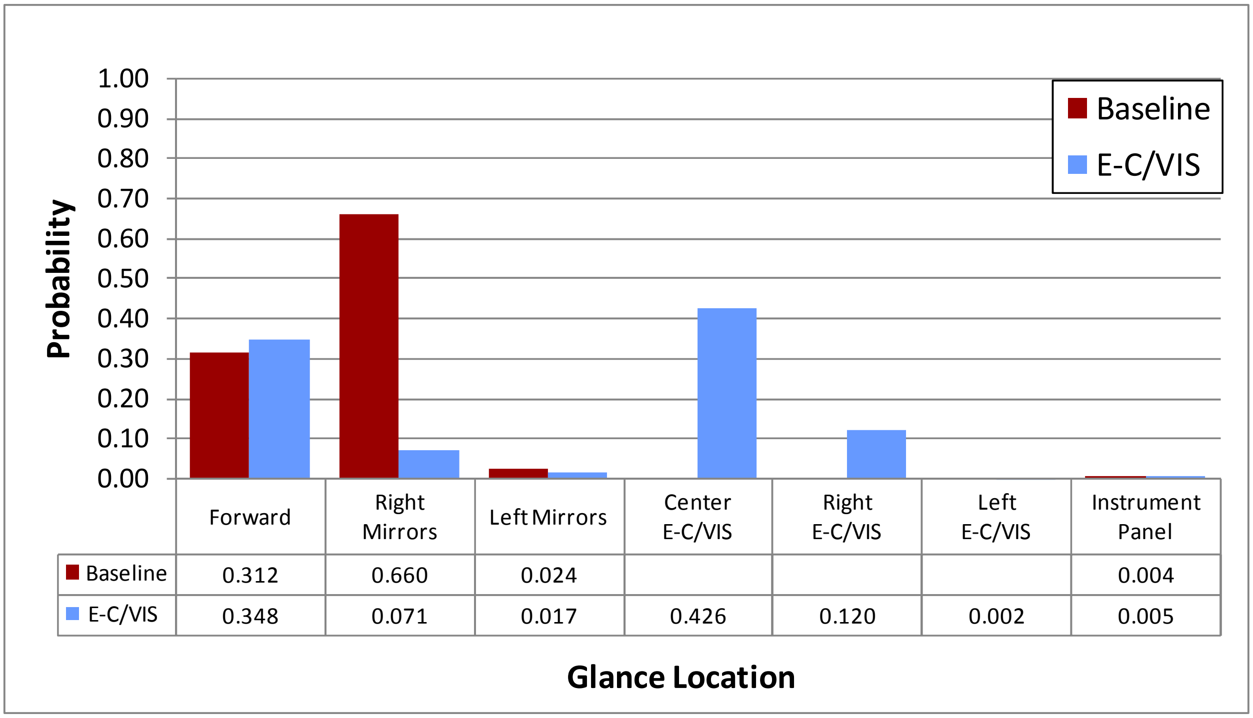


Figure 92. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Passenger-side Assessments under Dark conditions in the Smart Road Experiments

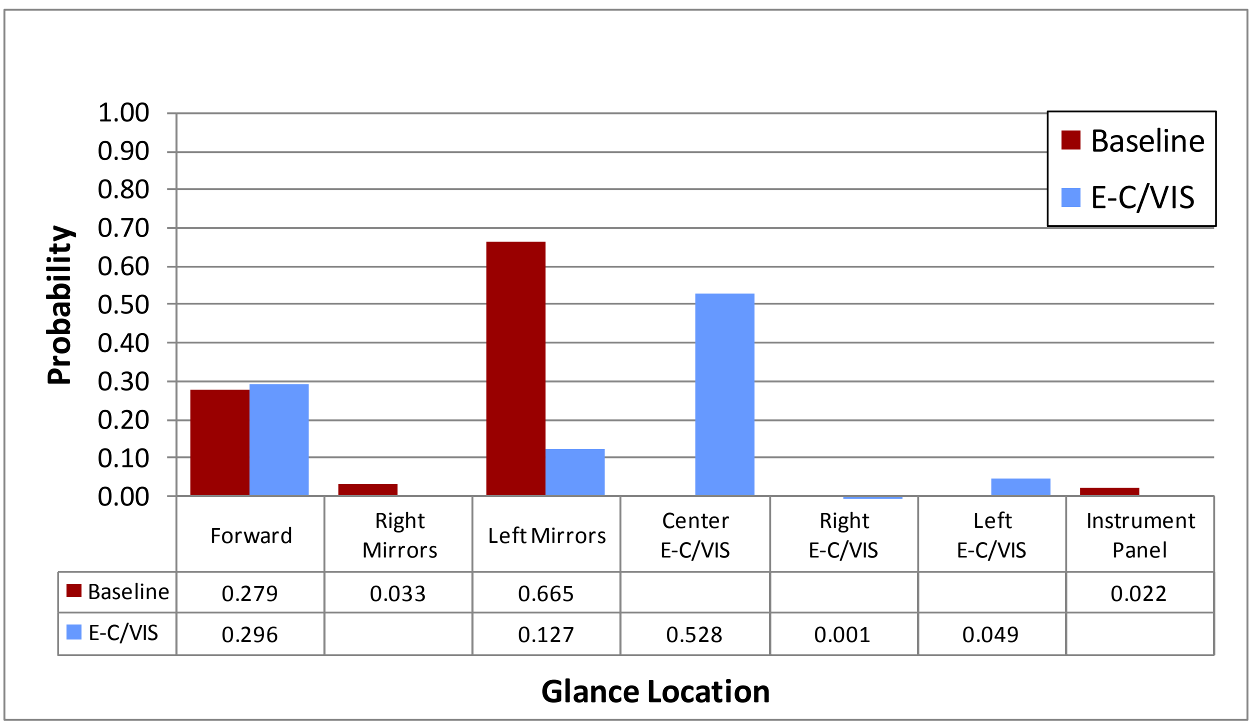
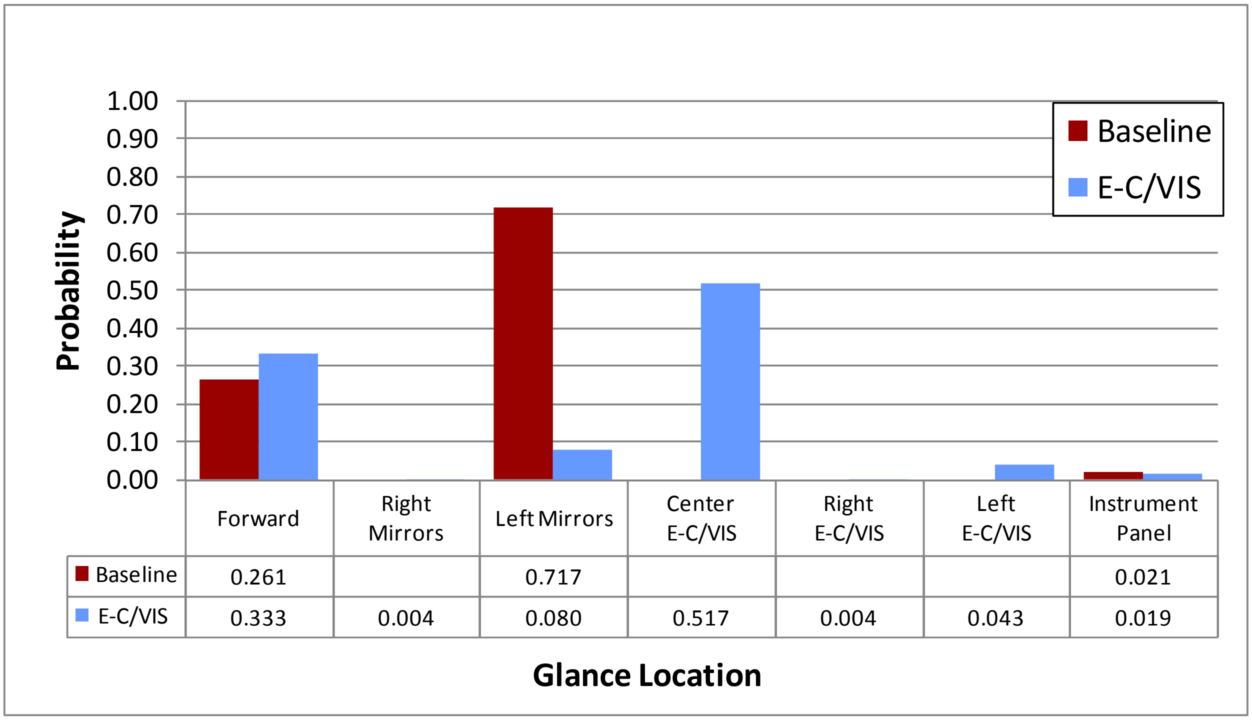
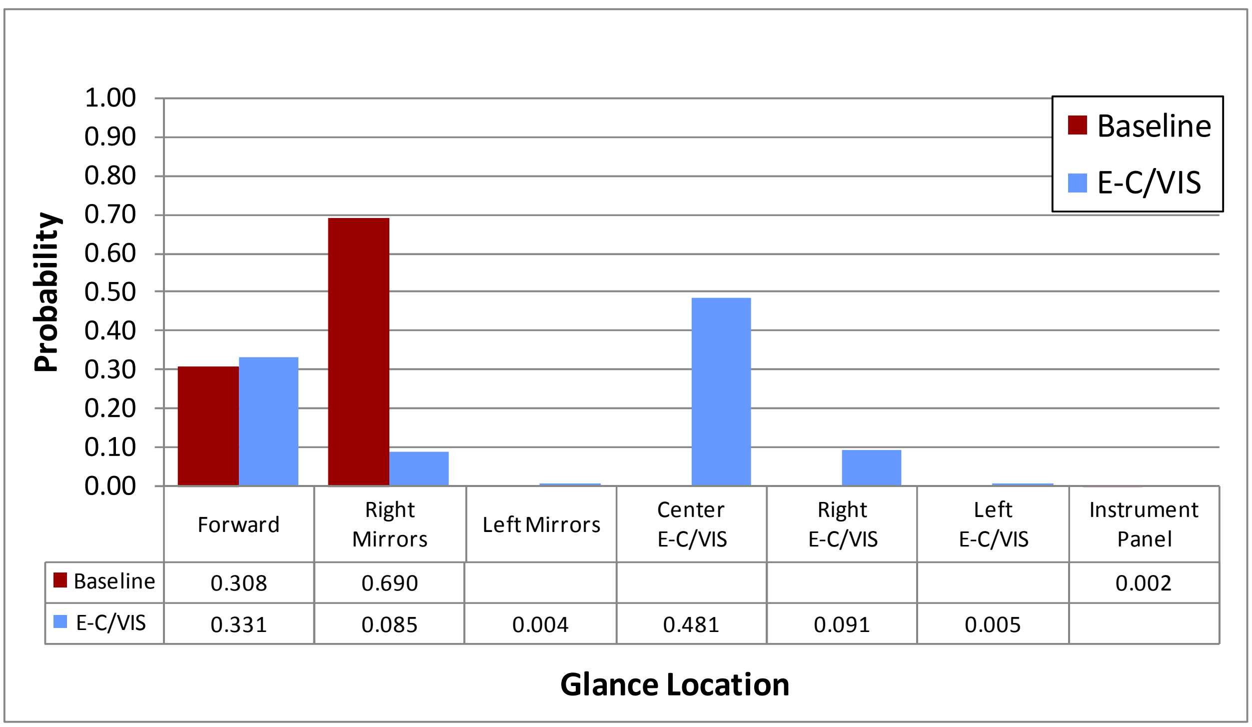


Figure 93. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Driver-side Assessments with the Streetlights On in the Smart Road Experiments



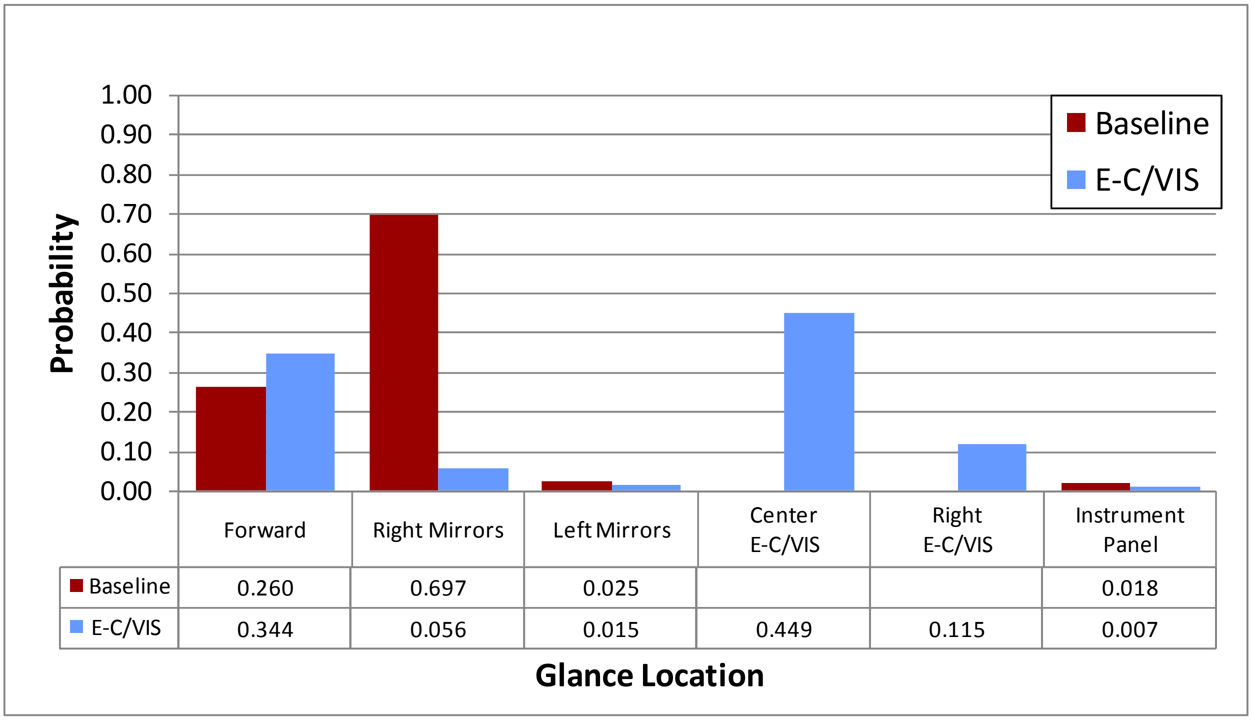
	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.261		0.717				0.021
E-C/VIS	0.333	0.004	0.080	0.517	0.004	0.043	0.019

Figure 94. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Driver-side Assessments under Dark Conditions in the Smart Road Experiments



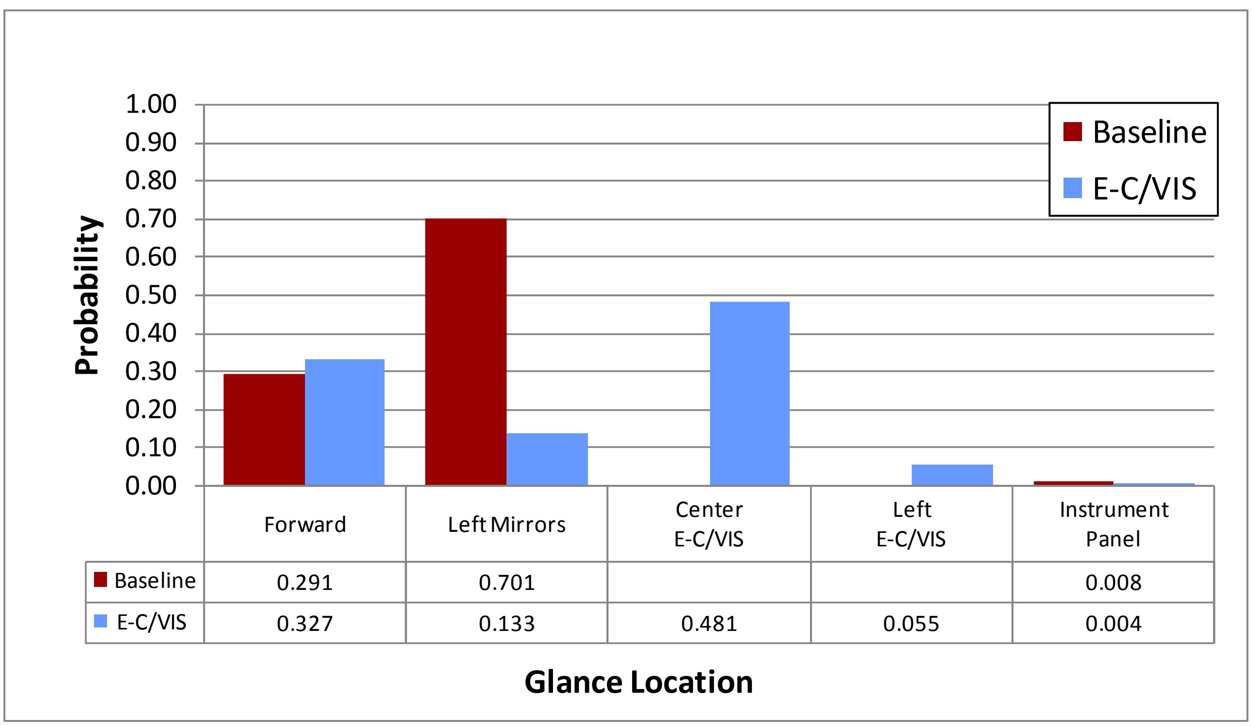
	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.308	0.690					0.002
E-C/VIS	0.331	0.085	0.004	0.481	0.091	0.005	

Figure 95. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Passenger-side Assessments for Rain Conditions in the Smart Road Experiments



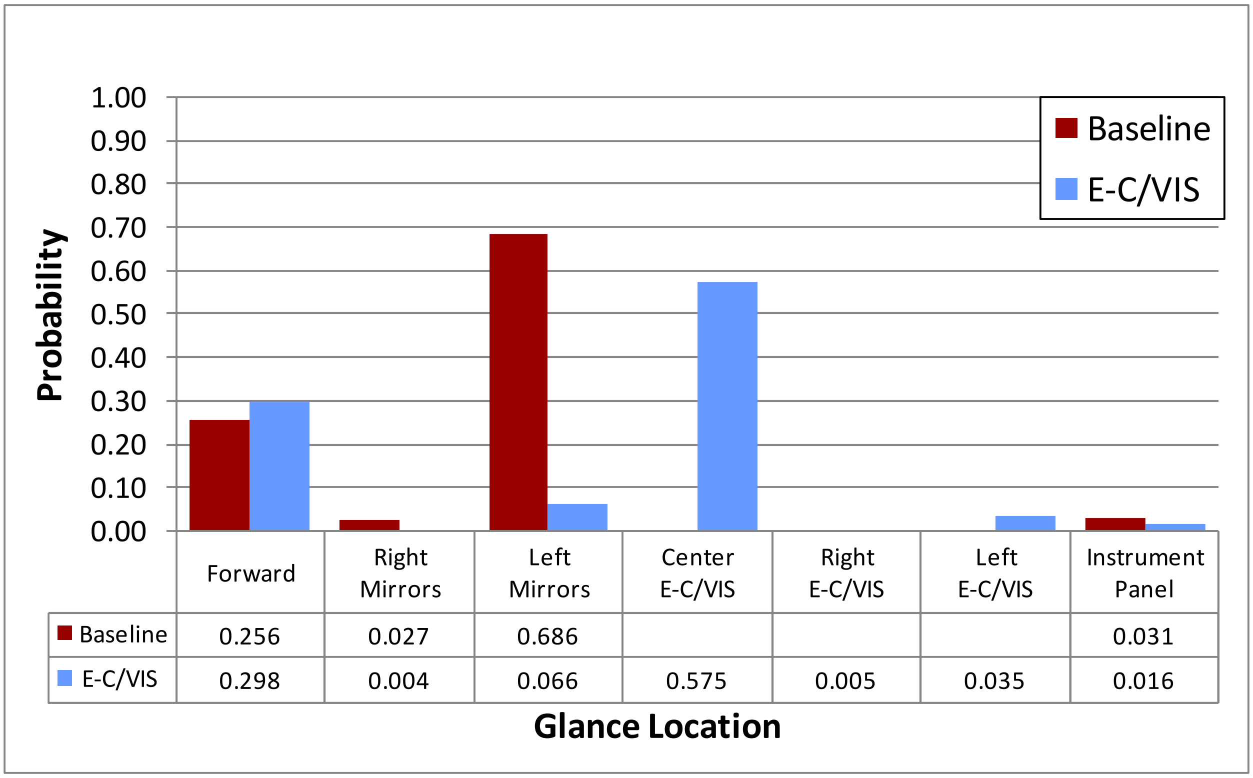
	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Instrument Panel
Baseline	0.260	0.697	0.025			0.018
E-C/VIS	0.344	0.056	0.015	0.449	0.115	0.007

Figure 96. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Passenger-side Assessments for Clear Conditions in the Smart Road Experiments



	Forward	Left Mirrors	Center E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.291	0.701			0.008
E-C/VIS	0.327	0.133	0.481	0.055	0.004

Figure 97. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Driver-side Assessments for Rain Conditions in the Smart Road Experiments



	Forward	Right Mirrors	Left Mirrors	Center E-C/VIS	Right E-C/VIS	Left E-C/VIS	Instrument Panel
Baseline	0.256	0.027	0.686				0.031
E-C/VIS	0.298	0.004	0.066	0.575	0.005	0.035	0.016

Figure 98. Glance Probabilities (as a Function of Baseline versus E-C/VIS) for Driver-side Assessments for Clear Conditions in the Smart Road Experiments

Subjective Ratings. It will be recalled that subjects performed two types of ratings: those comparing the Baseline to E-C/VIS conditions for all combinations of Weather (Rain versus Clear) and Street Lighting: (Street Lighting versus Dark). Thus, each subject provided four ratings of these combinations using the 9-point rating scales shown in Appendix D. In addition, on completion of all testing, subjects were asked to provide overall ratings associated with their experience using the E-C/VIS in the various experiments, including the static object detection/identification experiments, again using scales presented in Appendix D.

It is important to understand how the various scales were laid out. A center rating was provided a grading of 5 and was associated with the word “moderate”. Thus, a response of 5 would suggest moderate acceptance. Any value between 5 and 9 (the uppermost rating) was considered to be favorable, whereas scores below 5, and down to the lowermost score of 1, were considered to somewhat unfavorable or more so. The ends of the scale represented extreme positions, with 9 being extremely favorable and 1 being extremely unfavorable. All analyses were performed using the numerical equivalent of scores provided by the subjects.

Ratings During the Smart Road Experiment. A two-way ANOVA was performed on the four responses each subject provided for each comparison of Baseline versus E-C/VIS immediately following pairs of runs on the Smart Road. The independent variables in this analysis were Weather (Rain versus Clear) and Lighting (Street Lighting On versus Dark). The single dependent variable was the rating of “how helpful was the E-C/VIS compared to Baseline”. The analysis demonstrated no significant main effects or interactions. The interpretation of these results is that the ratings are not significantly different whether or not Rain is present or absent, and whether Street Lighting is On or Off. Figure 99 shows the mean ratings for the various conditions, indicating that even though there are no significant differences, all ratings are relatively high, averaging 7.67. This represents a high value of acceptance of the E-C/VIS by the subjects.

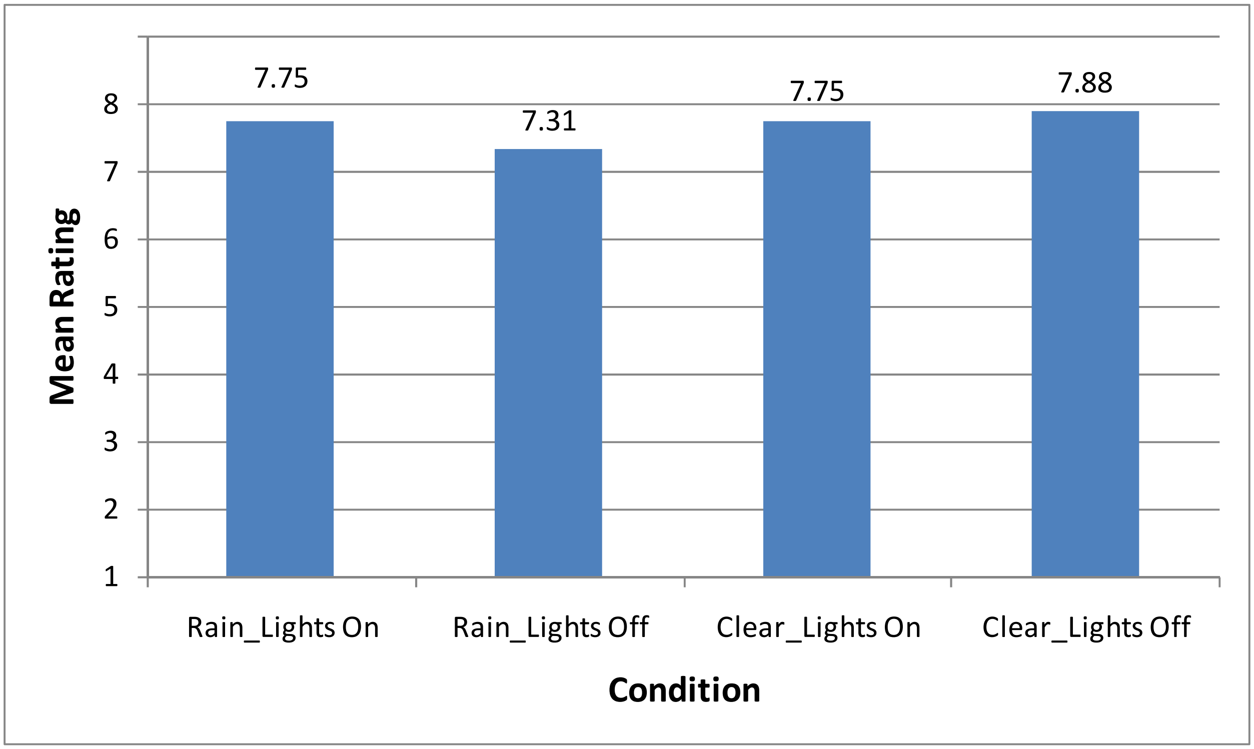


Figure 99. Mean Ratings of E-C/VIS Helpfulness as a Function of Weather and Street Lighting. Differences are not Significant; Average Rating is 7.67.

Overall Ratings. As indicated, once the experimental runs were completed, subjects rated the E-C/VIS along three dimensions (as shown in Appendix D). Paraphrasing, these were: "How useful overall?", "Would you like to have this integrated system on your rig?", and "Does the E-C/VIS improve your situation awareness (where situation awareness was defined for the subjects)?" The objective of these ratings was to determine whether or not subjects were receptive to the E-C/VIS after using it and to determine the degree to which they were receptive. Figure 100 shows the mean values for the responses to the three questions. As can be seen, average responses for the three ratings demonstrate a high overall level of acceptance, with a grand mean of 7.88.

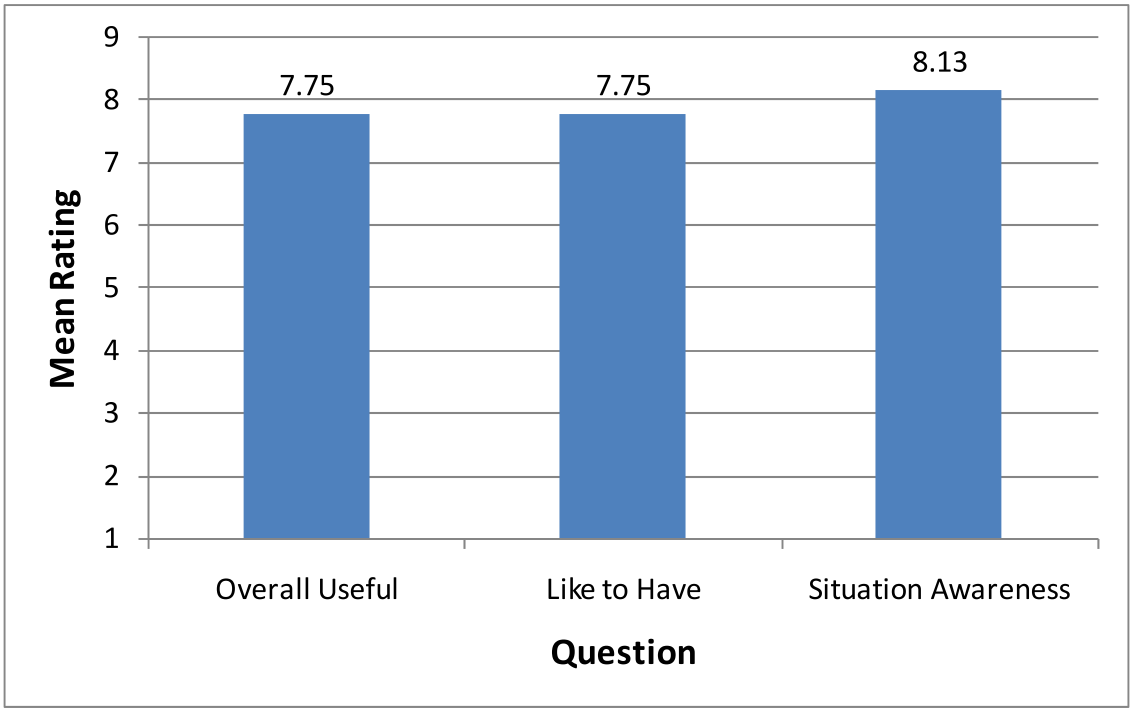


Figure 100. Mean Values for Post-experiment Ratings Regarding Receptiveness to the E-C/VIS

The ratings provided by the subjects following the experiment were further analyzed by examining occurrence data. Figures 101, 102, and 103 show the occurrence plots. None of the plots have ratings below the "moderate" level, and the last two have only one moderate rating each. All other ratings were very high. These occurrence plots suggest very high levels of acceptance.

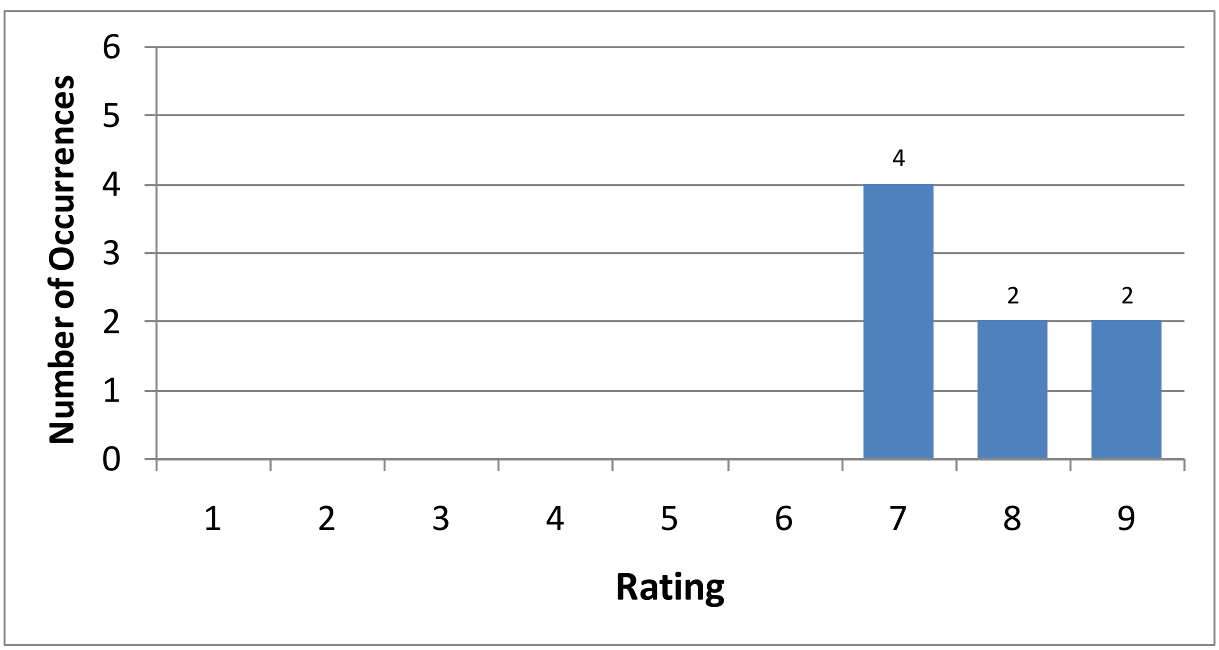


Figure 101. Occurrence Data for the Ratings of Usefulness

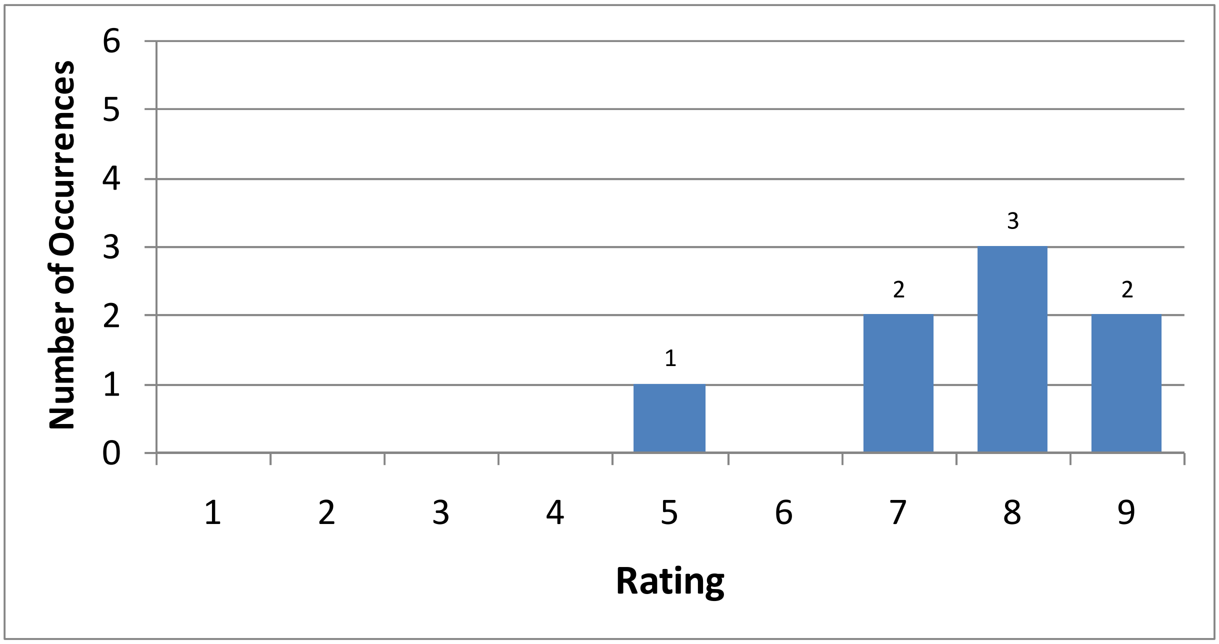


Figure 102. Occurrence Data for the Ratings of whether Subjects would like to have the E-C/VIS on their Rig

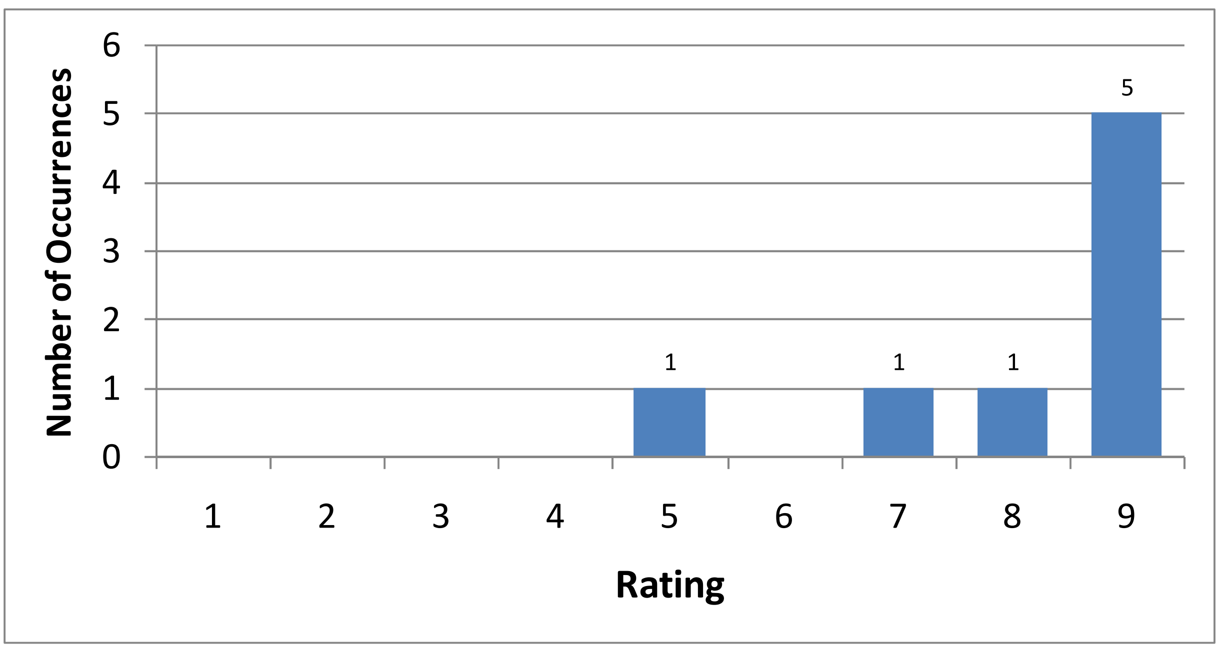


Figure 103. Occurrence Data for Ratings of Improved Situation Awareness

Final Written Comments by Subjects. After subjects completed their post-experiment ratings, they were asked to provide any additional information they wanted the experimenters to have. They did this by writing comments on a ruled sheet (Appendix D). Table 10 shows the unedited comments provided by the eight subjects.

Table 10. Unedited Post-experiment Comments Written by the Subjects

Subject	Additional Comments
1	E-C/VIS takes the guess work out of the maneuvers. The rear marker lights need to be more visible to the driver to help make a better comparison in judging distance.
2	Reflection of video monitors on inside of tractor left and right. Rear monitor on trailer very useful. Headlights on vehicle very bright on left and right monitors which is very distracting.
3	Glare of headlights in monitors.
4	Glare from passenger side monitor on driver mirror. Side monitors weren't very useful for this task. The other vehicle could be gauged by the center display. Going downhill on this road it is difficult to assess the other vehicle, while making the slight right hand turn with the tractor in the left lane.
5	The marker lights at the back of the trailer could not be seen and I use them for reference of vehicles' position
6	Processing Control Box on dash needs to be dimmer. There is a reflection in the driver side window of monitors from inside the cab.
7	The E-C/VIS system is a great aid/supplement to the mirrors on the truck. The lookdown camera is excellent for judging whether a vehicle is alongside the trailer or not, especially in poor visibility conditions. The fender cameras provide great visibility of the rear of the trailer while making hard turns in either direction and would prevent running into/over objects in poor visibility conditions. Mirrors are easier to use when overhead lights are on.
8	I found the system to be very useful in all tests and an additional area of watching the rear of my trailer and tandems while performing tight turns.

Subjects picked up on most of the problems that the experimenters had seen during development of the equipment. They noticed the glare problem (in the monitor images) created by headlights of vehicles alongside. They also noticed the reflective glare within the cab created by the two side monitors. Unfortunately, these monitors caused reflective glare on the opposite side window glass which sometimes interfered with the view out the side windows. It appears that this reflective problem may be difficult to solve in conventional cabs. However, the monitors could be moved, adjusted, or shielded to minimize these reflections. Another approach would be to move the monitors to the side headers, which would then eliminate the problem. A driver commented on the brightness of the side displays when a vehicle with headlights on approached. Of course, this glare problem is one that the experimenters and system designers worked with repeatedly. Further refinements would be desirable. A driver suggested a dimmer control, which was already present (brightness/contrast, Figure 57), but was not used during the current experiments so that uniform, nominal conditions would be tested. Another driver indicated that the control box itself (Figure 57) was too bright in terms of its own lighting. Finally, two drivers noted that the rear marker lights on the trailers could not be seen. They indicated that they used these lights to help locate the end of the trailer relative to objects alongside. There were two reasons why these lights were not visible. First, the two fender (side) cameras themselves were not sufficiently far out laterally to allow viewing of these rear marker lights when the tractor and trailer were aligned longitudinally. In addition, the lights were guarded so that they did not appear as a bright source in the cameras when there was a slight angle between the tractor and trailer. However, it should also be said that the rear look-down camera was specifically intended to replace the need to use these marker lights (from the driver's point of view), because the camera was capable of providing high quality clearance/overlap information.

CHAPTER 9. BRIEF OVERALL SUMMARY

This document indicates that a promising approach to an Enhanced Camera/Video Imaging System has been developed and tested in realistic experiments. The system has been configured to have three channels of video, one on each side of the tractor and one looking down from above at the rear of the equipped trailer. This system would use cameras sensitive to both visible and near IR illumination and would be suitable for day or night conditions and for clear or rain conditions. The system would provide color images in daytime and B/W images at night.

The system would use IR LED illuminators in the 940 nm range, which would produce illumination at night, visible only with the video system and not with the unaided eye. Processing would be used to "outline" target objects such as other vehicles. The level of processing would be set but could be adjusted in each direction (that is, more or less processing) by the driver.

Monitors for the two side cameras would be placed at the A-pillars of the tractor, making it possible to view them without great eye travel to and from the conventional side mirrors. (Note that if side mirror reflections become a problem, another location for the two side monitors might be needed.) This location (that is, the A-pillars) would have the advantage of not creating additional blind spots. The monitor for the rear wide-angle look-down camera would be placed in the upper center windshield area of the tractor, similar to that of an interior rearview mirror. All images would be horizontally reversed so that they would appear as familiar mirror images.

Research results reported in this document have shown that in preliminary stationary (but realistic) tests subjects found a one-channel side system to perform satisfactorily (or better) for all conditions tested.

A three-channel system was implemented and was tested on the Virginia Smart Road. Additional target detection/identification tests were also performed at that time. All results were encouraging and indicated that driver performance was better and driver opinion of the Enhanced C/VIS was high. The results of all static and dynamic tests have been positive.

A great deal has been learned in performing this research project. The current report documents these lessons learned. They are also summarized in the remainder of this chapter.

In regard to the indoor static tests, the following principles have been developed:

- Video cameras differ radically in their capabilities, and appropriate cameras must be used. The camera type selected (based on indoor tests) was the Toshiba IK-64DNA. This camera had the correct sensitivity to visible and near IR illumination, it would switch from daytime color to nighttime B/W, and it provided good resolution and image rendition. However, because of its high sensitivity at night it was also sensitive to blooming from headlights. This was partly offset by the fact that the bloom did not bleed horizontally or vertically. Camera output was digitally processed externally to minimize the effect of the bloom. It should be remembered that headlights are extremely bright compared with the nighttime background illuminance level. Thus, any camera sensitive enough to be used at night is quite likely to have the same problem.

- Both visible and near IR LED sources were found or developed that could be used to illuminate dark objects at night with an operating Enhanced C/VIS. Eventually, the near IR sources were implemented in dynamic tests because they produced *no* glare for other drivers and provided adequate illumination. These sources are at 940 nm wavelength and are totally invisible in terms of light output. Appendix A specifies these illuminators and Figure 42 shows how they should be aimed on a typical tractor-trailer. In regard to visible illuminators, these were developed from oval LED arrays with epoxied dispersive lenses. These illuminators work acceptably well, and they have low discomfort glare as determined in the outdoor static tests. Appendix A also provides specifications for these illuminators. However, the choice was made to use near IR illuminators in the final design because they produce no glare. If, however, such illuminators could not be used for a reason that is currently unknown to the investigators, the visible illuminators could still be used. It should be mentioned that the main reason for using illuminators is to illuminate objects at night when there is no other major source of illumination. It should also be reiterated that the IR illuminators do not provide any change or improvement in mirror detection or mirror identification of objects. It is only when they are used with an Enhanced C/VIS that improvements are obtained.

- The three-camera Enhanced C/VIS should consist of the two fender-mounted cameras and a rear wide-angle, look-down camera. C/VIS specifications for the rear camera appear in Appendix B. All cameras should be IK-64DNA or equivalent. The monitors for the three cameras should be at the A-pillars for the fender-mounted cameras and at the approximate rearview mirror position for the rear look-down camera. All images should be reversed horizontally, because drivers are accustomed to mirror images when glancing to the rear using mirrors.

- Driver control of the E-C/VIS should be by means of an IP or wing-panel mounted control similar to that shown in Figures 43 and 57. The driver should have the ability to offset the amount of processing from nominal to a higher or lower weighting. The reset button should reset the processing to the nominal setting. In addition, the driver should have the ability to offset the brightness/contrast to either a higher or lower setting. Again, the reset button should return the system to the nominal setting. It is to be noted that there should be a daytime and a nighttime nominal setting of the monitor brightness and contrast, because the daytime setting will be too bright for nighttime and the nighttime setting will be too dim for daytime. These settings could be determined by cab interior brightness or possibly by the switching of the cameras from daytime to nighttime settings, or vice versa (as depicted in Figure 44). Another important aspect is to get the legend brightness correct for the control itself. If it is too bright, it will create glare for the driver. If it is too dim, it will be difficult to see at night.

- The static outdoor tests using the wind/rain simulator worked quite well and allowed the gathering of opinion data under daytime and nighttime conditions, rain and clear conditions, and different object vehicle positions. The wind machine was developed using an airboat engine and propeller, and combined with rain nozzles and rain towers provided an effective method of simulating rain at highway speeds. The opinion data showed that all of the ratings were at the "moderate" level or above, indicating satisfactory operation of the Enhanced C/VIS camera and system on the passenger side of the heavy vehicle for all conditions tested.

- The static outdoor tests showed that driver ratings of glare produced by the visible illuminators were favorable; that is, the ratings showed the glare to be minimal even during rain and when trying to read the license plate of a vehicle ahead.

- In regard to object detection and identification, objects were correctly detected and identified significantly more often with the Enhanced C/VIS than with mirrors alone. Objects directly behind the heavy vehicle could be detected with the rear wide-angle look-down camera of the Enhanced C/VIS whereas such objects could not be detected with conventional side mirrors. The test conditions were relatively dark, except for the situations involving IR illumination (with which the Enhanced C/VIS functioned effectively). It should be noted that a great advantage of the Enhanced C/VIS in regard to object detection and identification is on the passenger side of the heavy vehicle. On this side of the vehicle the west coast mirror has the narrowest field of view, and both the west coast and convex mirrors are relatively far from the driver. On the other hand, the E-C/VIS monitor is easily viewable. Of course it has already been stated that the rear channel of the E-C/VIS provides the great advantage of detection and identification of objects to the rear.

- An additional finding in regard to object detection and identification was that the Enhanced C/VIS did not generally add to response time. In fact, response times were generally shorter when the system was activated, even though this produced several more sources for the driver to scan. This finding indicates that the improved detection *did not* come at the expense of increased response time.

- In regard to the Smart Road tests, results were also superior with the Enhanced C/VIS operating. These tests were set up using naïve CDL drivers and were intended to examine one of the most critical aspects of operating a heavy vehicle, namely, determination of clearance or overlap with an adjacent-lane vehicle and determination of the amount of clearance or overlap. These aspects are important in avoiding sideswipe crashes that can occur when a heavy vehicle must change lanes. Tests were run at night under rainy and clear conditions, with and without street lighting, for both Baseline (mirrors only) and Enhanced C/VIS conditions. (Note that sufficient daytime tests had been run under the previous contract.) Results demonstrated significant performance improvements both in regard to determining correctness of clearance or overlap and in determining the amount of clearance or overlap. The rear channel of the Enhanced C/VIS was designed specifically to be used to help in locating adjacent lane vehicles and their corresponding positions, as can be seen in Figures 68 through 71. Drivers were able to take advantage of this additional capability under all of the conditions tested.

- Eye glance data taken during the clearance/overlap and distance estimation tasks indicate that drivers relied heavily on the rear wide-angle look-down channel of the E-C/VIS to perform their estimations of when the channel was available. They used this portion of the E-C/VIS even though their side mirrors remained available. These results indicate that they gave preference to the E-C/VIS over their mirrors for the task, a finding that demonstrates the effectiveness of the configuration.

- Drivers tended to use both their side mirrors and their side E-C/VIS channels during the E-C/VIS conditions. This result suggests that drivers found both to be useful. However, use of the rear channel of the E-C/VIS was much more pronounced for the Smart Road tests performed.

- Opinion data taken from the drivers during the Smart Road tests demonstrated high levels of ratings when compared to Baseline. Values were in the numerical range of 7.31 to 7.88 (Figure 99) for the various combinations of driving conditions. These values correspond to "Very Helpful" or better (Appendix D).

- It will be recalled that drivers first performed in the object detection/identification tests and then on the Smart Road in the clearance/overlap and amount of clearance or overlap tests. Once all of these tests were complete, drivers were asked to rate on three additional scales prior to being dismissed. They rated on overall usefulness, whether or not they would like to have an integrated Enhanced C/VIS on their own rig, and whether or not the Enhanced C/VIS improved situation awareness (defined as being aware of the situation along the sides and to the rear of the heavy vehicle). In all three cases, ratings were very high (Figure 100), ranging from 7.75 to 8.13. These average values fall well above the "moderate" level and are in the range of "very" to "extremely" (Appendix D). Thus, acceptance of the Enhanced C/VIS by CDL drivers was very high.

- Finally, drivers provided comments on a lined sheet intended to help with further development. The comments generally reflected problems the investigators had seen previously. However, side glass reflections and lack of marker lights at the rear were problems the investigators had not addressed sufficiently and should be taken into account in any future efforts.

- It should be mentioned once again that the low position of the side cameras on the fenders would prevent small vehicles from going undetected alongside the tractor. This is an important consideration in camera placement and E-C/VIS development. Although fender placement presents some design problems, the fender position should definitely be retained in any future developments. It would be expected that such placement would help in reducing the number of sideswipe crashes; namely, those occurring at the sides of the tractor or front portion of straight trucks.

- Once again, it should be stated that this project resulted in a successful development effort that met performance objectives and also demonstrated good driver opinion ratings. An Enhanced C/VIS is believed to represent a distinct step forward in heavy-vehicle design and safety.

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APPENDIX A. Specifications for the Illuminators Used in the Stationary Outdoor Tests

Near IR Illuminator

Rectangular array with 12 rows and 12 columns. Total count: 140 LEDs (144 with one 2 by 2 corner unpopulated).

Predominant wavelength: 940 nm (determined from tests on an actual unit)

Approximate horizontal beam width: 60 deg

Visible output under nighttime conditions: no visible output

Vendor: DMA, Inc., Dallas, TX, Model No. 15-IL 05

Power requirement per unit: 13.5 v at 380 ma (approx. 5.25 watts)

Side-mounted Visible Illuminator

Composed of an amber (yellow) rectangular LED array base unit with 3 rows and 6 columns. Total count: 18 LEDs.

Base unit vendor: AnythingTruck.com, Model No. 602 YWB

Amber (yellow) dispersive lens epoxied to the base unit.

Lens vendor: Gately Communication Co., Hampton, VA.; Manufacturer: Federal Signal Corp., Model No. Z8573001A-02

Power requirement per unit: 13.5 v at 160 ma (approx. 2.25 watts)

Horizontal beam width: 40 deg

On-axis equivalent illuminance (measured at 8 m): 88.3 cd, with photopic filter in use.

Rear-mounted Visible Illuminator

Composed of a red LED array base unit with 13 LEDs in a 1-2-1-2-1-2-1-2-1 arrangement. The outer two LEDs were not effective with the lens used, leaving 11 effective LEDs.

Base unit vendor: AnythingTruck.com, Model No. 602 R

Red dispersive lens epoxied to base unit.

Lens vendor: Gately Communication Co., Hampton, VA.; Manufacturer: Federal Signal Corp., Model No. Z8573001A-01

Power requirement per unit: 13.5 v at 270 ma (approx. 4 watts).

Horizontal beam width: 40 deg

On-axis equivalent illuminance (measured at 8 m): 60.2 cd, with photopic filter in use.

APPENDIX B. Selected Specifications for the Wide-Angle Look-Down C/VIS Provided in the Final Report Specifications Document Submitted Earlier

Concept Name: Trailer Rear Wide-Angle Multipurpose Look-Down Enhancement

Application: Trailer; cargo box.

Purpose: To provide a multifunction rear view used for the following purposes:

1. To provide a view directly behind the trailer/cargo box, for backing and parking in yard/ urban situations.
2. To provide a view of the traffic situation behind the trailer/cargo box for use in highway driving (note that the view does not go out to the horizon).
3. To provide a view of the adjacent left lane for purposes of showing rear clearance when merging to the left.
4. To provide a view of the adjacent right lane for purposes of showing rear clearance when merging to the right.

Camera location, angle of coverage, and aim direction:
Rear top center of the trailer or cargo box, aimed downward so that the bottom edge of the camera view includes the rear vertical surface of the trailer or cargo box. The camera itself has a 102º (horizontal) F.O.V.

Camera should be in sharp focus for objects ranging from 6 to 80 ft (1.83 to 24.4 m).

Monitor location and approximate size:
Upper center of windshield. Size 2.

Image presentation: Reversed scan.

Backup: Not required.

Image Distortion: Because of the wide-angle lens used with this enhancement, there will be noticeable image distortion appearing on the monitor. However, tests have shown that drivers can use this system for its intended purposes.

APPENDIX C. Rating Scales Used for the Outdoor Stationary Tests

Nighttime Visibility Tests

Illumination:________________

Position: Rear; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>LIGHTS OFF</u>

- How well does this configuration perform in the Nighttime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Illumination:________________

Position: Rear; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>LIGHTS OFF</u>

- How well does this configuration perform in the Nighttime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; <u>Lights ON</u>

- How well does this configuration perform in the Nighttime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Nighttime Discomfort Glare/Discriminability Tests

Position: Extreme Rear, Adjacent Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Rear, Adjacent Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Intermediate, Adjacent Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Near, Adjacent Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Extreme Rear, Adjacent Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Rear, Adjacent Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Intermediate, Adjacent Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY	VERY	MODERATELY	SLIGHTLY	NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT	BY A LARGE AMOUNT	MODERATELY	SLIGHTLY	NOT AT ALL

Position: Near, Adjacent Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward down the road?

How uncomfortable?

EXTREMELY VERY MODERATELY SLIGHTLY NOT AT ALL

- By how much does the lighting on the trailer reduce your ability to discern details in the lead car (for example, ability to read the license plate characters)?

Reduced by how much?

BY AN EXTREME AMOUNT BY A LARGE AMOUNT MODERATELY SLIGHTLY NOT AT ALL

Position: Rear, Same Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward?

How uncomfortable?

EXTREMELY VERY MODERATELY SLIGHTLY NOT AT ALL

Position: Near, Same Lane, Clear, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward?

How uncomfortable?

EXTREMELY VERY MODERATELY SLIGHTLY NOT AT ALL

Position: Rear, Same Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward?

How uncomfortable?

EXTREMELY VERY MODERATELY SLIGHTLY NOT AT ALL

Position: Near, Same Lane, Rain, Nighttime

- How uncomfortable is the lighting on the trailer, assuming you are driving at night and looking forward?

How uncomfortable?

EXTREMELY VERY MODERATELY SLIGHTLY NOT AT ALL

Daytime Visibility Tests

Position: Rear; Lights ON

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; Lights ON

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; Lights ON

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Rear; <u>Lights ON</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>Lights ON</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; <u>Lights ON</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Rear; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime clear weather test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Rear; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Intermediate; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

Position: Near; <u>Lights OFF</u>

- How well does this configuration perform in the Daytime rain test?

NOT AT ALL	POORLY	MODERATELY WELL	QUITE WELL	EXTREMELY WELL

APPENDIX D. Rating Scales Used in the Smart Road Tests

Nomenclature Used in the Following Rating Scales

Enhanced Camera/Video Imaging System (E-C/VIS)

- This is the three-camera/three-monitor system that has been added to the conventional tractor-trailer. A camera is mounted at each fender, aimed back along the sides of the trailer, and one camera is mounted at the back of the trailer, looking downward and outward somewhat. Conventional side mirrors remain available.

Baseline

- This is the conventional tractor-trailer with the E-C/VIS blanked (turned off). Conventional side mirrors remain available.

SMART ROAD EVALUATIONS

How helpful was the Enhanced Camera/Video Imaging System (E-C/VIS) compared to Baseline for the RAIN/STREETLIGHTS ON tests?

How Helpful?

NOT AT ALL HELPFUL	SOMEWHAT HELPFUL	MODERATELY HELPFUL	VERY HELPFUL	EXTREMELY HELPFUL

How helpful was the Enhanced Camera/Video Imaging System (E-C/VIS) compared to Baseline for the RAIN/STREETLIGHTS OFF tests?

How Helpful?

NOT AT ALL HELPFUL	SOMEWHAT HELPFUL	MODERATELY HELPFUL	VERY HELPFUL	EXTREMELY HELPFUL

How helpful was the Enhanced Camera/Video Imaging System (E-C/VIS) compared to Baseline for the CLEAR/STREETLIGHTS ON tests?

How Helpful?

NOT AT ALL HELPFUL	SOMEWHAT HELPFUL	MODERATELY HELPFUL	VERY HELPFUL	EXTREMELY HELPFUL

How helpful was the Enhanced Camera/Video Imaging System (E-C/VIS) compared to Baseline for the CLEAR/STREETLIGHTS OFF tests?

How Helpful?

NOT AT ALL HELPFUL	SOMEWHAT HELPFUL	MODERATELY HELPFUL	VERY HELPFUL	EXTREMELY HELPFUL

FINAL EVALUATIONS

Now that you have completed all of the tests this evening we would like to have your overall opinion regarding the Enhanced Camera/Video Imaging System (E-C/VIS) that was used. Therefore, please fill out the following rating scales and also provide any additional comments you feel would be helpful on the next page.

Considering all of the tests that have been run, how useful do you feel the E-C/VIS is compared with baseline?

How Useful, Overall?

NOT AT ALL USEFUL	SLIGHTLY USEFUL	MODERATELY USEFUL	VERY USEFUL	EXTREMELY USEFUL

Assuming your employer offered to equip your new rig with an E-C/VIS (and assuming there would be no cost to you and that the system was well integrated into the interior), how would you respond?

Your Response?

NOT AT ALL POSITIVE	SLIGHTLY POSITIVE	MODERATELY POSITIVE	VERY POSITIVE	EXTREMELY POSITIVE

Do you feel that the E-C/VIS improves your "situation awareness" (meaning your understanding of what is going on to the sides and rear of your rig)?

Your situation awareness?

NO IMPROVEMENT	SLIGHT IMPROVEMENT	MODERATE IMPROVEMENT	GREAT IMPROVEMENT	EXTREME IMPROVEMENT

Please provide any additional information that you think would be helpful to the researchers working on this project.

Thank you for your participation this evening!

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