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Development of a Performance Specification for Camera/Video Imaging Systems on Heavy Vehicles

Final Report: Supporting Research

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16. Abstract

Video technology has advanced rapidly and is available today at relatively low cost, with relatively high performance and small size. An important potential application for this technology is in heavy vehicles. It can be used to provide views to the driver that were previously unavailable ("enhancements"), and it can also be used to take the place of certain mirrors ("surrogates"). Enhancement applications are directed toward reducing blind spots or allowing better views around the heavy vehicle, whereas surrogate applications are directed toward replacement of essential mirrors. Such mirrors create aerodynamic drag and require the need for external structures. Consequently, there is a desire to replace them with video, if it is feasible to do so.

This research project had the main objective of devising and testing a variety of concepts for the use of camera/video imaging systems (C/VISs) applied to heavy vehicles, with emphasis on tractor trailers but potentially also applying to other heavy vehicles. Part of the objective was to develop operational specifications for feasible C/VISs, which would be supported by the research results. The current report provides an overview of the research conducted to support the final specifications which are provided in a companion document (Wierwille, Schaudt, Gupta, Spaulding, & Hanowski, 2007).

The current report reviews all of the work performed. Earlier topics covered in summary in the report include: review of video technology, identification of viewing needs, development of candidate use concepts, conducting a driver focus group, and preparation of initial specifications. Later topics included experimentation; specifically, the following were carried out: preliminary road testing of various C/VISs, preparation and performance of formal road testing, analysis of all results, and documentation of the entire project. Both the earlier and later topics are covered in the current report and form the justification for the final specifications document.

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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)

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ABBREVIATIONS AND NOMENCLATURE

accommodation: the process by which the human eye changes the shape of the lens of the eye to obtain optical focus of the image on the retina

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

ambinocular view: a view that is seen by either eye or both eyes; the total view

ANOVA: analysis of variance (a statistical analysis technique)

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: the heavy vehicle configured without the C/VIS under test

binocular disparity: the relative displacement laterally of images on the retinae of the two eyes because the eyes are displaced laterally from one another in human beings

cab-over: a design of road tractor in which the driver and passenger sit over the engine compartment

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

CB: citizen's band or citizen's band radio transceiver

CDL: commercial vehicle driver's license

CIE: International Commission on Illumination

Cochran Q: a type of nonparametric statistical test

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

confederate automobile: an automobile driven by a co-experimenter or confederate during an experiment; such an automobile provides necessary support for the desired scenario

counterbalance: a technique used in behavioral research experiments to control for learning, fatigue, and time of task

CRT: cathode ray tube

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

deg; °: angular unit of measurement, degree

DGPS: differential GPS, differential global positioning system

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

eyellipse: the locus of eye positions for drivers of various heights and corresponding seating positions

fisheye lens: an extreme wide-angle lens that produces substantial field distortion

FMCSA: Federal Motor Carrier Safety Administration

FMVSS §571.111; CFR §571.111; §571.111: a section of the U.S. Code of Federal Regulations dealing with road vehicle mirrors

FOV: angular field of view

Friedman: a type of nonparametric statistical test

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

interlace: in video systems, a method of reducing flicker by sequentially generating every other line of a reproduced scene and then sequentially generating the lines in between

Kruskal-Wallace: a type of nonparametric statistical test

LCD: liquid crystal display

Mann-Whitney: a type of nonparametric statistical test

NHTSA: National Highway Traffic Safety Administration

NTSC: National Television Standards Committee

occlusion: the blocking of light from an object by an opaque object nearer the viewer

on-road; over-the-road: a term implying operating at highway speeds

pixilation: the replacement of individual pixels (points) in a video scene by larger blocks, because of slow data transfer

post hoc test: a statistical test performed after the main tests, used to further specify significant differences

RF: radio frequency

SAE: Society of Automotive Engineers (SAE, Inc.)

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

Task A: a group of subtasks performed on-road

Task B: a group of subtasks performed in a yard environment (backing, primarily)

TMC: Technology and Maintenance Council

t-test: a statistical analysis technique

Tukey; Tukey HSD/multiple comparisons: a post hoc statistical test used to further define where significant differences are occurring

USPTO: U.S. Patent and Trademark Office

VTTI: Virginia Tech Transportation Institute

west coast mirror: a flat, elongated mirror used on the side of a heavy vehicle; usually, this mirror is approximately 6 in (15.2 cm) wide by approximately 14 in (35.6 cm) long.

Wilcoxon: a type of nonparametric statistical test

yard/urban: a term used to describe backing and sharp turn maneuvering

ABSTRACT

Video technology has advanced rapidly and is available today at relatively low cost, with relatively high performance and small size. An important potential application for this technology is in heavy vehicles. It can be used to provide views to the driver that were previously unavailable (“enhancements”), and it can also be used to take the place of certain mirrors (“surrogates”). Enhancement applications are directed toward reducing blind spots or allowing better views around the heavy vehicle, whereas surrogate applications are directed toward replacement of essential mirrors. Such mirrors create aerodynamic drag and require the need for external structures. Consequently, there is a desire to replace them with video, if it is feasible to do so.

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This research was conducted under two NHTSA contracts: DTNH22-00-C-07007, Task Order No. 18, Track 2; and DTNH22-05-D-01019, Task Order No. 5, Track 2. Earlier tasks were completed under the former contract, and later tasks were completed under the latter contract. Funding for the project was provided jointly by NHTSA and FMCSA.

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CHAPTER 1: INTRODUCTION

PROJECT BACKGROUND

Video technology has advanced rapidly in recent years. The transformation of electronics to solid-state and the use of integrated circuits has brought with it great benefits for both consumer and industrial applications. Video technology that was once expensive, bulky, and power consuming has now become relatively inexpensive, compact, and low in power consumption. Meanwhile, capabilities have increased with regard to resolution, dynamic range, color, and reliability.

Video technology is fundamentally a method of providing dynamic remote views and can be used for diverse applications in closed-circuit, broadcast, cable, and satellite television. Because of its availability and affordability, video is beginning to be applied to vehicles to provide views that are otherwise not easily available. For example, in ground transportation, some new vans and sport utility vehicles have video options that allow drivers to view the blind spot directly behind the vehicle.

Heavy vehicles could potentially take greater advantage of video to reduce blind spots, to add views that are difficult for the driver to obtain, or to replace existing mirrors. In fact, this process has already started, with manufacturers offering options for blind-spot coverage of various kinds. It is expected that there will be an ever-increasing use of video to provide various views for the driver. These uses have the potential of making heavy-vehicle driving safer by reducing the uncertainties that exist in the vehicle's interactions with other vehicles, as well as with pedestrians and obstructions.

Video also offers the possibility of providing different camera vantage points and of allowing small reductions in aerodynamic drag that occur when using mirror replacements that do not protrude into the air stream around the vehicle. In fact, video offers a great deal of flexibility in design, suggesting that certain conventions may be needed.

Heavy-vehicle manufacturers are very likely to increase their use of video systems in the near future. These systems have the marketing advantage of making the driver's job easier. Moreover, as stated, video is now relatively inexpensive. Manufacturers are in great competition with one another, and low-cost options are one way of distinguishing a product from that of a competitor. The desire to streamline vehicles may also provide an impetus for manufacturers to replace existing mirror systems with video, resulting in a "cleaner" appearance and slightly better fuel mileage.

In this report, close-circuit video systems used on heavy vehicles are referred to as Camera/Video Imaging Systems. It is assumed that such systems would be used to either take the place of mirrors or to provide additional views which would reduce or eliminate blind spots.

Manufacturers have been quite responsible in making vehicles that are safe and durable; therefore, one would expect that if and when various C/VISs are added, the manufacturers will attempt to make the systems safe and reliable. However, in the absence of minimum conventions and specifications, it is quite likely that each manufacturer will find different solutions for the use of video, resulting in variation from vehicle to vehicle. Some variation may be desirable, in that novel uses may be developed. However, more conventional uses should be standardized so that a driver entering a new or different vehicle will not have to encounter unorthodox video systems to obtain standard, needed views when driving. Driver expectancy, therefore, plays an important role in video replacement for mirrors as well as in the addition of needed views. Based on interviews with cognizant personnel, it appears that manufacturers would welcome guidelines and conventions for these situations.

This project was undertaken with the objective of developing minimal specifications for the use of C/VISs. Such specifications must be application-specific, particularly in regard to the use of video mirror replacements, which hereafter will be called surrogates. Locations of cameras and monitors are clearly application-specific and must be designed for each given application. In the research reported here, the position is taken that there are general specifications that apply to a variety of applications, and there are also more detailed specifications that are needed for each given application. Thus, application type must be carefully considered when evolving any specification.

This project has been justified on the basis that, in the absence of eventual minimal specifications, drivers may encounter a wide variety of video systems in the future, and these systems might vary widely depending on the type of application and type of configuration. It is important to take advantage of driver expectancies and to try to standardize display locations, particularly for mirror surrogates and, possibly, for additional enhancements. It is also important to standardize the views that are seen on displays.

FINAL REPORT AS JUSTIFICATION FOR THE FINAL SPECIFICATIONS

This final report provides an overview of the research that was completed in support of the final specifications. The specifications appear in a separate document (Wierwille, Schaudt, Gupta, Spaulding, & Hanowski, 2007). The reader should understand that the fundamental purpose of this final report is to accompany the specifications document, so that the research leading to the specifications can be reviewed.

TECHNICAL DEFINITIONS OF SURROGATES AND ENHANCEMENTS

The use of video in heavy vehicles can be divided into two major applications categories: mirror surrogates (or, simply, surrogates) and enhancements. A surrogate is a video system in which one of the four basic mirrors usually found on the sides of a heavy vehicle is replaced by a video system (Figure 1). The four basic mirrors are the two flat (west coast) mirrors (one on each side) and the two convex mirrors (one on each side). Each system is intended to take the place of the mirror and is expected to be used routinely while the heavy vehicle is in operation. An enhancement is a video system that is designed either to (a) supplement the four basic side mirrors, (b) take the place of some other mirror or mirrors found on at least some heavy vehicles, or (c), add a view not otherwise available to the driver. Note that replacement of a mirror other than one of the four basic mirrors with a video system would be considered to be an enhancement. It should be noted that these are the final definitions of surrogates and enhancements. Earlier definitions (found in previous project documents) were slightly different. One of the most important questions to be answered in this research was whether or not surrogates (as defined in the present document) provide sufficient views and whether they should be permitted on heavy vehicles, recognizing that basic mirrors would then not be used.

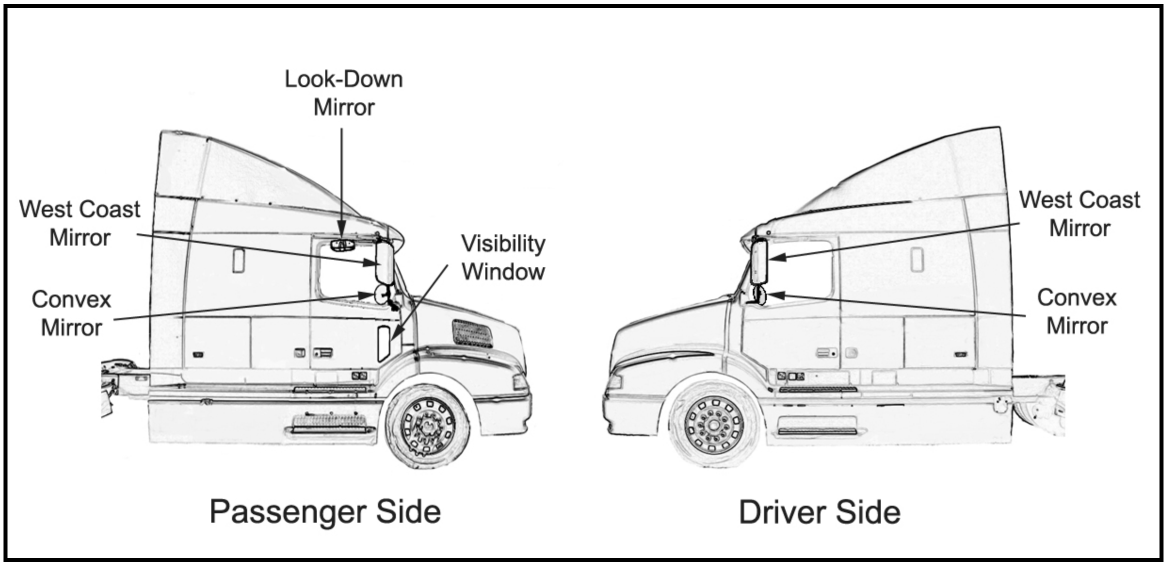

Figure 1. Standard mirror complement.

There is another way of distinguishing surrogates from enhancements. If a surrogate were to fail, an essential side view would not be available, thus compromising safe driving. On the other hand, if an enhancement were to fail, views would still be available to allow the heavy vehicle to be driven. Therefore, the heavy vehicle on which the enhancement is installed could still be driven reasonably safely, even though the driver may have a somewhat more difficult and, possibly, less efficient time doing so.

The terms surrogates and enhancements have been defined based largely on reliability aspects. Failure of a video system that replaces an essential mirror means that the heavy vehicle is not safe to drive in traffic. On the other hand, failure of a video system that serves as an enhancement means that the vehicle could still be driven reasonably safely, although perhaps inconveniently. In addition, any video system operating as a surrogate should provide essentially the same information to the driver as the corresponding mirror.

MAJOR PROJECT STEPS

This multiyear project included several major steps, with the goal of providing a final set of operating specifications for C/VISs, with appropriate justification. These steps are shown in Figure 2. In general, the steps were performed sequentially. The steps are briefly reviewed here to provide the reader with a general understanding of how the project was conducted.

This project was initiated under one contract (DTNH22-00-C-07007, Task Order 18) and completed under another contract (DTNH22-05-D-01019, Task Order 5). There was a seven-month cessation of project activity (between October 1, 2005, and April 30, 2006) as a result of funding exigencies at NHTSA. This cessation occurred through no fault of the task order manager at NHTSA or the contract team at VTTI. In the following outline of project steps, and throughout this final report for that matter, the project is described in terms of the order in which goals were accomplished.

Initially, a project work plan was developed (Wierwille, Spaulding, Hanowski, Koepfle, & Olson, 2003). This work plan contained a review of existing and near future camera systems (Figure 2). It also included an analysis of viewing needs and a variety of suggested concepts intended to satisfy these needs. On approval of the work plan, a heavy-vehicle drivers' focus group was convened for the purpose of reviewing and revising the various concepts. A report was then submitted on the focus group results as well as the revised concepts (Wierwille, Spaulding, Koepfle, & Hanowski, 2004).

Once the final description and listing of concepts was available, work began on the preliminary specifications (Wierwille, Spaulding, & Hanowski, 2004). The objective was to provide as many details in regard to each concept as possible, with the idea of obtaining a better grasp of the needs for experimentation. In particular, the writing of the preliminary specifications made clear where reasonable assumptions could be made and where experimental work needed to be done. Thus, the specifications pointed the way toward the experimental investigations that needed to be undertaken.

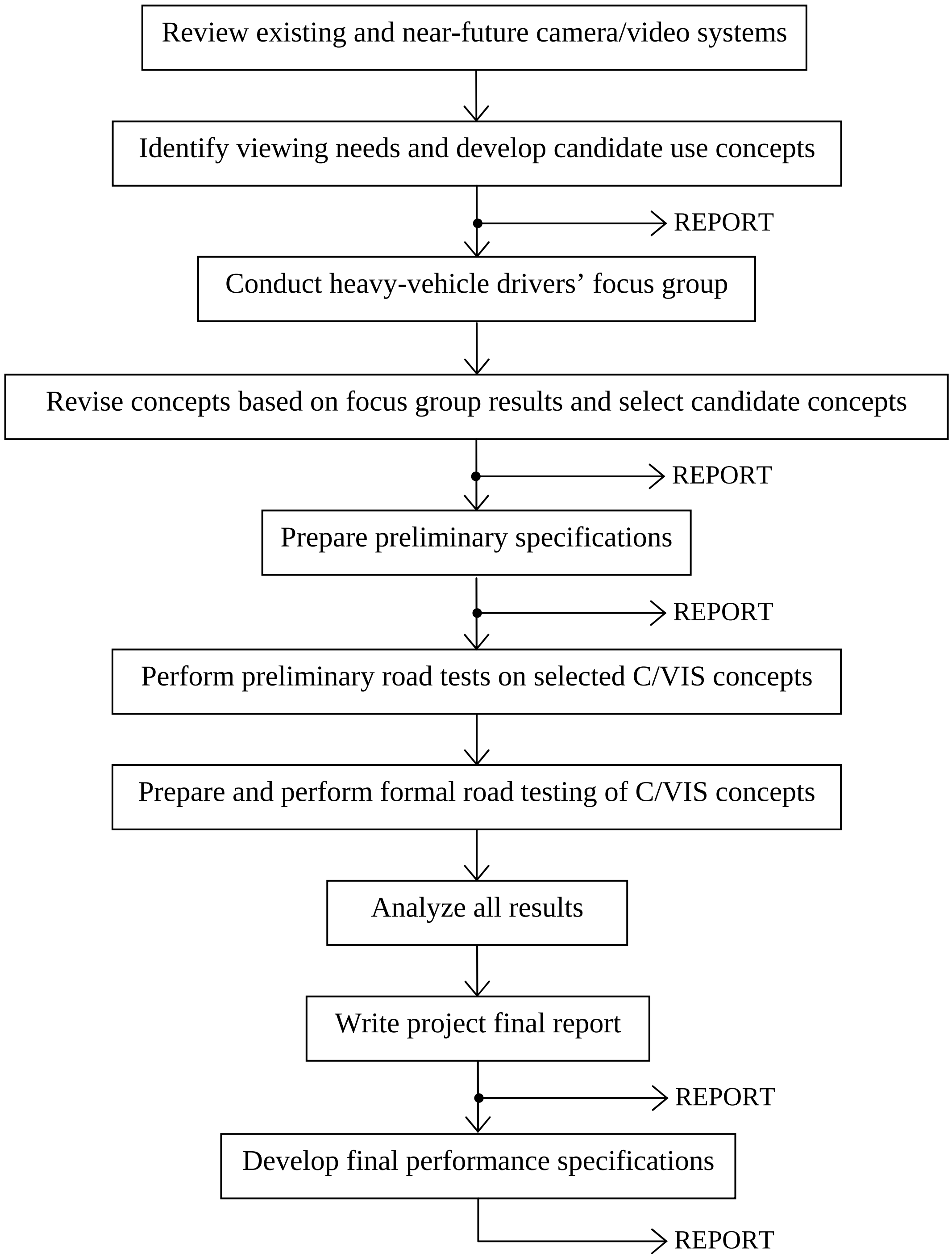

Figure 2. Flow diagram of the project.

On-road experimental plans were developed. Both a preliminary set of tests and a formal set of tests were performed. The preliminary tests were of a developmental nature. They employed usability testing methods in which VTTI's licensed heavy-vehicle drivers used various configurations to determine if changes were needed and to determine if the configurations were helpful. Numerous variations were tried in an effort to optimize configurations. Of course, this set of tests required preliminary equipment setups so that testing could be done. Consequently, while these tests were preliminary, they were quite complex and provided important results. The preliminary tests have not been reported previously and are presented in this final report for the first time.

The formal on road tests were performed using naive licensed heavy-vehicle drivers. In all, 24 drivers performed in the tests and also provided opinion data. The tests were divided into three groups with 8 drivers in each group. Knowledge gained from the *preliminary* tests was used in developing the final configurations for the formal tests. This final report documents the formal tests for the first time. One chapter is devoted to a description of the final tests and the following chapters are devoted to presentation of the results.

The final aspects of the project were the completion of this final report and the writing of the final specifications. This final report is intended to support the final specifications, as was mentioned earlier. The specifications are in an accompanying document (Wierwille, Schaudt, Gupta, Spaulding, & Hanowski, 2007).

This final report summarizes the work that has been documented in previous reports and then provides more detail for the work that has not been previously documented. Readers requiring detailed information on the earlier stages of the project should obtain copies of the earlier reports. However, the latter aspects of the work are most directly relevant in regard to development of the final specifications and, as indicated, are documented in this final report.

CHAPTER 2: IDENTIFICATION OF HUMAN FACTORS ISSUES RELEVANT TO VIDEO IN HEAVY VEHICLES

MIRROR REGULATIONS AND RECOMMENDED PRACTICES FOR HEAVY TRUCKS

There are no known regulations or recommended practices regarding C/VISs. Consequently there is nothing to report in this subject area. However, there are regulations and recommended practices for mirrors on heavy vehicles. These are briefly reviewed and provide some insight into important viewing matters.

Regulations

FMVSS §571.111

This safety standard was developed to stipulate requirements for the location and operation of rearview mirrors. The standard defines several terms to help the reader understand matters associated with the topic. The terms defined include the following:

- Convex Mirror – a mirror having a curved reflective surface whose shape is the same as that of the exterior surface of a sphere,
- Effective Mirror Surface – the portion of a mirror that reflects images, excluding the mirror rim or mounting brackets, and
- Unit Magnification Mirror – a planar or flat mirror with a reflective surface through which the angular height and width of the image of an object is equal to the angular height and width of the object when viewed directly at the same distance except for flaws that do not exceed normal manufacturing tolerances.

A tractor trailer with a gross vehicle weight rating (GVWR) of 11,340 kg or more must have outside mirrors of unit magnification with 323 cm^2 or more of reflective surface. These mirrors are to be mounted on both sides of the cab of the truck with permanent, fixed, supporting devices. The mirrors should be adjusted both horizontally and vertically so that the driver can see the truck along the inner sides of the driver and passenger-side mirrors and has a representative view of the rearward area in the rest of the mirror.

The construction of the mirrors used on the truck must be specific as well. All single-reflectance mirrors must have an average reflectance of 35 percent or more. If the vehicle employs a day-night adjustable rearview mirror, then the day mode must have an average reflectance of at least 35 percent, and the night mode of the same mirror must have an average reflectance of at least 4 percent. If there is an electronic multiple-reflectance mirror on the truck and this mirror were to have an electrical failure, the mirror must either be able to adjust itself to a reflectance of at least 35 percent, or the driver needs to be able to adjust the mirror to the same specifications.

SAE Standards

There are several SAE "J Standards" that pertain to rearview mirrors, visual behavior, and the truck viewing environment. Below is a description of those that are most pertinent for the current project.

SAE J985 – Vision Factors Considerations in Rearview Mirror Design

This document defines the driver's field-of-view (FOV) in the horizontal and vertical planes and discusses the perceptual characteristics of the eyes and how such characteristics affect visual performance. The highlights of this standard include the following:

- The monocular FOV in a horizontal plane from either eye is approximately 150º while the combination of the left and the right eyes' fields-of-view creates a binocular FOV of approximately 120º. The FOV in the vertical plane is between 50-55º above and 60-70º below the horizontal plane.
- Optimal horizontal eye rotation is 15º to either side of the forward line of sight. The forward line of sight is the same as the longitudinal axis that runs through the truck. Acceptable eye rotation in the horizontal direction can be as much as 30º to the left and right of the forward line-of-sight. Optimal vertical eye rotation is 15º up and 15º down from the forward line-of-sight. The maximum vertical eye rotation is 45º up from the line-of-sight and 65º down.
- Easy and maximum horizontal head movements are 45º and 60º, respectively, in either direction from the forward line-of-sight. Easy vertical head movements are defined as 30º up and down, and the maximum vertical head movement is 50º in both directions. Therefore, with head and eye movements combined, optimal viewing takes place 60º to the left and right and 45º up and down from the forward line-of-sight. A rear-vision mirror would be easiest to use if located within these parameter ranges.
- The farther a mirror is placed away from the forward line of sight, the smaller the FOV becomes, making it more difficult to accurately perceive the scene. Having a mirror closer to the forward line of sight results in a larger and more easily perceivable image of the rear environment and a reduced reaction time for the driver. Moreover, the mirror should be mounted so that it is within the optimum viewing area (as previously described) such that it is not occluded by the upper and lower edges of the combined head and eye movements.
- Mirrors should have the highest amount of reflectance possible in order to be as close as possible to the brightness of the front view. This will reduce the amount of adjustment that the driver's eyes have to achieve when switching from one scene to another, thereby decreasing viewing time.
- Glare should be reduced as much as possible or completely eliminated so that view to the front and the rear is obstructed as little as possible and so that no undue irritation or fatigue is imposed on the driver. This can be obtained through the use of a low-light transmittance function on the mirrors or by moving the mirror farther away from the forward line of sight.

SAE J1750 – Describing and Evaluating the Truck Driver's Viewing Environment

This standard establishes two different methods for determining the truck driver's viewing environment: the Polar Plot and the Horizontal Planar Projection. Both are based on the "eyellipse," a combination of the words "eye" and "ellipse" to signify that the driver's eye location range is elliptical in shape. Also, both create monocular representations of the environment but can be combined to form binocular or ambinocular views (an ambinocular view is one that is seen by either one or both eyes, that is, the total view).

Recommended Practices Documents

Two recommended practices pertaining to proper mirror adjustment were found in the course of the literature review. The two practices are: (a) the Technology and Maintenance Council Mirror Positioning and Aiming Guidelines and (b) the Liberty Mutual Mirror Check Station. These two recommended practices are described in the following section.

Technology and Maintenance Council

There are two recommended practices outlined by the TMC that are relevant for this project: mounting and aiming.

In regard to mounting, west coast (planar) mirrors should be mounted so that the inner edge of the mirror is at least one inch outside of the widest part of the truck and trailer. The FOV of the primary mirrors should in no way be obstructed by any part of the truck, the trailer, or the cargo, and the view of the mirror should not be blocked by any hardware in the cab of the truck. For trucks with wide loads, the mirrors should be set farther outboard and mounted on extension brackets. If a truck will be carrying various types of loads, the west coast mirrors should be placed so that the inner edges of both mirrors are 104 inches apart or more and located between two imaginary lines; the first line is a line that runs parallel to the truck and is one inch out from the widest section, and the second line should be tangent to the body of the truck.

Convex mirrors, both spherical and aspheric, should be mounted just below the west coast mirrors so that the entire mirror is visible through the window and outboard of the widest part of the truck or trailer. If the convex mirror is blocked in any way, it may be shifted up so that it partially covers the west coast mirror. Aspheric mirrors must be used with slightly greater precaution than the convex mirrors. Aspheric mirrors are designed for either the left or the right side of the truck, and care should be taken to see that the appropriate mirror is mounted to the appropriate side of the truck. (Current authors' note: neither convex nor aspheric mirrors are required by Federal regulations for heavy vehicles.)

Fender mirrors need to be mounted on the hood or fender of the cab in such a way that vibration of the mirrors is at a minimum. Look-down mirrors should be attached to the top of the passenger-side door and look-forward mirrors should be mounted to manufacturer’s specifications and so that they do not block any of the other mirrors or create additional blind spots.

In regard to aiming, all mirrors should be aimed such that the widest part of the tractor trailer can be seen along the inside edge of the mirror and can, thus, be used as a reference point. They should also always be positioned so that the FOV is at a maximum and the blind spots are at a minimum.

Convex mirrors should be aimed so they not only show traffic in adjacent lanes but also provide a view of the trailer and the wheels of the trailer. A typical trailer forms a 68º angle from the truck when making a 90º turn; therefore, the convex mirrors should be aimed so that no less than 70º can be seen outward from an imaginary line bisecting the cab of the truck.

The other auxiliary mirrors should be aimed according to manufacturer's standards and so that as much as possible of the adjacent lanes is visible in the mirrors. Fender-mounted mirrors should be positioned so that the driver can quickly scan at least one lane on either side of the truck with ease. Look-down mirrors should be aimed to include part of the side of the cab as a reference point instead of the trailer.

Motorized mirrors simplify aiming for the drivers. The aim of both single- and dual-axis mirrors can be altered to view different parts of the truck, trailer, and other traffic while the truck is in motion.

Liberty Mutual Insurance Company

According to a Liberty Mutual document (Money, 2000), 29 percent of commercial-vehicle accidents occur in three different scenarios: side-swiping, backing, and pulling forward from a parking place. These accidents are often the result of inadequately placed or poorly aimed mirrors. When selecting mirrors, commercial-vehicle manufacturers and drivers should use a system of both flat and convex mirrors.

Flat mirrors provide narrow reflected vision width and very long (the entire extent of the driver's line of sight) reflected vision length, both of which are undistorted fields-of-view. Convex mirrors present a wider FOV, but the image is somewhat distorted (actually minified), even more so as the radius of the mirror decreases in size. When slightly overlapped, these two types of mirrors produce a viewing environment that includes objects next to and around the truck, as well as ones that are to the rear of the truck or in the distance.

However, even with a two-mirror system, blind areas around the front of the truck still exist. Liberty Mutual suggests that a fender-mounted mirror be placed on the truck, especially on the right side, in order to reduce blind spots as much as possible. Before doing this, the driver or manufacturer should consider the configuration and dimensions of all of the windows present in the cab in addition to the position of the driver's seat. This will ensure that the mirrors are not blocked by any of the structural parts of the truck; if they are, the seat could be repositioned in order to remedy the problem.

Other key points that the drivers and manufacturers should consider include the following (Money, 2000):

- The mirrors should provide a clear view to the rear and both sides of the tractor trailer.
- The complete surface of each mirror should be able to be seen by the driver.
- The dimensions of the windows dictate the minimum distance needed between the left and right-side mirrors. If spaced correctly, the driver can eliminate certain blind spots. This can be limited by the length of the mounting brackets. If they are too short, the driver may end up with a blind spot regardless of his or her intentions (p. 22).

Liberty Mutual recommends that each truck company establish a mirror-adjustment station. Each station would be located on a large flat surface with various boxes and lines painted on the ground to help with the aiming process. When this is not feasible, drivers should always adjust their own mirrors. It is noted that the mirrors should be positioned so that their viewing area is as large as possible, and not so that the driver is comfortable.

Summary Regarding Mirror Regulations and Recommended Practices

These regulations and recommended practices indicate that mirror placement, aiming, shape, and driver use are important topics that are known to affect roadway safety. They further indicate that care must be taken in development of new viewing concepts, since driver workload and driver vision can be heavily influenced by various design aspects.

CURRENT C/VIS WORK

For the current research effort, researchers visited a heavy-truck manufacturer and the SAE Truck and Bus meeting and exhibition in an effort to determine the status of current C/VIS use in practice. Presently, use of C/VISs is limited to enhancement applications. Cameras being used are wide-angle cameras that provide a view similar to that of a convex mirror. Use of these systems is targeted primarily at blind areas, such as in the vicinity of the right front fender or the rear of the truck. In addition, to address current visibility concerns in heavy trucks, the SAE Human Factors subcommittee is currently conducting a review of the SAE standard J1750 for content and validity.

PATENT RESEARCH OVERVIEW

The United States Patent and Trademark Office Web site (http://www.uspto.gov/) was searched for existing concepts and systems pertaining to indirect visibility systems. The terms searched were: “truck and camera,” “truck and back assist,” “truck and mirror,” and “bus and camera.” The methodology behind the terms searched was to consider patented concepts directly related to, or relevant to, heavy vehicles. The results of this search were used to create a summary of patented concepts specifically directed toward heavy vehicles.

Many different system concepts for indirect visibility around heavy vehicles have been developed. In fact, the idea of a C/VIS for heavy vehicles is not new, and the patents searched contain dates filed as far back as 1978. Most of the concepts, however, were filed in more recent years (44 of 53 between 1996 and 2001). Search results included not only camera visibility concepts, but also advanced technology incorporations, such as distance tracking, radar, collision avoidance, and head-up displays.

Many of the conceptual systems involved indirect visibility enhancement to the rear of the vehicle for the purposes of backing tasks or parking. Some systems did not specify a particular location; rather, the purpose was simply to enhance visibility. There were also some system concepts intended for-side vision enhancement. Other assistive technologies, such as object detection, were uncovered.

Appendix B of Wierwille et al. (2003) contains a list of patents identified as pertaining to camera-based indirect visibility systems for heavy vehicles that were identified in the search. Listed in that appendix are the patent number, the inventor, date filed, title, and an abstract describing the concept system.

HUMAN FACTORS CONCERNS AND COMPARISON OF MIRRORS TO C/VISS

The primary goal of an indirect visibility system is to provide a driver with enhanced visibility that reduces the likelihood of a collision. An imaging system designed to accompany and enhance a mirror system, or to completely replace a mirror system, would have a similar goal. A minimal requirement of a surrogate or enhancement system is to ensure that the frequency or severity of collisions is no greater than that resulting from the current mirror system.

Viewing conditions in current mirror systems on large vehicles are limited to the quality and size of the reflective surface. When a camera and monitor system are incorporated into the existing system, or are used to replace it entirely, viewing conditions are affected by a different set of factors. For example, viewing conditions for a camera-based imaging system are limited by the quality of the lens/optics system, camera technology, image quality, and a variety of other factors. This new system must be at least comparable in terms of "quality" to the existing mirror system if it is to replace the mirror system.

Mirror versus Camera System Comparisons

An existing mirror system and a camera imaging system are similar in terms of the intended goal, which is to reduce driver blind spots around the vehicle. Camera systems are more complex than mirrors, involve many more components, and may be more susceptible to failure than existing mirror systems. Unlike current mirror systems, camera systems could potentially provide expanded viewing areas, better visibility in adverse viewing conditions, and new views not possible with mirrors. Nonetheless, incorporating a new and more complex system into an already-complex operating environment would likely affect human performance and human system interaction. If not properly taken into account, camera systems, greater complexity, more viewing monitors, and other human factors considerations may result in poorer performance and a greater susceptibility to crashes than using the existing mirror system.

A mirror simply reflects an image of an object or scene. Although each eye sees a different image, three-dimensional aspects still are preserved in a mirror. A conventional video image, on other hand, is a purely two-dimensional representation of the captured three-dimensional scene. Therefore, one could infer that there will be performance and compatibility issues when using this two-dimensional representation.

Federal Register Vol. 68, No. 14 (Office of the Federal Register, 2002) states that camera systems could provide the operator of the vehicle with views not previously possible with mirrors, thus increasing the visibility around the vehicle. Furthermore, the incorporation of filters and electronic effects into a video system could reduce visual degradations and obstructions caused by poorly lit viewing environments, or by environments clouded by debris or particulate. Whereas mirror systems may provide the viewer with a more mentally compatible image, video systems could potentially increase the range of visibility.

Environmental Concerns and Reliability

Visibility in Poor Weather

Both mirror systems and video systems can be affected by debris and particulate accumulation. Mirrors can become fogged or frozen, and lens protective glasses may have the same problem.

Current camera systems can be susceptible to image degradation in viewing conditions where many moving particles are clouding the FOV (e.g., in a snow storm). Auto-focus mechanisms in some cameras may refocus on falling particles rather than on the intended region, or they may simply lock up if highly dynamic material exists throughout the extent of the focal range (Ray, 1992).

Contamination, or even condensation, on the surface of the lens or the transparent housing in front of the lens could create critical deficiencies in the viewing environment by obstructing, distorting, or blurring the viewing area. In an event such as this, information gleaned through the system may not be of sufficient quality to be readily usable, or it may be lacking in critical detail.

Operating Temperature Range

Many electronic components are very climate sensitive and are susceptible to failure in extreme hot or cold climate conditions. Camera and display electronics may likely have to operate in an extreme temperature range (approximately -20ºF to 120ºF, depending upon the driving environment) without susceptibility to failure. An example of such a failure would be LCDs exhibiting a reduction in image contrast because of the liquid crystals solidifying. Lueder (2001) describes LCDs as thermotropic (phase changing with temperature), and consequently becoming potentially inoperative at low temperatures. However, all of the electronic components in a camera visibility system would require a relatively wide operating temperature range. Thus, it may be necessary to determine an acceptable temperature range of operation for electronic components or to provide heating or cooling at the ends of the range.

Vibration of Truck and Camera

Heavy vehicles vibrate quite extensively while in operation, causing anything mounted to the truck to vibrate as well. According to Rawicz and Jiang (1992), 30 to 40 resonant vibration modes, including rigid body, tire, axle-hop, and frame, are present below 25 Hz. C/VISs can be susceptible to damage from extensive vibration or shock due to bouncing or driving over roadway imperfections. Furthermore, displays are often as delicate as camera systems and are equally susceptible to damage from shock or vibration.

Vibration could also disrupt or degrade the quality of the displayed image. Widdel and Post (1992) state that instances of vibration can obviously result in a displayed image being blurred. Furthermore, vibration at a frequency similar to that of flicker (for interlaced image displays) or refresh rate could result in a "strobe" effect. However, this is also true for mirror systems in that images are often distorted or unclear because of vibration. Although it may not be possible to fully stabilize the image in the event of bouncing or driving on rough surfaces, it may be possible to design countermeasures, either electronically or mechanically, that reduce vibration in a camera system to an acceptable level.

Back-up in Event of System Failure

Although a mirror can break or be damaged such that it is rendered useless, it will not fail if there is an electronic failure or power failure. However, a camera imaging system contains many parts and many powered components. According to Federal Register Vol. 68, No. 14, problems associated with electronic failure are critical and must be addressed. The use of certain technologies has been prohibited due to the lack of a reliable fail-safe mode or an immediate replacement system. Federal Register Vol. 68, No. 14 addresses the issues of reliability by asking, "Would a failure of a video-based system be acceptable, should they contain a failure alert or warning, and should there be a back-up system?" Countermeasures for failure could be incorporated in any design.

The life of the potential system may need to be determined when considering time between failures. All systems have a certain life cycle that is intended to predict how long a developed system is expected to last (Chapanis, 1996). It is currently unknown how long these camera imaging systems should last, how often they should be maintained, and when they should be replaced. Acute system failure may be completely random; however, an average known lifespan of a typical system may help to determine the likelihood of system failure.

Imaging Concerns

Camera and Monitor Location

Camera placement

Camera position is very important when considering operator performance. Placement of the cameras in a video imaging system could be critical to safe use. As previously discussed, current standards and recommended practices provide information on the mounting and aiming of mirrors. For surrogate systems, camera placement must be comparable to the views obtained from the existing system in order for performance to be comparable. Although camera placement is less restrictive than mirror placement, and view points not previously available could be achieved, cameras must be placed such that the intended FOV in regard to viewer expectation is achieved. This issue is discussed in detail later in the current report.

One very important factor to consider is driver expectation; that is, what the driver expects to see in the monitor. For example, a standard mirror system allows the driver to view the left side of the heavy vehicle when looking into the left rearview mirror. Camera position should correspond to the driver's expectations of what is supposed to be seen, including a reversed image as provided by the mirror. As stated earlier, there are currently no regulations or recommended practices established for camera placement.

Unlike a mirror, a camera could be placed nearly anywhere on the vehicle, thus allowing great freedom in design. Brandt and Jamieson (1989) briefly examined a conceptual video-based imaging system for a light vehicle. The use of three indirect visibility cameras located at the rear of a car is intended to provide replacements for both the left and right-side mirrors and the center rearview mirror. However, a heavy vehicle is much larger, and the blind areas can extend around the vehicle including, specifically, the right front of the vehicle (Flannagan, Reed, Owens, Lehto Way, & Blower, 2003). It may also be important to consider how many cameras should be used to achieve an optimum level of usability. Too few cameras may result in improper visibility and large blind spots, whereas too many cameras may result in confusion such that critical viewpoints are cluttered by less important views.

Image reversal

Unlike a mirror image, an image captured by a camera is not ordinarily reversed. When a driver looks into a mirror, everything the driver sees is horizontally reversed. Conversely, a camera system would display an actual image from the viewpoint of the camera. Although both images may be of high quality, the expectation of the image layout by the driver is an important consideration. Ware (2000) states that motion viewed from the wrong, or misrepresentative, viewpoint can lead to disorientation. This could be critical to a driving task. It is probable that video systems used as surrogates should use reverse imaging to avoid problems. However, additional views may or may not need to be reversed, depending on the application.

Monitor placement

Similar to camera placement, monitor placement is relatively unconstrained as compared to a mirror. The mirror serves as the display for the current system, and its visibility is dependent entirely upon the mirror's location, which can limit the placement of the display. According to previously mentioned standards and recommended practices, there is a fixed-position location for the mirrors. However, a video display could conceivably be located almost anywhere. Display location presents another human factors concern, especially in regard to driver performance. Display location and size are examined in further detail in the current report.

Display location involves issues of possible distraction. The Federal Register Vol. 68, No. 14, states that placement of the displays in an area more centrally located on the instrument panel could lead to performance degradation and confusion while driving. Also, Brandt and Jamieson (1989) located the right- and left-side mirror surrogate displays on the right and left ends of the instrument panel closest to a relative location for the side mirrors. It follows that it is the natural tendency of drivers to glance, for example, into the left mirror to see a reflection of the left side of the truck. In a more recent study by Li and Fuksang (1998), a series of mirrors placed a reflected image at the bottom of the A pillar on the driver side to replace the conventional side mirror on the driver side. The placement of this mirror was such that the driver had to glance in a direction similar to the conventional mirror. This study resulted in objects being detected sooner in the surrogate system as compared with the conventional mirror system. One could infer from the Li and Fuksang study that placement of a monitor in the same area would achieve similar detection time results.

The configuration and placement of the monitors is very important to ensure that a video-imaging system is usable and conveys the necessary and critical information to the driver in an effective manner. There are currently no regulations or recommended practices for placement of displays for mirror surrogates or enhancements. However, the Japan Automobile Manufacturers Association has created a safety guideline for the placement of in-vehicle displays (Asoh, Kimura, & Ito, 2000). This guideline pertains to currently available system displays, primarily in the instrument panel, and not mirror surrogate or enhancement displays. However, according to the JAMA guideline, displays should not interfere with the forward field of vision in any way.

The JAMA guideline elucidates a very important element of display placement. If possible, the added display should not increase view blockage, which is equivalent to saying that the display itself should not cause a blind spot. If the monitor for a C/VIS is placed in front of an A-pillar, for example, then the display does not materially increase the size of the blind spot that is already present as a result of the structure of the vehicle.

It should be recognized that in many cases a mirror is placed such that the surface area of the mirror creates a blind spot by blocking part of the direct normal viewing area due to its position. Potentially, the size and placement of a display monitor could create a similar blind spot if it is located in the direct normal viewing area. If housed in the instrument panel, or the A pillar, this blind spot could be reduced or eliminated.

Monitor size and monitor viewing distance

Size of the display monitor and distance from the monitor to the driver may differ from system to system. A display may be capable of producing the desired output; however, the driver's physical eye location may be too far from the monitor for the information to be usable. Minimum size of the monitor may have to be determined, just as minimum reflected area for a mirror system was determined. More detail on this issue is presented later.

Field-of-View

Camera

The FOV of a *mirror* system is relatively fixed and is only adjustable in terms of position—not necessarily the angle of the reflected viewing area. If FOV changes must be made with mirrors, they can only be accomplished by changing the convexity or size of the mirror itself. However, once a mirror is no longer flat, it produces distance distortions of objects. Camera systems, however, have a different set of distance characteristics. The lens of a camera, the distance to objects, and the size of the image surface determine the FOV, and all three are adjustable. Lenses can range in angle-of-view from 2.5^{o} to 170^{o}. Thus, the FOV is highly adjustable and, as such, perception of critical information obtained from different configurations may not be consistent. Two very important human factors considerations regarding the FOV are object size and distance preservation, and viewable area (Flannagan, Sivak, & Mefford, 2002; Flannagan & Sivak, 1993).

Object size/distance preservation

Object size may need to be preserved in the image to portray correctly an object in the FOV in terms of position, size, and shape. This may be important so that the perceived dimensions and location of the object are correctly and effectively assessed. If done incorrectly, the result may be confusion or performance degradation leading to greater susceptibility to collisions. FMVSS §571.111 states that mirrors of "unit magnification" provide a reflected view that is equivalent to that of the actual view at the same distance. According to the standard, this is critical to maintaining accurate speed and distance judgments of images in mirrors. One could infer that the same is true for a video image.

Since lenses vary in terms of focal length, placement, and viewable distance, objects captured and displayed may not necessarily be of unit magnification or even of consistent proportion. In some applications, it may be critical that object size be preserved.

Viewable Area

In situations where the conventional mirror system is replaced with a camera, the driver must be able to maintain a viewable area that is comparable. In addition, systems beyond the capabilities of the conventional mirror system need to provide a view that is intuitive and not visually distracting.

Current mirror systems allow the user to move his or her head slightly to change the FOV (Flannagan & Sivak, 1993). This enables the driver to increase the effective viewing area without physically repositioning the mirror. The fact that C/VISs do not allow this capability means that certain compensations must be made. This matter is covered in the current report.

Distance Distortion

Certain camera lenses can result in distance perceptions that misrepresent the actual distance (e.g., fisheye lenses, similar to convex mirrors). Both the FMVSS §571.111 and the Federal Register Vol. 68, No. 14, state that planar mirrors having unit magnification need to accompany convex mirrors. Although convex mirrors provide an expanded FOV, they distort speed and distance information. Thus, there is a trade-off between viewable area, and speed and distance information. One could infer that the same is true for a video image. Furthermore, other factors in a video-based system can result in a distortion of distance. Examples of this may include effects like “pin-cushioning” or “barreling” of the image, which can result from the use of telephoto or wide-angle lenses (Whitaker, 2001). Pin-cushioning “stretches” the four corners of the image outward while barreling “pulls” them inward.

Distance perception

Distance perception is very important in a driving task for making judgments of speed and position. Ware (2000) and Wickens and Hollands (2000) describe various perspective cues and how they relate to a human’s ability to discriminate the distance between two objects. Vision capabilities, such as binocular disparity, occlusion, and accommodation, are very important for speed and distance judgments made while driving. A study by Flannagan, Sivak, and Simpson (2001) found that binocular distance perception was not necessary to make accurate distance judgments, provided there were other distance cues present. This could be very important when considering the use of video-based displayed images, since both eyes view the same image and the binocular disparity cue utilized in mirrors is no longer available.

Use of Color

Conventional mirror systems are not limited in terms of color rendition since they are merely reflected images. If a mirror is not tinted, the only major color shift associated with mirrors is that the image may be slightly darker. For a camera system to capture color images, more advanced circuitry is needed. Less expensive color cameras may trade resolution for color rendition, and they may be less sensitive.

Color requires a certain amount of light, approximately $3cd/m^2$, to be perceived (Widdel & Post, 1992). Changes in light intensity levels can change the hue and the brightness of a color. At a certain point, if there is not enough light, color will not be perceived (Widdel & Post, 1992). Thus, color images captured in subdued light may appear darker than black-and-white images (Holst, 1998). A monochrome grey-scale image requires less light intensity for detail to be perceived. Since color is based upon perception, the International Commission on Illumination recommends that a certain standard be used when capturing and displaying color.

The perception of color in a display depends upon hue, brightness, and saturation, and the representation of color involves red, green, and blue combinations. Standard National Television Standards Committee (based in CIE values) color video represents color via one luminance signal and two chrominance signals. Although this standard, or another standard, may be used when representing color, differing color-coding techniques may result in small differences in perceived color across displays. Unlike mirrors, displays recreate every aspect of the scene, including color. Differences in the appearance of color may result in differences in perception of objects. Color representation in video-based imaging systems should be correct.

Contrast

Contrast helps the viewer decipher details and lightness information in an image. According to Ware (2000), when a person perceives brightness, the person actually perceives surface lightness. Moreover, since both light/shadow and luminance/proximity can act as distance perception cues (Wickens & Hollands, 2000), it is possible that contrast could affect accurate distance perception. If the display contrast is too low, objects in the image may not be separately distinguishable or clear. However, if contrast is too high, detail may be lost. Display contrast of the video image should be such that objects are clearly displayed with adequate detail. However, electronic displays can have problems with contrast illusions. Cathode ray tube displays, for example, are self-luminous, or emissive, which could confound lightness consistency. Moreover, uniform pixels in the display and the lack of actual texture can also affect contrast (Ware, 2000).

Color requires a certain amount of illuminance to be detected, and color contrast occurs in a similar manner to luminance contrast. The discrimination between edges and colored regions depends upon chromatic contrast (Ware, 2000). Color contrast is similar to luminance contrast because both depend upon changes in light intensity; however, color contrast adds chrominance when determining the viewable scale. This chrominance area expands the grey scale to different wavelength components, which enables people to perceive colors (Widdel & Post, 1992). Changes to the perceived lightness, however, can still affect contrast. Thus, discrepancies in color contrast, as with luminance contrast, could potentially affect distance perception and image detail.

Driver Performance and Control

Driver Control of Imaging Features

Driver control of imaging features may be important to help the driver accommodate the displayed image to the viewing environment. Simply adjusting the luminance output of the display could potentially increase the quality of the image. However, driver control of image characteristics may need to be minimized, as addressed in the Federal Register Vol. 68, No. 14 document. Furthermore, driver control of certain features, such as image magnification, could potentially result in a misrepresentative image that may give the driver false information. However, adjusting image characteristics could potentially benefit the driver since the driving environment is so variable.

Ambient Light

Ambient light levels may have an effect on a driver's perception of information that is displayed by a video imaging system. As previously noted, the light level inside the cab is highly variable and can range from near total darkness to moderately high brightness. High levels of ambient light falling on a display surface may result in glare or washout of the image on the screen. Moreover, if it is very dark inside the cab, other luminous surfaces may reflect off the viewing screen, thus obscuring the displayed image. The level of ambient light inside the vehicle and the reflective properties of the display surface may have an impact in perception of information. Of course, mirrors have similar problems in that high levels of illumination may create glare.

Display brightness

A video monitor is a light-emissive device that must be of sufficient brightness to be seen. Most monitors are viewable under standard indoor viewing conditions in which indoor light levels are typically anywhere from 200 to 6,000 lx. The cab of a vehicle, however, is an environment in which ambient light levels are constantly changing. The interior of a vehicle typically ranges from nearly 0 to 5 lx at night (Arumi, Chauhan, & Charman, 1997) to 40,000 lx in the sun, with direct sunlight being approximately 60,000 to 80,000 lx (Schuman, Flannagan, Sivak, & Traube, 1997). If the display is too bright in a darkened environment, glare and visual fatigue can result. Likewise, if the display is too dim in a very bright ambient environment, it may be unusable (Sanders & McCormick, 1993).

Low-light visibility

Light levels while driving constantly change and often require driving in darkened conditions. Conventional solid-state imaging-based camera systems require a certain amount of light to accurately portray a scene (Holst, 1998). With the absence of adequate light, conventional camera systems may not be able to capture critical information in a scene. Whereas small objects may possibly be viewable in darkened conditions with a mirror, the same objects may or may not be viewable with a camera, depending upon the available ambient light and the camera sensitivity.

Camera technology has progressed to a point where it is possible to display fairly high quality images in very low-light conditions either with cameras or an intensified video signal, or with specialized components and infrared illumination (Holst, 1998). However, most conventional camera systems that are currently available offer lower light detection limits between 5 and 10 lx. However, cameras continue to improve. Some cameras have a dual mode capability in which they can switch automatically for nighttime or very low light conditions, with capabilities down to 0.001 lx.

Supplementary Technical Issues

Video-based imaging systems have a wide array of technical concerns which need to be addressed when considering replacement or enhancement of mirror systems. Concerns including flicker, refresh rate, signal delay, frame rate, resolution, aspect ratio, and electronic noise are not currently a factor in mirror systems. Extensive previous research has addressed these issues and provides a multitude of recommendations based on the situation in which the system is used (Myers, 2002; Lueder, 2001; Ware, 2000; Whitaker, 2001; Holst, 1998; MacDonald & Lowe, 1997; Vincen, 1997; Ray, 1992; Widdel & Post, 1992; and Kimura, Sugiura, Shinkai, & Nagai, 1988). The following section contains descriptions of these various potentially influential factors and why they may be of concern.

Flicker and flicker fusion

Image flicker refers to a rapid change in the brightness level of a displayed image, which can be due to the refresh rate of the display or interlacing of the image. Flicker of an electronic display can cause discomfort and visual fatigue. Visible flicker of an image is typically unfavorable for most situations. Flicker that is not visible is still detectable by the retina, and it is possible that this type of flicker can result in visual fatigue. Thus, even at frequencies above the critical flicker fusion threshold (e.g., 60Hz field or 30Hz frames), where flicker is not visually apparent in displays, it is possible that the driver's retina could detect this flicker, and the driver could still experience adverse effects.

Flicker is also more noticeable in darkened conditions and/or in peripheral vision. If driving at night, it is possible that monitor flicker could be visible and apparent even if the driver is looking straight ahead.

Monitor Refresh Rate

Most of the flicker from video monitors is attributed to interlacing and monitor refresh rate in CRT monitors; however, it is still present in other display technologies as well.

Monitor refresh rate refers to the time it takes for the image to completely refresh on the screen. In North American video displays, the refresh rate is typically 60 Hz, which is roughly the same as the 60 Hz electrical power frequency. Most conventional video systems use interlace, which refreshes every other line every $1/60^{th}$ of a second. Nonetheless, flicker associated with monitor refresh rate can be visible, depending upon the ambient illuminance in the surrounding environment and whether or not the driver is viewing the monitor peripherally. However, as previously stated, even at frequencies above the critical flicker fusion threshold, where flicker is not visually apparent in displays, it is possible that the driver's retina could detect this flicker, and the driver could still experience adverse effects.

Signal Delay

The mirror system provides the driver with instantaneous feedback when viewing the display (in this case, the mirror) in relation to the position of the vehicle. When driving, a mirror provides feedback that is current to a vehicle's exact position; other adjacent vehicles viewed in the mirror are representative of where they actually are. Thus, the information obtained from the mirror regarding the position of other vehicles in the immediate vicinity is very accurate. Furthermore, when driving, the information gathered from looking straight ahead is in perfect sync with the information attained peripherally from the mirror. Any difference in this perceived motion sync may cause distraction, discomfort, or possibly even uneasiness.

In a camera imaging system, there are multiple signal transfers among electronic components as well as, possibly, even computer-based image digitization and/or enhancement. All of this takes some amount of time, and even a small delay in the signal may result in potentially adverse effects. It may be necessary for a designer to determine how much time delay is allowable before it is noticed by the driver as being distracting or debilitating.

Minimum Frame Rate

Motion video should be captured at a certain frame rate to appear seamless to the human eye. The critical value of frame rate for seamless action is, conservatively, 48 pictures per second for the human eye. This value gives the illusion of continuous movement. Motion pictures use a standard of 24 frames per second to show fluid motion, with each frame being exposed twice. Early silent films used 16 frames per second, each being exposed three times. During high-speed motion, this frame rate may have to increase to keep fluidity of motion. Whereas the standard 24 frames per second may suffice for standard video, motion video captured at higher speed may require a higher minimum frame rate.

Minimum Resolution

A video imaging system requires a certain level of detail to be effective for object recognition. The camera requires a certain resolution to obtain a critical level of detail. A display monitor must also have a minimum resolution in order to effectively display the output from the camera. Most are designed to meet the US NTSC 525 interlaced lines of resolution standard, but may provide screen resolution substantially below that standard.

It may be necessary to determine what minimum resolution is required to effectively display the desired system output.

Objects need to be seen in sufficient detail to determine what they are. Detail of the scene needs to be fairly fine, and motion needs to be fluid in order to preserve the reality of the image. The camera should have a minimum resolving power and should be capable of displaying an accurate portrayal of what is going on around and behind the heavy vehicle. If the resolving power of the camera is too low, images may not be distinguishable or representative of what they actually are. Furthermore, objects close together may appear to be fused. In addition, as previously stated, distance distortion of objects may occur. Thus, a minimum resolving power of the cameras in a surrogate or enhancement may need to be defined.

Image Aspect Ratio

Picture format may be of importance when considering camera systems. Although standard displays currently default to a 4-by-3 aspect ratio, this may change. Furthermore, many cameras adhere to a common 4-by-3 aspect ratio as well. Although a 4-by-3 aspect ratio is more conventional, a 1.85-by-1 or 6-by-9 aspect ratio provides a slightly wider viewing area. Aspect ratio may be important when considering image layout.

Noise

Electronic images can be susceptible to noise or interference from other electronic sources, radio frequencies (RF), electronic communication devices, and carrier frequencies, power sources, and other various electrical phenomena. RF interference can cause distortions in the picture, such as black granules or “graininess” throughout the picture, to complete loss of the vertical or horizontal sync of the image, or both. In addition, an increase in temperature on the sensor can cause thermal bursts, resulting in dark or thermal noise in the image. This can be controlled by reducing the temperature of the image sensor. Mirrors are not susceptible to this problem, and design should be such that this problem is minimized in a camera system.

In digital imagery, compression quality of the image needs to be fairly high, especially when fast-moving images are captured. If the camera quality or compression quality is too low, the picture could pixelate, drop out, freeze, or ripple.

Blooming, Overdriving, and Ghosting

Unlike mirrors, cameras have many components to capture an image. Sometimes, the limitation of the design can cause distortions in the picture that are produced by the camera under extreme conditions. Blooming, overdriving the composition, contrast or color, and ghosting of the image are distortions that may be seen in images. This is especially true of moving images since dynamic changes in scene may not be accommodated fast enough to be corrected when displayed on screen. Although this problem may occur with any camera system, magnitude and time of image problems should be minimized.

Blooming of an image can occur when rapid changes in light level for part of the image causes bleed-over in contrast or color to adjacent parts of the image. This can create a halo effect, or a "bloom" of the light, or a clouding of an image. Changes to the aperture of the lens could help accommodate this problem by transferring less light. Electronic corrections to the image can also reduce this effect. Overdriving, or overexposing, of the image can occur when the light levels change very rapidly across the whole image causing some or all of the image to be unclear. Again, aperture changes or electronic correction could reduce this effect.

Ghosting may also exist in a captured image. Ghosting occurs when a ghost or weaker, shadowy image is superimposed over the captured image. This effect is due to transmission effects of the video signal where the primary signal is followed by a weaker, delayed version of the same signal. This effect can occur in any lighting condition and could degrade the quality of the image to the viewer. This can be reduced as well through proper design and electronic ghost cancellation.

Camera Functions

Cameras that use motorized apertures may be necessary to accommodate variability in light levels during use. However, there are some potential problems with this. For example, a camera with a motorized aperture that is focused at infinity may encounter problems similar to those encountered with blooming, overdriving, and/or ghosting, even though these effects may be reduced. Delay time of the motorized aperture could potentially lengthen or shorten the duration of blooming or overdriving effects caused by lighting.

Cameras with auto-focus lenses may also present potential problems. This would mean that the camera would re-focus on different objects in the scene or on various parts of the scene. The focusing and re-focusing may be distracting to the driver. One potential problem may be that the camera is focusing on the wrong part of the scene, possibly causing the driver to lose critical information. Another potential problem with auto-focus mechanisms is continuous re-focusing while in motion or an object is moving within the scene. Focusing and re-focusing could be distracting or could draw attention away from critical information within a scene.

Summary of Findings

In regard to a video-based indirect visibility system, there is a wide array of potentially influential human factors concerns that need to be taken into consideration. There are, however, a few critical issues that stand out as being particularly important.

As previously stated, the driver has to be able to maintain a viewable area comparable to that of the existing system in situations where the conventional mirror system is replaced with a camera. Drivers have certain expectations when using a conventional mirror system. This means that a driver will look in a certain direction and expect to see a specific image or view. This may be very important when considering the situation of a mirror surrogate. A driver will expect to see a specific image when glancing in a specific direction.

There are currently no regulations or recommended practices established for camera placement or monitor location for video-based indirect visibility systems. Placement of monitors and cameras appears to be critical to the safe operation of indirect visibility systems.

Cameras and monitors are sophisticated electronic devices and are subject to noise, vibration, wide temperature swings, and input and cab environment light levels. These systems must be selected and configured so that their desirable characteristics are properly utilized, while their undesirable characteristics are minimized.

CHAPTER 3: IDENTIFICATION OF VIEWING NEEDS AND EARLY DEVELOPMENT OF CANDIDATE C/VIS CONCEPTS

DISCUSSION OF ISSUES ASSOCIATED WITH MIRROR SURROGATES

Flat Mirrors

Replacing a flat mirror with a video system involves important issues of perspective which must be understood prior to implementation. Perspective can be defined as the maintenance of correct size (and proportion) of images relative to viewing frame. If the image presented to the driver has all objects correctly sized and located relative to the frame, then the perceived distances to the objects in the scene should appear nearly correct. A lack of appropriate perspective results in apparent distance distortions and possible misinterpretations of distance estimates.

A familiar example of a lack of correct perspective occurs when convex mirrors are used on vehicles. As shown in Figure 3, a vehicle or other object appears smaller and farther away than it actually is. This situation could be dangerous in driving because a driver may assume that there is room to change to an adjacent lane when, in fact, there is not. NHTSA (FMVSS 111) allows the use of convex passenger-side outside mirrors on light vehicles but requires the caption “Objects in mirror are closer than they appear.”

The difficulty with video replacement of flat mirrors may be similar. Because camera FOV and monitor distance affect the object size, there is the possibility of misinterpreting distances to objects.

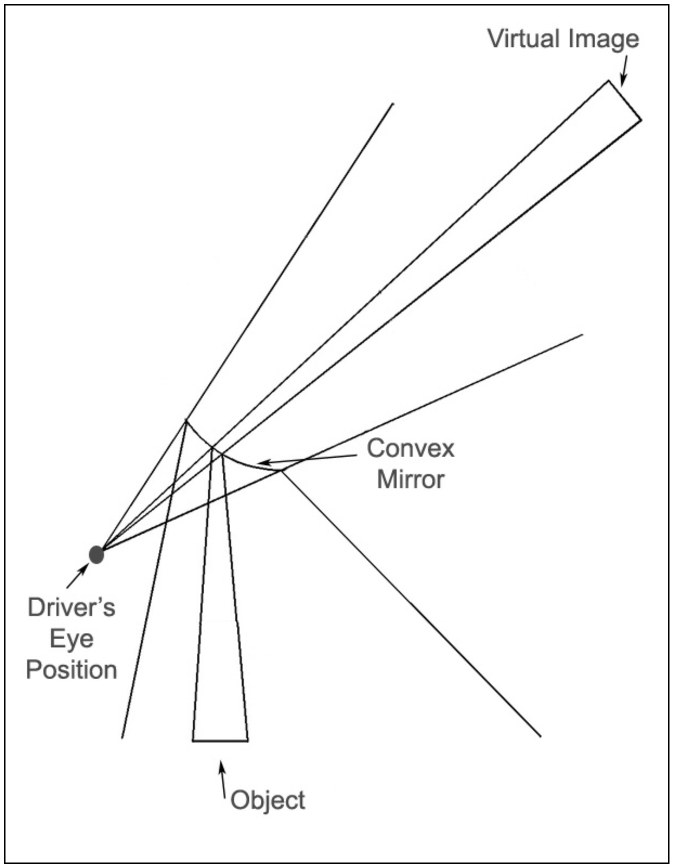

Figure 3. Object and virtual image for driver using a convex mirror.

The concept of distortion resulting from improper perspective is not new. Ray (1992) states the problem (in photography) succinctly, as follows:

> Perspective Distortions
> If the strict taking and viewing conditions are not adhered to, then apparent perspective distortions occur. Use of a wide-angle lens and subsequent viewing of the print from too great a distance gives exaggerated perspective. Diminished perspective results from close viewing of a print taken with a long-focus lens. Both types of lenses used from the same viewpoint faithfully record perspective but respectively include more or less of the scene than the approximately 50^o angle perceived sharply by the eye at rest. Confusion of these apparent perspective errors with imagery due to lens acceptance angle is common. (p. 76)

Figure 4 shows the situation that exists when a driver views an object with a flat mirror. The virtual image appears at the same distance as the object, giving the driver an accurate portrayal of distance. It should be noted in the figure that the total distance to the virtual image is the same as the total distance to the object. This total distance is the eye-to-mirror distance plus the mirror-to-object distance.

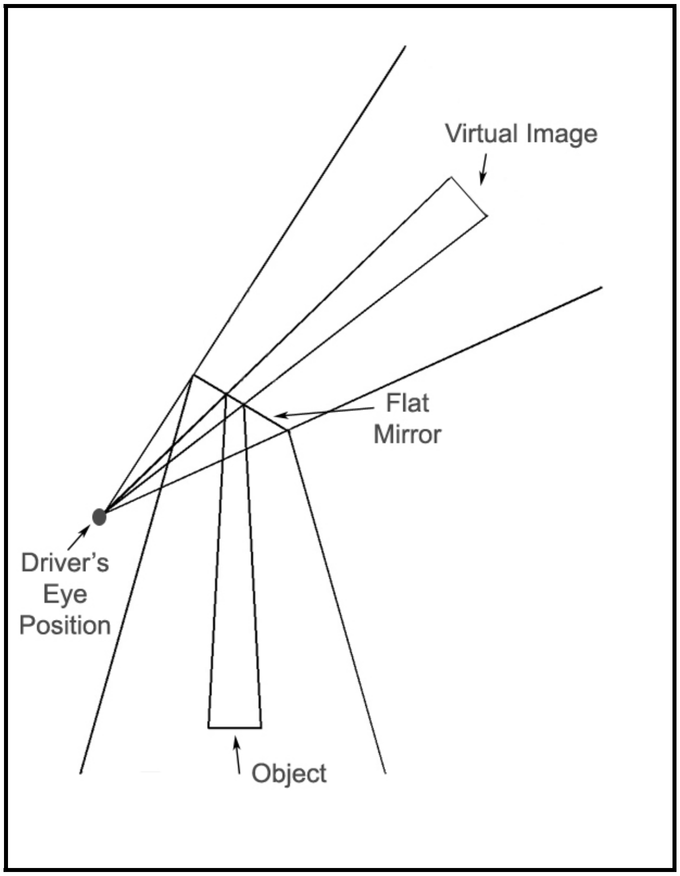

Figure 4. Object and virtual image for driver using a flat mirror.

How could this proper perspective be maintained with the use of a mirror surrogate? Since it would be desirable to maintain spatial relationships in the monitor image, this is a very important question. Figure 5 shows how a video image could be obtained with the identical size and perspective that is obtained with a mirror. The camera placement and lens FOV are selected so that the rays being reflected backward are captured in a way that is identical to that of the mirror. The image is then presented on a monitor that has the same angular subtense as the mirror, when viewed from the driver's eye position.

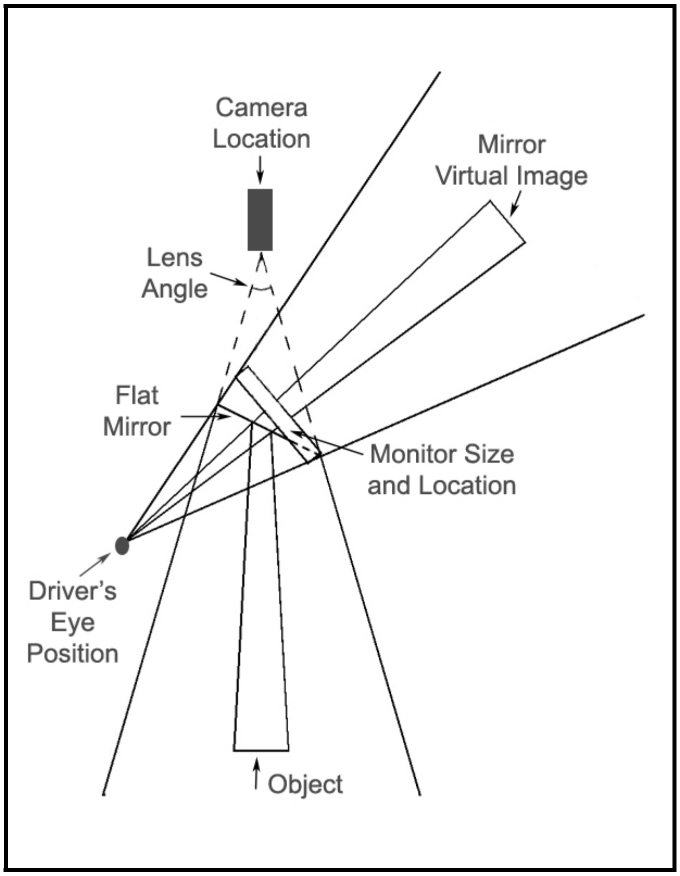

Figure 5. Hypothetical equivalent video system for a mirror.

In this configuration, any object at any distance subtends the same angle as the mirror virtual image. Therefore, correct perspective and image size are maintained. It would seem that a design objective for mirror surrogates (for flat mirrors) should be to maintain these relationships as closely as possible.

Before introducing additional issues, it is important to note that the monitor position could be changed without changing perspective. Figure 6 shows that as the monitor distance from the eye is changed, the display size must change in proportion to the distance to maintain the correct perspective. As long as the monitor size is adjusted properly, perspective will remain correct. Of course, the driver's focus distance will have to adjust, but it is believed that this does not affect perspective to any appreciable extent.

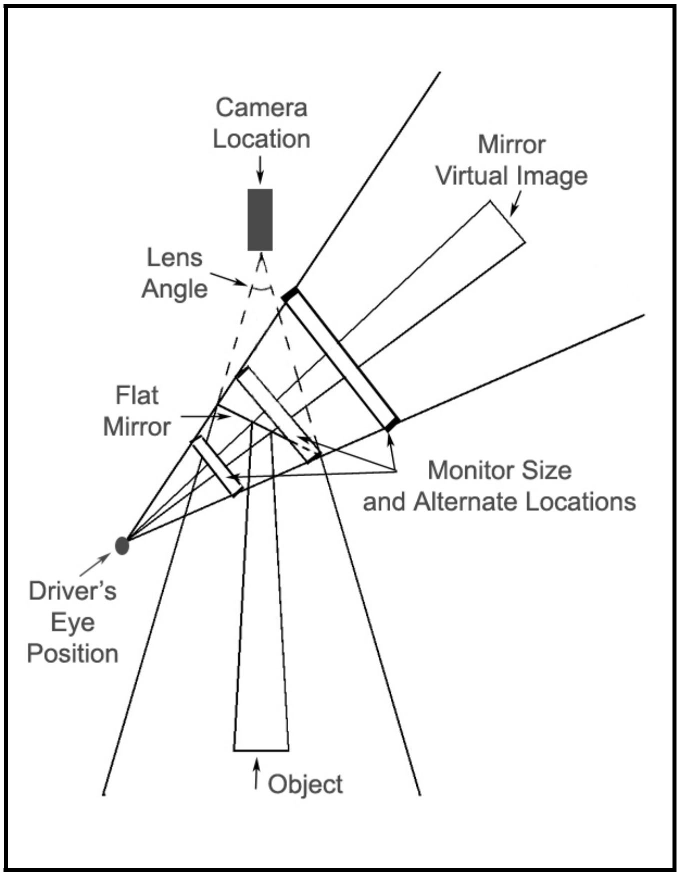

Figure 6. Equivalent monitor locations for a mirror surrogate video system.

Limitations in Maintaining Correct Perspective

There are a variety of problems associated with maintaining correct perspective. Some of them are a result of physical constraints, while others occur because of driver behavior and capabilities. These problems and their ramifications will be described in this section.

Camera location

As Figures 5 and 6 indicate, the best camera location to achieve correct perspective is out in front of the vehicle, with the camera pointing toward the rear. Clearly, such a position is impractical because it would require a structure to hold the camera in the correct position. This structure would protrude forward.

Some heavy vehicles have fender-mounted convex mirrors. Conceivably, a similar location might be used for a camera mount for a side-mirror surrogate. However, to maintain the identical perspective, the structure would have to extend farther upward and outward, away from the fender. It would appear that such a structure would be undesirable and, probably, impractical. Thus, some compromise in camera position must be considered.

Monitor location

For flat-mirror surrogates, it would seem reasonable to place the monitor in a location close to that of the mirror being replaced. Such a location would reduce learning time and driver transition difficulties because looking in the direction of the mirror would provide the equivalent video image. However, side mirrors are suspended outside the cab. In the case of a video surrogate, placing the monitor outside would subject it to weather, shock, and vibration hazards. Moving the monitor into the cab along a line of sight similar to that of the mirror being replaced appears to represent the best compromise. Note that, as in Figure 6, accurate perspective can be maintained as long as monitor size is proportionally reduced as the monitor is moved closer to the driver.

Small adjustments in monitor angular position within the cab probably would not adversely affect driver performance because mirror placement relative to driver eye position varies a small amount from tractor to tractor. However, the monitor's angular position probably should not differ greatly from that of a corresponding mirror so that the driver may adapt readily to the monitor.

Binocular disparity

Normal human vision uses the perspective differences between two eyes as one means of obtaining depth and object distance cues. Such stereoscopic cues are missing in conventional video systems. Observers using video, therefore, rely on a variety of other cues to derive depth/object distances. Textbooks in psychology (Wickens & Hollands, 2000) describe these cues, which include the following:

- Perspective - Has already been discussed at the beginning of this chapter.
- Interposition - A solid object in front of another object obscures the view of the object behind it.
- Height in the plane - Height or vertical angular subtense may provide a cue regarding object distance.
- Light and shadow - These provide indirect cues of distance based on contrast and size.
- Relative familiar size - If the true size of another object is known, its visual image size allows a judgment of distance.
- Proximity – Proximity illuminance covariance—at night in particular, brighter lighting suggests closer location.
- Aerial perspective - Distant objects are hazier. This effect may be important in fog and mist considerations.
- Motion parallax - Objects closer may appear to travel faster.
- Surface texture – Texture is more apparent for short distance.

The fact that stereoscopic cues are missing in video suggests that other cues should be reproduced as faithfully as possible in flat-mirror surrogates so that the driver can estimate distance to an object as accurately as possible.

Later in this research, the idea of superimposing a horizontal line on the monitor to designate the projection (on the pavement) of the end of the trailer (or cargo box) was developed. The purpose was to provide a substitute for the lack of stereoscopic viewing. This line can be carefully calibrated on a flat road and can then provide the driver with a relatively reliable indication of clearance in passing and merging. Note that this line is not dependent on driver eye position. It is only dependent on camera aim and other camera lens parameters that do not change under ordinary circumstances. Such a line should only be relied upon on flat roads, however.

Ambinocular FOV

When a driver looks into a mirror, the horizontal angular FOV exceeds that seen by either eye separately. This effect is shown in Figure 7. The left eye sees farther to the right in the mirror, and the right eye sees farther to the left. Therefore, the total FOV includes an edge region seen only by the left eye, a similar edge region seen only by the right eye, and a central region seen by both eyes. The overall effect is that of a small increase over the horizontal FOV. Generally, the human visual system fuses these two images so that one is hardly ever aware that only one eye is viewing each edge of the mirror scene.

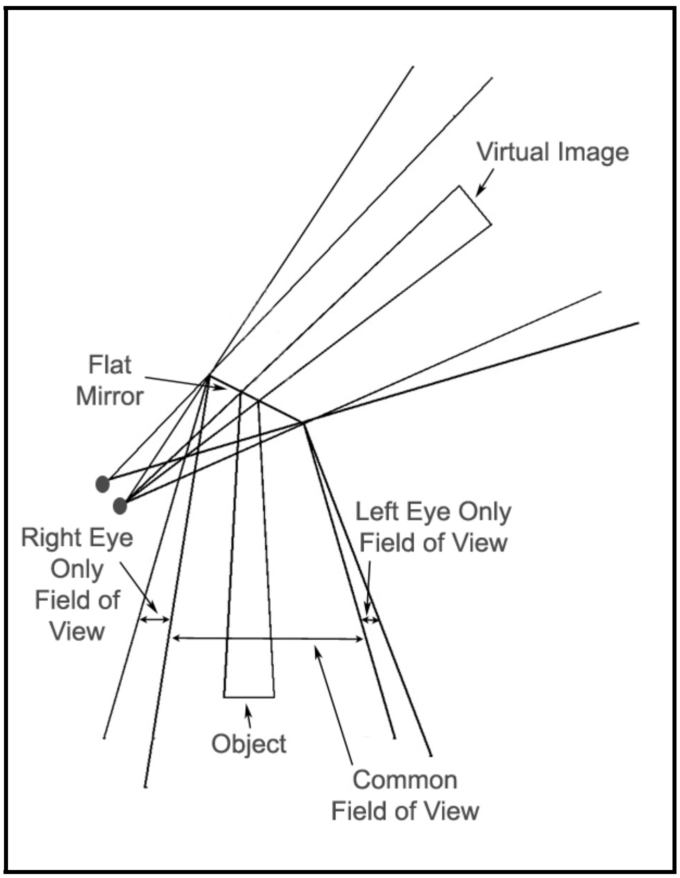

Figure 7. FOV for ambinocular vision.

Just how large is the increase in horizontal visual FOV for ambinocular vision? Woodson, Tillman, and Tillman (1992) give the 50th percentile male interpupillary distance for truck and bus drivers as 2.44 in (6.2 cm). Assuming the head turns to within 20º of the center of the mirror, the equivalent distance between the pupils in the direction of the mirror is 6.2 cos 20 = 5.83 cm.

If the mirror is 5 ft 6 in (167.6 cm) away (on the right side of the heavy vehicle), the increase in FOV will be approximately [(5.83*57.3)/167.6] = 2.0^{o}. However, for the mirror at approximately half this distance (on the left side of the vehicle), the FOV increases by approximately 4^{o}. These results suggest that there is a small, but reliable, increase in FOV with mirrors due to ambinocular viewing. Note that video used as a mirror surrogate *does not* provide this increase in horizontal FOV.

Visual search including head movements

This factor is quite important in mirror use. A driver can purposely change head position to change FOV sequentially. This type of movement can be used to search for vehicles and other objects that might be just outside the normal FOV.

Assume that the driver may move the head and neck forward by 3 in (7.62 cm) or may move the head and neck back by 2 in (5.08 cm). The corresponding increases in horizontal FOV (actually, the detection of FOV) would be to increase the field to the right for head movements in the forward direction and to increase the field to the left for head movements in the backward direction.

Assuming an angular movement relative to the mirror of 45^{o} and a distance to the right mirror of 5 ft 6 in (167.6 cm), the angular increase at the mirror is (7.62 cos 45) = 5.39 cm. This produces an angular subtense of 1.84^{o}. Similarly, backward movement produces 1.23^{o}. This suggests that the driver can comfortably increase the FOV by approximately 3^{o} for the right-side mirror and can nearly double that amount for the left-side mirror; that is, 5.5^{o}. As with ambinocular vision, the FOV increase resulting from head movements *does not* occur with the use of a mirror surrogate since the video image remains essentially the same regardless of small changes in eye position.

<u>Typical Mirror Fields-of-view</u>

While it is possible to calculate the fields-of-view for left and right-side mirrors, it is also possible to measure them using a typical driver in typical heavy vehicles. Two such vehicles were used to obtain such data: a 1997 Volvo and a 1994 Peterbilt. The Volvo had a sloping hood and semi-integral fenders, whereas the Peterbilt was an upright, conventional design. Each vehicle was tested statically, using a 48 ft (14.6 m) trailer and a typical driver, who was 5 ft 10 in (178 cm) tall. The limits of coverage were determined at the back edge of the trailer at a height above ground of 54 in (137 cm).

Left eye, right eye, and both eyes tests were conducted. The driver was permitted to turn the head comfortably toward the mirrors being measured. In the single-eye tests, the unused eye was covered during the test.

Flat Mirrors

The left and right flat (west coast) mirrors were initially adjusted (using both eyes) so that the driver could just see the edge of the trailer in the mirror. The mirrors remained in these positions throughout all of the tests. (In the case of Peterbilt, the inside edge of view was obstructed by the muffler insulators.)

Results are shown in Table 1 for FOV. The table provides the total angular coverage to the rear. Since the mirrors were not readjusted for the single eye tests, the trailer could not be seen in one single-eye test on each side. In these cases, the total angular coverage begins away from the trailer.

Table 1. Angular coverage of heavy-vehicle flat (west coast) mirrors.

		Angular coverage (degrees)		
Vehicle Side	Vehicle	Left Eye	Right Eye	Both Eyes
Left	Volvo	12.66	11.91	14.45
	Peterbilt*	5.64	7.65	8.99
Right	Volvo	4.49	5.01	6.00
	Peterbilt*	4.72	4.65	6.01

** Inside limits were sometimes obstructed by muffler insulators.*

The results show that the Volvo had better coverage on the left side. The increased coverage was a result of the wider west coast mirror used on the Volvo (7 $^3/_8$ in versus 6 $^5/_8$ in; 18.7 cm versus 16.8 cm), the lack of obstruction by the muffler insulators, and seating differences (seating differences affect eye-to-mirror distance). The “both-eyes” data takes into account the ambinocular view aspects previously described, but the data does not take into account head movements in search situations. Allowing 5.5º for the left mirror and 3º for the right mirror (as per previous discussion), the total equivalent fields-of-view become 20º on the left and 9º on the right.

Convex Mirrors

Convex mirrors used on heavy vehicles play an important role, one that is not met by flat mirrors. Since convex mirrors are, by their design, wide-angle, they are used to detect objects relevant to safe driving, even though apparent distances are distorted. As shown earlier in Figure 3, a convex mirror increases the FOV at the expense of perspective distortions. In particular, objects appear farther away than they actually are. Also, if an object is near the mirror, its image in the mirror will have perspective distortions that appear as geometric distortions. Drivers learn to use convex mirrors primarily for detection because the mirrors provide the necessary coverage. It is unlikely that they are used for estimating distance, except possibly through a good deal of experience and cross comparison with a flat-mirror image.

Convex mirrors are subject to the effects of binocular viewing and head movement in much the same way as flat mirrors. Each eye sees a slightly different view, with the left eye seeing farther to the right and the right eye seeing farther to the left. Moreover, moving the head forward or backward allows increases in temporary FOV. These factors, however, do not appear to be as important for convex mirrors because the mirrors already have larger fields-of-view. Thus, a few extra degrees do not matter as much as they do with flat mirrors, where angular fields-of-view can be quite limited.

During the earlier tests with the Volvo and Peterbilt tractors, fields-of-view were also measured for the convex mirrors. These tests were performed for "both eyes" only. The mirrors were adjusted so that they included the rear of the tractor and the edge of the trailer (perhaps 10% of the total FOV). These values are usually recommended by experienced drivers.

Table 2 shows the results for the convex mirrors. Clearly, the fields-of-view are large when compared to the flat mirrors. The results suggest that an appropriate FOV would be about 45^o on the left side and, perhaps, 43^o on the right side. Since it is unlikely that differences of 2^o could be detected, fields-of-view of 45^o could probably be used on both sides of a heavy vehicle.

Table 2. Angular coverage of heavy-vehicle convex (side) mirrors (using both eyes).

Vehicle Side	Vehicle	Coverage (degrees)
Left	Volvo	43.5
	Peterbilt	42.1
Right	Volvo	38.2
	Peterbilt	40.8

<u>Guidelines</u>

What guidelines can be developed from the previous discussion of mirror surrogates for flat and convex mirrors? There appear to be several. They are listed here for later use and experimental testing:

- Because a flat mirror provides accurate portrayal of distance, object size, and perspective, any video surrogate should be developed to maintain accurate distance and perspective portrayal to the maximum feasible extent.
- In developing a flat-mirror surrogate, FOV considerations should include the ambinocular FOV effect and head-movement effect, both of which increase the usable FOV of the mirror. These effects suggest that the video surrogate for a flat mirror should have a larger FOV than the "single-eye, fixed" FOV of the flat mirror.
- The monitor for a flat-mirror surrogate should be correctly "sized," based on distance from the driver so that perspective and object size are maintained relative to viewing frame.
- The monitor for a flat-mirror surrogate should be located in a direction similar to that of the mirror being replaced. Doing so will minimize learning time and con-

fusion because drivers' expectancies regarding mirror placement will not be violated.

- Since convex mirrors do not maintain either accurate distance or perspective portrayal, convex-mirror surrogates should not be required to do so.
- Video surrogates for convex mirrors should match the usable ambinocular fields-of-view, with the addition of a few degrees to account for head movement.
- Video surrogates should use a left to right reversal so that interchangeability and transfer problems with mirrors are minimized.
- Monitors for convex-mirror surrogates should be located in a direction similar to the mirror being replaced. Doing so will minimize learning time and confusion.
- Camera placement for both flat and convex-mirror surrogates will likely involve a compromise. This compromise occurs because the "correct" position for the camera is out in front of the vehicle.
- Based on preliminary data, the horizontal video fields-of-view for the mirror surrogates are as shown in Table 3.

Table 3. Video horizontal fields-of-view for mirror surrogates.

Vehicle Side	Mirror Type	FOV (Degrees)
Left	Flat (west coast)	20
Left	Convex	45
Right	Flat (west coast)	9
Right	Convex	45

<u>Camera and Monitor Placement Design Considerations</u>

Camera Placement

As previously described, most heavy vehicles have a single flat west coast mirror on each side, and they have at least one convex mirror on each side. These mirrors are mounted outside the vehicle on a structure that places them away from the cab. The purpose of the structure is to hold the mirrors steady and to allow rear vision that is largely unobstructed by the trailer. (The trailer may be slightly wider than the cab.)

The diagram in Figure 6 shows that flat-mirror surrogates are heavily constrained in terms of camera location, monitor location, and FOV. In particular, camera location should be in front of the vehicle which, as previously discussed, is probably unfeasible. What, then, are the feasible locations for the camera, and which location offers the best compromise? Figure 8 shows a top view of a typical tractor with the front of its trailer. There appear to be four candidate locations and variations within these: fender mounting, mirror structure mounting, aft cabin mounting, and trailer mounting.

Fender mounting

Placing the camera on the fender has the advantage that the horizontal perspective is nearly correct. Referring to Figure 9, it can be seen that there is a strong similarity of camera position in this figure and in the fender mounting of Figure 8. In particular, fender mounting is out in front of the driver's position. Fender mounting also has the advantage of allowing better coverage of the right-front blind spot that exists on many tractors. There is, however, a disadvantage associated with fender mounting, as shown in Figure 9. This figure shows that the theoretically correct camera position is above that of the fender mounting, causing the camera vantage point to be lower than the theoretical optimum. However, in lowering the vantage point, one gains the advantage of reducing the right-side blind spot. Specifically, a small vehicle cannot get "under" the camera, whereas it could get under the mirror without being detected. It appears, therefore, that fender mounting may actually be superior (from a vertical perspective point-of-view) to the theoretical position shown in Figure 9.

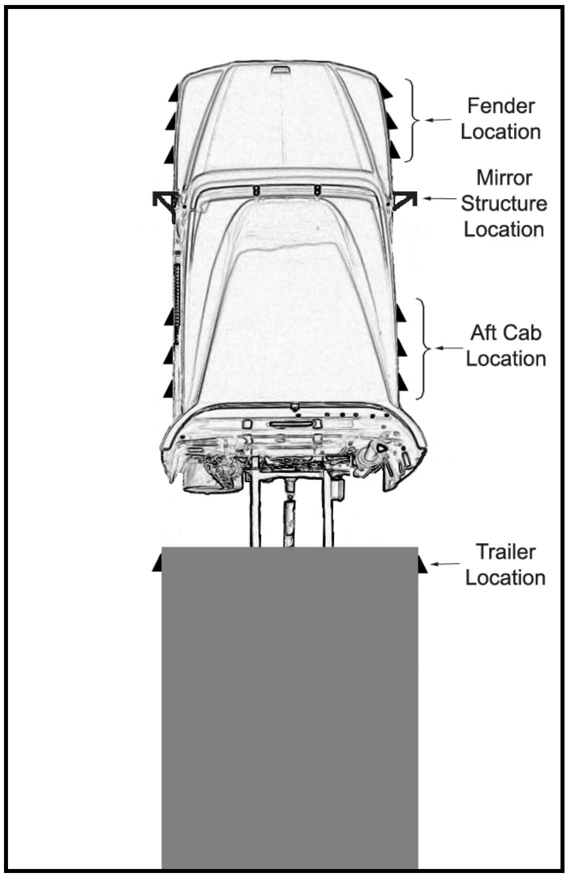

Figure 8. Potential camera locations for mirror surrogates.

Fender mounting does have one slight drawback, namely that this camera location may produce a small blind spot along the side of the trailer. Because the tractor width at the fenders may be a few inches narrower than the trailer width, a small shadow zone may exist. However, many drivers aim their west coast mirrors so they are centered in the adjacent lane (roughly at the rear end of the trailer). Consequently, they may already have a small shadow zone when using these mirrors. In addition, future designs of fenders could be widened slightly to accommodate the cameras.

Mirror structure mounting

Mirror structure mounting may give the appearance of being an optimum location but, in fact, offers little in the way of advantages. First, the structure must be retained, thereby retaining much of the wind drag associated with the mirrors and placing the camera in a vulnerable position. Secondly, the camera location is not optimum because it conflicts with the theoretical optimum location shown in Figure 9. The only advantages that this camera location has are that there is no shadow zone along the trailer and that camera height is approximately the same as the mirrors. The latter may not be an advantage, actually, because of the continued ability of small vehicles to get under the camera without detection.

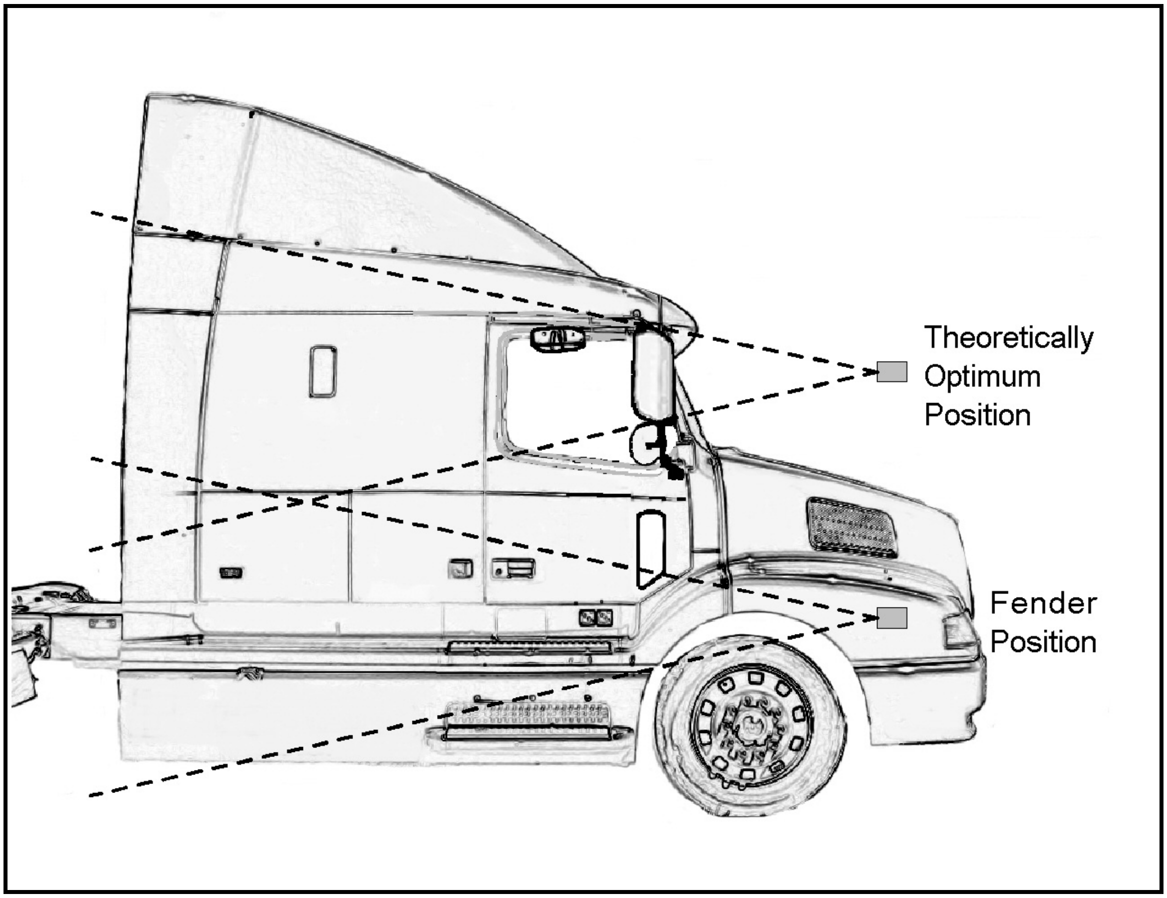

Figure 9. Comparison of theoretically optimum and fender-mount camera positions.

Aft-cab mount

This location also has the advantage that it has height similar to the mirror location. However, this location has the disadvantage that it differs greatly from the theoretical location shown in Figure 9. Thus, the vantage point of the camera is quite different from the optimum; in addition, there is a large blind spot on the side of the tractor or cab.

Trailer mount

Trailer mounting has the same advantage and disadvantages as aft-cab mounting. However, the disadvantages are increased because the camera location is even farther away from the theoretical optimum, and the blind spot is even larger. In addition, there is the necessity of having to connect the camera by either hardwire or RF transmission across to the tractor. Furthermore, every trailer used with such a tractor must be equipped with the camera.

Recommendation on Camera Location

Clearly, fender mounting of cameras appears to provide the greatest number of advantages. The properties (both positive and negative) can be summarized as follows:

- Theoretically correct horizontal perspective;
- Greatly reduced lateral blind spot;
- Aerodynamic mounting possible;
- Lowered perspective position; and
- Possibly, a small shadow zone along the trailer.

The diagram in Figure 8 shows that the position on the fender may be farther forward, farther back, or in the middle. But which position appears to be the best? The forward position appears to offer the greatest advantage in that blind spots alongside the tractor are minimized. Since the range of possible positions is probably less than 2 ft (0.61 m), moving the camera forward or backward on the fender should have little effect on perspective.

Flat versus convex mirrors

In the discussion of camera location, emphasis has been placed implicitly on flat-mirror surrogates. However, since perspective need not be maintained for convex mirrors, there appears to be no reason why convex-mirror surrogates cannot use the same camera locations. Note in particular that placing the cameras for the convex-mirror surrogates on the front fenders *greatly* reduces any blind spots along the side of the tractor.

Camera Protection

An important consideration regarding camera mounting is to protect the camera from being struck and from accumulating debris. Housings currently exist that incorporate appropriate design features. Figure 10 shows an enclosure that has the shape of a trapezoidal solid. This type of enclosure minimizes the likelihood that a stone or other object thrown backward from a vehicle in front would damage the camera. Additionally, the enclosure has an aerodynamic groove that directs debris away from the clear window through which the camera lens obtains the image of the rearward scene.

Figure 10. Fender-mounted camera in a protective, aerodynamic enclosure (courtesy of Sidetracker, a division of V-Tech USA, LLC).

Turning Vehicle Problem

Another important consideration in regard to camera mounting is the occasional use of the mirrors when making a sharp "urban" turn. It has been estimated that the maximum angle between a tractor and trailer in driving through a 90^o turn is 68^o (Technology and Maintenance Council, 1999). Figure 11 depicts this situation for a 48 ft (14.6 m) trailer and for a 53 ft (16.2 m) trailer. This diagram shows that if the convex-mirror surrogate camera is aimed outward slightly, there is good coverage of the rear trailer. Usually it is the trailer wheels and the cargo box that the driver is observing in the mirror, ensuring that they are clear of any obstructions. Even if the camera is not aimed outward, the wheels are still in the video image. Also, under extreme circumstances the driver can sometimes take a direct look, particularly on left turns.

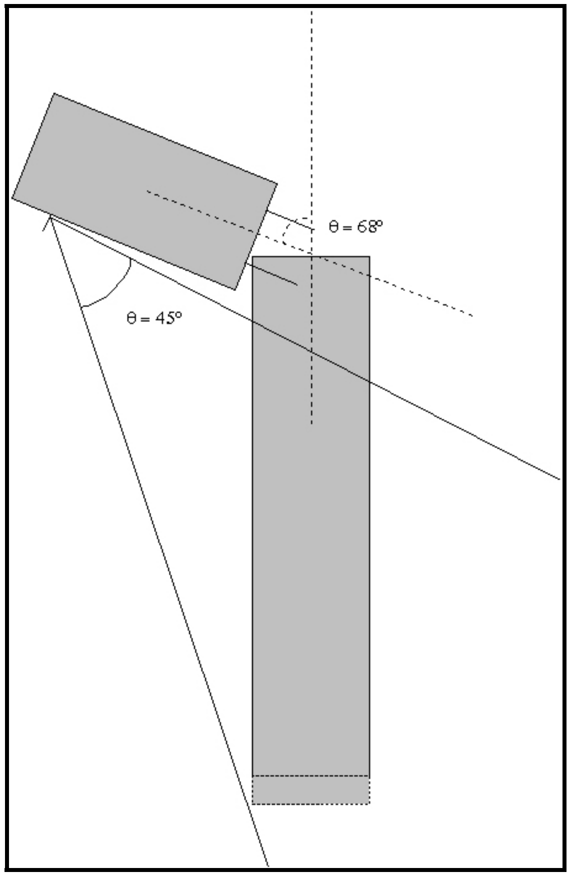

Figure 11. Turning vehicle trailer visibility.

Monitor Placement and Size

Monitor placement for mirror surrogates similarly represents a complex design problem with several compromises. The fundamental goal is to provide the same information that the driver receives from the mirrors and to present the image at an angular location similar to that of the mirrors.

As previously described, the camera angular fields-of-view are shown in Table 3. A design goal must be to approach these angles of view for monitors used in flat-mirror surrogates. Thus, on the left side, the FOV presented to the driver by the monitor should be close to 20^o. In other words, the monitor width should subtend a 20^o angle at the nominal driver's eye position. Similarly, on the right side, the monitor should subtend a 9^o angle at the nominal driver's eye position.

In the way of review, Figure 12 shows that the monitor must account for both ambinocular view and for head movement. This means that the monitor will be slightly larger than the equivalent mirror. The 20^o and 9^o fields-of-view already account for ambinocular view and head movement. Monitor width, as previously depicted in Figure 6, is a function of viewing distance, assuming that correct perspective is to be maintained. The equation giving monitor width as a function of desired viewing angle is as follows:

$$W = 2d \tan\frac{\theta}{2}$$

where *W* is the width of the monitor, and *d* is the eye distance to the monitor. (*W* and *d* must be in the same units of measure.)

This equation assumes that the monitor is perpendicular to the driver's line-of-sight. Table 4 shows how the monitor width varies as a function of viewing distance. As can be seen, monitor width appears to be in a feasible range, except at the longer sight distances (where monitor widths exceed 9 in [22.9 cm]).

Table 4. Monitor screen width as a function of distance from the driver's eyes.

Side	Angular subtense (degrees)	Viewing distance (inches)	Monitor width (inches)
Left	20	12	4.23
		18	6.35
		24	8.46
		30	10.6
		36	12.7
Right	9	48	7.6
		54	8.5
		60	9.4
		66	10.4
		72	11.3

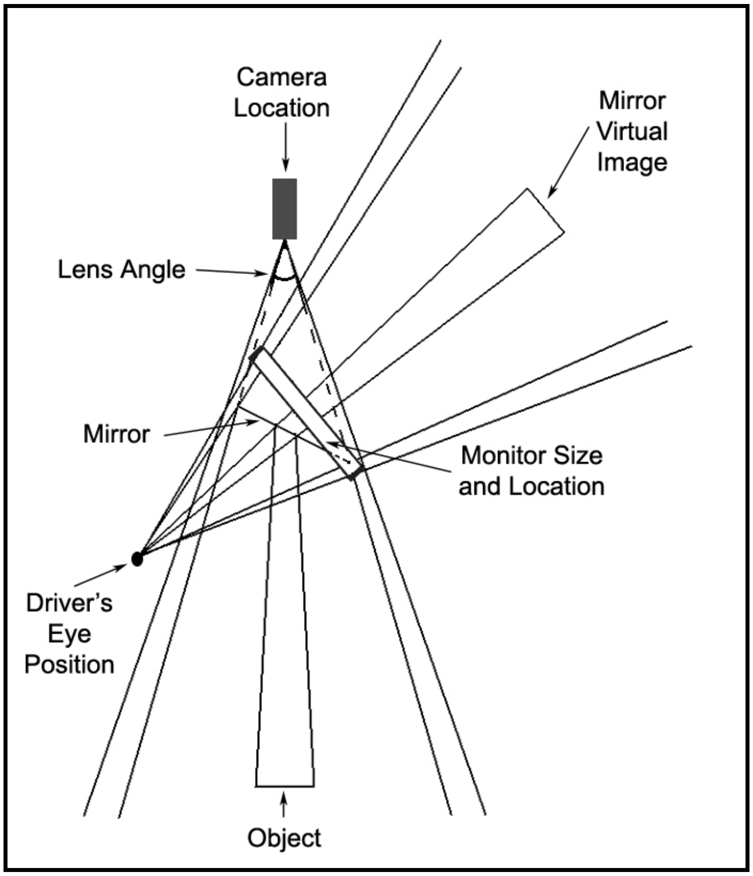

Figure 12. Use of wider lens FOV and larger monitor to account for ambinocular view and head movement.

Monitor Locations

It has already been stated that a monitor for a mirror surrogate should be placed roughly in the direction of the mirror being replaced. In so doing, driver expectancy is retained, and driver adaptation problems are minimized. A monitor will ordinarily occlude (block) visibility of any object to its rear; thus, care must be taken to avoid any major increases in visibility blockage when selecting a location for the monitor. It is important to recognize that the west coast (flat) and convex mirrors on each side of a heavy vehicle actually block visibility out to the sides of the vehicle. Consequently, the replacement of the mirrors by video surrogates represents a tradeoff: there is a gain in visibility by the removal of the mirrors and a potential loss of visibility with the installation of monitors.

Figure 13 shows a visibility diagram of an actual heavy vehicle (VTTI's 1994 Peterbilt tractor). The diagram shows visibility at a height of 54 in (137 cm) above the ground outside the vehicle. The diagram shows blockage around the front of the vehicle due primarily to the hood of the vehicle. However, there are also four other significant areas of blockage: two created by the cab A-pillars and two created by the side mirrors. Note that at 54 in, it is possible to look under the mirrors. Therefore, there is some "close-in" visibility below the mirrors. As the driver's view approaches the horizontal, however, the blockage definitely occurs.

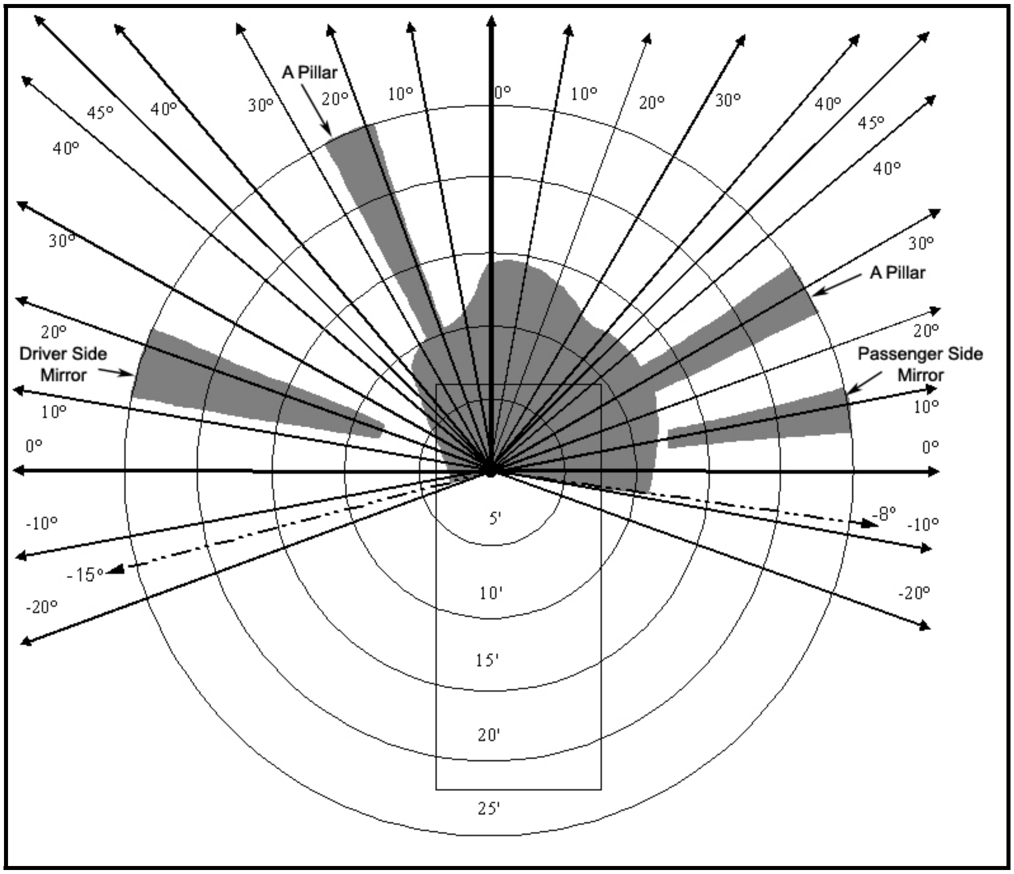

Figure 13. Typical seated visibility diagram for a heavy vehicle.

It would seem prudent to locate the monitors for mirror surrogates in places that already have visual blockage. Doing so minimizes the adverse effects of visual occlusion. The monitors could be placed on the side windows in line with the current mirror positions. However, to account for "look-around" and binocular vision, the areas of horizontal blockage would be a few degrees larger than the mirrors. Moreover, the advantage of improving side visibility by mirror removal would be lost.

A better plan appears to be to locate the monitors at the A-pillars, or below in the IP (instrument panel), or possibly the doors. Doing so minimizes additional visual blockage, while maintaining the general direction for the driver's visual glances to the mirrors. It should be noted that two monitors may be needed on each side of the vehicle. One of these would replace the west coast mirror, and the other would replace the convex mirror.

In anticipation that such a design would require changes to the interior, a survey of several newer model tractors was undertaken. Nominal distances from A-pillars to the driver's eye were obtained along with other pertinent data. In addition, digital photos were taken of each front corner of the cab, showing the A-pillars. The various dimensions are designated in Figure 14, and the values for several tractors are shown in Table 5.

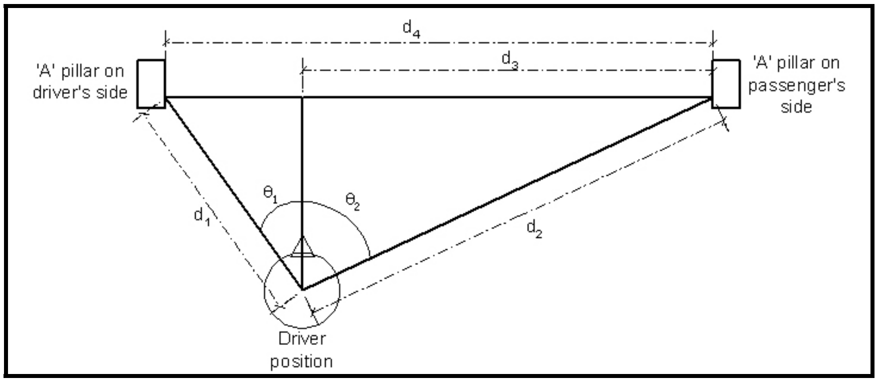

Figure 14. Measured dimensions.

Table 5. Measured quantities for seven tractors.

Tractor	A	B	C	D	E	F	G
d_1 (in)	34	36	32	28	32	32	28
d_2 (in)	50	55	52	58	61	63	56
d_3 (in)	43	43	43	53	56	56	53
D_4 (in)	57	57	57	68	70	71	68
θ_1 (deg)*	38	32	40	42	48	42	44
θ_2 (deg)*	64	60	66	74	76	70	78

** (Measured, not computed.)*

The results show that the average distance to the left A-pillar is 31.7 in (80.5 cm), with a range of 28 in (71.1 cm) to 36 in (91.4 cm). Similarly, the average distance to the right A-pillar is 56.4 in (143.3 cm), with a range of 50 in (127.0 cm) to 63 in (160.0 cm).

Figures 15 and 16 show photos of A-pillars of a typical heavy vehicle. Most heavy vehicles appear quite similar. Note in particular in Figure 16 that the right A-pillar has roughly the same angular subtense as the right west coast mirror.

Figure 15. Left A-pillar area of a typical tractor.

Figure 16. Right A-pillar area of a typical tractor.

A-pillars are structural elements of the tractor cab and must remain intact. However, trim over the structural elements can be modified to accept flat panel monitors. In a redesigned A-pillar trim section, the monitor image surface, aimed toward the driver, would likely protrude an additional 2 in (5.1 cm) toward the driver. Consequently, the average distances to the left and right monitors would become 29.7 in (75.4 cm) and 54.4 in (138.2 cm), respectively. At these distances, the corresponding correct monitor width would be 10.5 in (26.7 cm) for the left-mirror surrogate and 8.6 in (21.8 cm) for the right-mirror surrogate, for the west coast mirrors.

It appears that it would be feasible to place an 8.5 in (21.8 cm) monitor in front of the right A-pillar; however, there is some question as to whether a 10.5 in monitor could be accommodated at the left A-pillar. What causes this monitor on the left to be so large? The answer is that the driver sits relatively close to the left-side mirror. Therefore, ambinocular viewing and head movements create a greater FOV. If, say, an 8.5 in monitor were used at the left A-pillar, the corresponding camera should then have a 16.3º FOV to maintain correct perspective. A compromise of this type will probably be necessary in order to avoid excessive monitor size in the cab.

Placing the monitors for the left and right-side west coast mirrors over the A-pillars seems to represent the best compromise, in that visibility blockage is minimized. However, care should be taken not to occlude any portion of the windshield. If the monitor is slightly wider than the A-pillar, the overlap should be toward the rear (side) and not toward the front.

Monitors for the left and right convex-mirror surrogates should be placed below the flat-mirror surrogates, if possible. Unfortunately, such an arrangement may require extensive redesign of the instrumental panel for almost all heavy vehicles. Alternatives appear to be to place the convex surrogate monitor at the door or to place both monitors on the A-pillar, with the west coast surrogate below the convex surrogate. This latter alternative is the one that was tested experimentally.

Height Dimension

Throughout the discussion of camera fields-of-view for surrogates, emphasis has been placed on the *horizontal* FOV. The reason for this emphasis is to ensure coverage equivalent to the mirrors that are being replaced. Vertical FOV must also be considered in the design process. It should be noted that the fender location for the cameras reduces blind spots because of the lower vantage point. With the cameras in this location, it is impossible for another vehicle to get under the camera FOV, as previously explained. Therefore, there is really no need for a vertically-elongated monitor; that is, one that matches the west coast mirror. It appears that a driver should have no difficulty detecting objects alongside his/her heavy vehicle with a video screen that has a conventional 4 to 3 ratio of width to height.

Monitor dimensions for convex-mirror surrogates are more flexible, as previously indicated. Since convex mirrors do not preserve correct perspective, it is not required that surrogates should do so. In fact, screen sizes would be prohibitively large if this were attempted. It would be best to choose a screen width similar to that of the west coast mirror surrogate, or slightly smaller.

Look-Down Enhancement

The look-down mirror found on the passenger side of many heavy vehicles is intended to eliminate the blind spot along the passenger side of the cab. This mirror is usually convex and is mounted just outside the passenger-side window at the top of the window, as shown in Figure 1. The driver can look into this mirror to see if there is a smaller vehicle alongside the tractor (or cab).

The purpose of the look-down mirror is to eliminate the blind spot *below and in front of* the west coast mirror. Figure 13 illustrates this blind spot quite clearly. A smaller vehicle can easily get under the FOV of the side mirrors (measurements in Figure 13 were made at a height of 54 in; 137cm). This blind spot occurs only on the passenger side of the vehicle. On the driver side, the driver can look directly through the driver-side window to detect adjacent vehicles.

In some cases, the heavy vehicle may not have a passenger-side look-down mirror. In these cases, the passenger-side window is relatively large or an auxiliary window is installed either in the door or forward of the door.

Figure 9 shows that fender mounting of the cameras for the west coast and corresponding convex-mirror surrogates largely eliminates the need for a look-down mirror. If the cameras are placed as far forward on the fender as possible, the combination of windshield direct view and coverage by the cameras, particularly the convex-mirror surrogate camera, should eliminate the blind spot on the passenger-side of the vehicle.

Additional Design Recommendations

After examining the problems of camera and monitor placements for mirror surrogates, it is possible to provide additional recommendations. These help to form the basis for hardware design:

- Taking all considerations into account, the best camera location for mirror surrogates appears to be the fenders of the tractor. Both flat-mirror and convex-mirror surrogate cameras should use this location.
- Fender mounting of cameras may produce a very small shadow zone (blind spot) at the side of the trailer near the rear. This is a result of the fender-to-fender width being slightly smaller than the trailer width. However, convex-mirror surrogates may be aimed outward slightly anyway to cover 53-ft (16.2 m) trailers when making sharp turns. In addition, future fenders might be flared a bit more to give the cameras a slightly better view along the sides of the trailer. Such a design change would seem to be minor.
- Fender mounting of cameras should reduce blind spots alongside the heavy vehicle because it would be impossible for a small vehicle alongside to get under the camera FOV.

- Fender mounting of the cameras appears to eliminate the need for the look-down mirror (or corresponding enhancement) on the passenger side of the vehicle.
- Surrogate cameras should be protected from damage and debris to the maximum extent possible.
- The camera of the convex mirror surrogate should have horizontal angular coverage of 45^o.
- The best monitor location for flat-mirror surrogates seems to be at the A-pillars, with any monitor overlap toward the rear. (There should be no additional windshield occlusion.)
- The best monitor location for convex mirror surrogates seems to be above the flat-mirror surrogates on the A-pillars. Other possibilities are in the IP, or in the doors. However, these latter possibilities may require extreme head movements by the driver.
- Flat-mirror surrogate monitors should be approximately 8.5 in (21.6 cm) wide, if possible, and cameras should have a corresponding horizontal FOV that produces correct perspective. The *camera* horizontal FOV should be specified according the following equation:

$$\theta = 2\arctan\frac{w}{2d}$$

  where θ is the horizontal angle of coverage of the video camera, *w* is the width of the monitor, and *d* is the nominal distance from the driver's eye to the monitor.
- Selection of the left flat-mirror surrogate monitor represents a compromise since it is unlikely that a monitor larger than 8.5 in could be accommodated.
- The monitor of the convex-mirror surrogate should have a width roughly compatible with that of the flat-mirror surrogate monitor. However, it can have slightly less width because it does not need to maintain correct perspective.
- It is quite clear that important aspects of mirror surrogates should be tested in a realistic environment. The theoretical design considerations presented here may need modification based on experimental results.
- West coast (flat) mirror surrogates can use a horizontal line on the monitor to help overcome lack of stereographic presentation. The line would designate the rear end of the trailer or cargo box, projected to the horizontal roadway.

DISCUSSION OF ENHANCEMENTS

As defined previously, enhancements are video systems that improve or facilitate visibility around the vehicle. They are distinct from mirror surrogates, which are intended to replace the four main mirrors (two flat and two convex) that all heavy vehicles should have. Generally, enhancements are intended to provide coverage of blind spots that are created by the vehicle configuration itself. As discussed previously, the heavy vehicle could be driven without such enhancements, but doing so may make driving less convenient or less efficient.

As an important preliminary, it should be recognized that camera FOV for enhancements must be chosen judiciously. Choosing a field that is too narrow may cause important information/objects to be missed by the driver. This could create a false sense of security or, possibly, anxiety over the missing information. On the other hand, choosing a field that is too wide produces extraneous information or clutter. In addition, wide-angle lenses tend to produce perspective distortions, making straight lines appear curved and generally creating a video image that appears distorted.

Another important aspect is monitor size and monitor placement. Enhancements do not have the same constraints as mirror surrogates. There is more freedom in choosing both monitor size and monitor location. True perspective need not be maintained since absolute distances are generally not being estimated. In most cases, monitor size and placement will be a matter of deciding how to integrate the display with existing cab interior structures and equipment. Nevertheless, if there is a "natural-appearing" location, from the standpoint of the driver, every effort should be made to accommodate such a location.

In the following discussion, tractor enhancements for articulated vehicles are first presented. Thereafter, trailer enhancements are presented. Following these two aspects, straight truck differences are considered.

Tractor Enhancements

Heavy-vehicle tractors are ordinarily operated with a trailer, but they can be used in a bobtailing (uncoupled) maneuvering mode. In this section, candidate enhancements using video will be described. Some of the concepts are currently being studied by the manufacturers or are being shown in concept vehicles at various trucking symposia. Three such concepts have been developed and are discussed in this section.

Tractor Rear Backing/Bobtailing Enhancement

Figure 17 shows the concept of a backing/bobtailing C/VIS. The camera is placed at the back of the cab, facing toward the rear and aimed downward somewhat. A 70^{o} camera horizontal FOV would seem to be appropriate. The primary use of this system would be for uncoupled backing of the tractor. However, such a system could also serve as a rear-view video system when bobtailing.

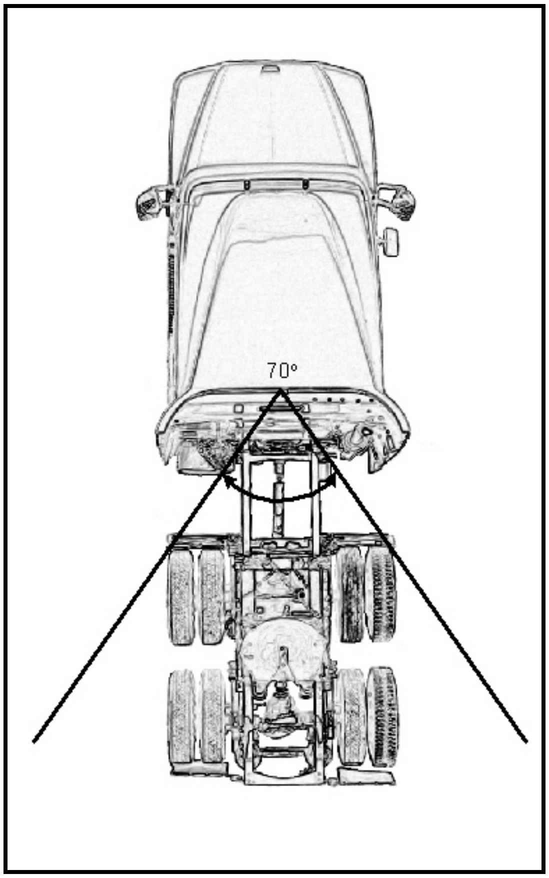

Figure 17. Candidate video camera location for backing in an uncoupled mode (camera can also be used for rear-view in bobtailing mode).

Particular care should be taken to ensure that the rear extremes of the tractor are covered in the video image so that clearances around the vehicle can be observed. Such a design should greatly facilitate backing into tight spaces and should help to prevent pedestrian accidents and object collisions when backing.

Monitor location for this backing video would seem to be on the center header of the vehicle, just above the windshield. This would place the monitor in a location similar to a center rear-view mirror in light vehicles. However, there are often other items in this header area, such as a CB radio. In addition, later tests showed that placing monitors on the front header caused neck strain for drivers. Consequently, formal tests were performed with the monitor at the top of the windshield where it did not block the forward view. Some manufacturers have chosen to use a pop-up display that is embedded in the top of the IP. When not in use, the display retracts into the dash.

Clearly, a backing video system is a prime candidate because it should enhance safety and increase efficiency. The same system can also be used for rear views when bobtailing.

Front Blind Spot Enhancement

Most tractors have a blind spot directly in front of the vehicle. This blind spot occurs because the hood and fenders obstruct the driver's forward/downward view. Figure 13 shows this blind spot for a typical vehicle. As can be seen, the blind spot is larger to the right of center because the driver must look over the hood. The shape of the hood and fenders does affect the magnitude and extent of the blind spot. Some newer vehicles have sloping hoods, which may reduce the total area of the blind spot. However, such a blind spot does not appear to be totally removed on any conventional-design vehicle (as opposed to cab-over vehicles).

Figure 18 shows one possibility for locating the camera of a front blind-spot video system. The camera has been placed on the left and aimed to the right so that it gives best coverage to the right-front of the vehicle, where the largest area of the blind spot is likely to exist. The camera could be placed on the front of the fender or above the bumper, whichever provides the best coverage. (An alternative would be to place the camera on the center of the hood, looking down, but this would probably maintain a small blind spot close to the vehicle. Yet another alternative would be to place the camera above the right corner of the windshield, aimed downward. All of these alternatives were attempted in the preliminary testing phase.)

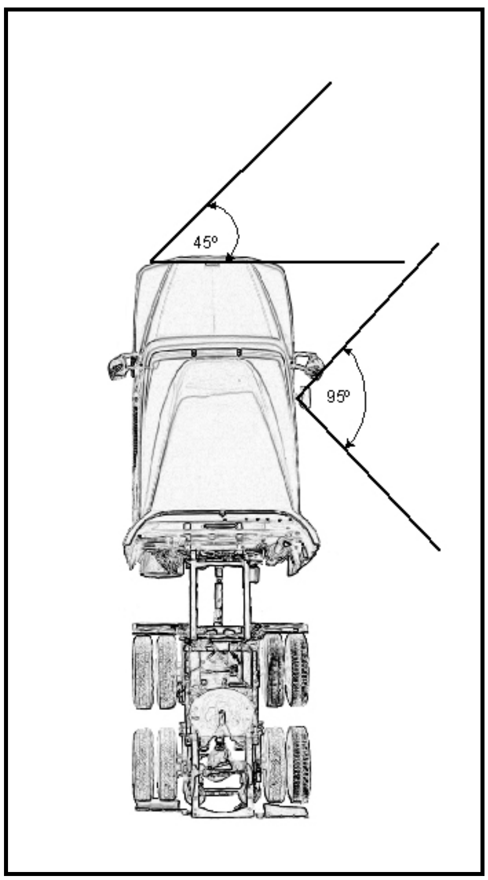

Figure 18. Candidate video camera locations for front blind spot and look-down (passenger-side) blind spot (early versions).

The front blind-spot system has several problems. First, there is the problem of debris collecting on the camera lens window because the camera is at the front of the tractor where debris is likely to collect. The camera may also be vulnerable to damage by road stones thrown up by a lead vehicle or, possibly, by front tire forward release of a stone from the tractor itself (and bouncing from the pavement). Second, there is the problem of deciding when such a system should be activated. Clearly, this type of system is only needed occasionally since it has no function while the vehicle is moving forward at any speed above creeping. For rolling speeds, if there were some object in the forward blind spot, there would be no way that a collision could be avoided. Also, for "yard/urban" maneuvering, the driver may not choose to turn such a system on. Third, monitor location represents another unknown. Where should the monitor be placed? While it appears that a straight (unreversed) image should be used, little else is known about placement.

In general, the front blind-spot enhancement seems to have several problems. While there are occasional mishaps caused by the forward blind spot, it is difficult to design a system that will provide the necessary information at the right time, while not distracting the driver. (These statements, however, do not apply to vehicles such as school buses and transit buses, where the probability of a pedestrian accident is much higher.)

Tractor Right-side Look-Down Enhancement

When video cameras replacing the flat- and convex-mirrors on each side of the vehicle are moved to the front fenders, as described in the previous section on mirror surrogates, the blind spot on the passenger side of the heavy vehicle is largely eliminated.

Figure 18 shows that a camera could be installed in a location very similar to the look-down mirror. A relatively wide FOV should be used so that coverage is adequate, particularly in the adjacent lane. The camera should be aimed so that it covers the adjacent lane well, particularly the near side. To avoid unnecessary image distortions, the lens FOV should not be greater than 95^o. Even this FOV will create substantial distortions.

It would seem that monitor placement should be above the passenger-side door. An alternative location would be below the glass in the passenger-side door, provided it can be placed above a seated front-seat passenger.

Later testing eliminated this look-down enhancement because other enhancements covered the blind spot. Both the wide-angle right-side blind-spot enhancement and the right-side convex mirror surrogate precluded the need for a look-down enhancement on the right side, since the cameras for these latter two C/VISs are mounted at the right front fender.

<u>Trailer Enhancements</u>

Because of the size of cargo trailers relative to tractors, blind spots of various kinds occur. Video enhancements can be used to help overcome these blind spots. Several concepts have been developed and are presented here.

It is important to recognize that trailer video enhancements will require a connection across the fifth wheel. This could be a hard-wire video connection or, alternatively, an RF connection. Connecting across the fifth wheel complicates matters and requires that there should eventually be some form of recommended practice for new connections between the tractor and the trailer. It should be noted, however, that RF video links are becoming less expensive and more reliable as time passes. The likelihood is that eventually hard-wire video connections across the fifth wheel will become unnecessary.

Another important consideration is the interchanging of trailers. The great majority of tractors are used with more than one trailer. Consequently, for any trailer enhancement to be effective, both the tractor and the trailer must be equipped, and the two must be compatible with one another. Again, use of RF may help in development of a uniform set of standards for trailer videos. It should be noted that such links must be immune from interference by other vehicles that are similarly equipped. This may require coding, similar to that used on garage door openers, for example.

There is the alternative of having the video cameras, mountings, and wiring remain with the tractor. In this case, when the tractor hooks to a different trailer, the video would be strung to the new trailer. However, such a procedure seems a bit complicated and is likely to meet with driver/company resistance because of the time and effort lost in stringing and mounting.

It is quite clear that recommended practices will be needed to standardize the interface between tractors and trailers. At this time, such practices do not exist. However, there is currently discussion of this topic in SAE committees, and it is quite likely that some form of recommended practice for interconnection will be forthcoming.

In presenting the concepts for trailer video enhancements, there is yet another problem. Most concepts make use of mounting at the rear of the trailer. Such mounting must take into account possible interference with the rear doors of the trailer. In most cases, doors are very large and may take up the entire rear surface. Cameras must be placed so that they clear these doors or are mounted to the doors while at the same time being designed so they are not easily damaged.

Finally, there is the problem of debris accumulation. As mentioned at various places throughout this document, dust and dirt can form over the protective glasses in front of video camera lenses. The rear surfaces are particularly susceptible to this problem because of the turbulent air currents at the back of trailers. It is likely that cleaning at regular intervals will be necessary.

Trailer Rear Look-Down Enhancement

This form of video is depicted in Figure 19. The camera would be mounted high on the trailer and would be pointed downward to cover the area directly behind the trailer. The figure shows the area of coverage on the ground by means of a dotted outline.

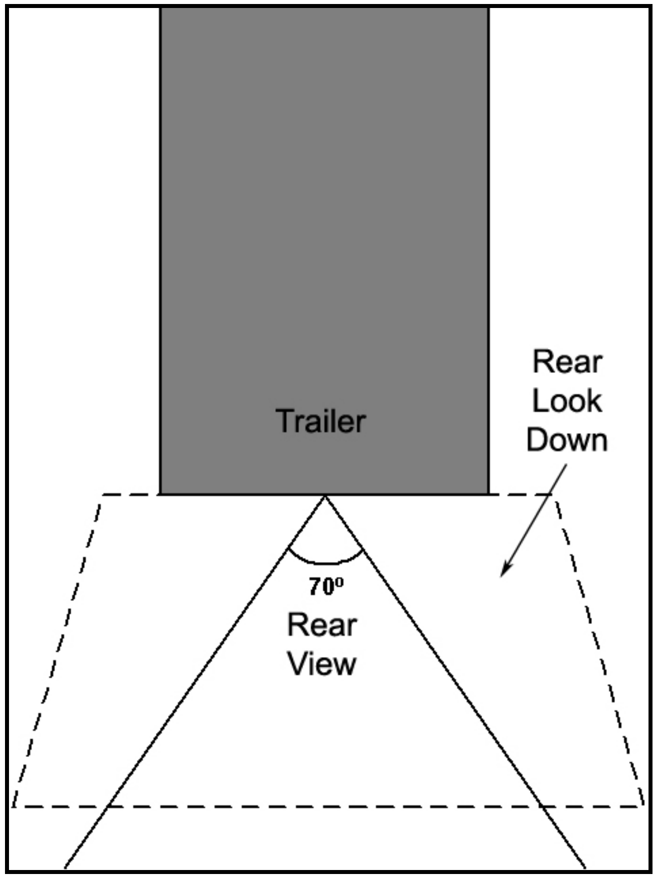

Figure 19. Candidate trailer rear-view and rear look-down enhancement camera locations.

This video camera arrangement is intended to be used during backing maneuvers, specifically for avoiding collisions with objects and pedestrians. The estimated angle of view for a standard 13 ft 6 in (4.1 m) trailer height would be 50°(this value was increased later on the basis of preliminary testing) . It could be used during parking/loading operations as well as during street driving when backing maneuvers must be performed. There are many documented accidents with pedestrians/dock workers. Such a video system could greatly reduce the likelihood of such accidents.

In terms of monitor location, it would appear that, once again, the header location would be most appropriate. However, as previously mentioned, neck strain was shown to be a problem. Thus, such a system can use the same monitor locations as the backing/bobtailing enhancement system. Since the rear look-down enhancement is essentially a rear-view system, the image on the monitor should be reversed.

Trailer Rear-View Enhancement

Figure 19 also shows the concept of a rear video. This video would be used during over the road travel to assess the situation behind the tractor trailer. A 70^{o} FOV was chosen which would extend the view somewhat into the adjacent lanes as well as behind the trailer. The rear video would essentially take the place of a center rear-view mirror as implemented in light vehicles. Consequently, the monitor should once again preferably be placed in the same location as that used for the backing/bobtailing and rear look-down enhancements, and the image should be reversed.

Two questions would eventually have to be answered for the trailer rear-view enhancement: one has to do with the height of camera placement, and the other has to do with FOV. It would likely be feasible to place the camera at the top of the trailer, or it might possibly be feasible to locate the camera lower in one of the doors, but near center. Trailers have various types of doors, including roll-up doors, so there would definitely be complications in locating a camera and protecting it.

Left and Right Merge/Re-merge Enhancements

Figures 20 and 21 show the initial concepts of left and right merge/re-merge enhancements. A camera is aimed across the back of the trailer and is intended to be used to detect clearance of a vehicle being passed. The driver can then eliminate the guesswork in determining when there is adequate clearance to pull in front of a passed vehicle. If the driver "can see daylight" plus a safety margin between the trailer and the front of the passed vehicle, it is safe to pull in front. This is an application where color video would be helpful since it could be used as an additional identifier in daytime, if there is more than one vehicle being passed.

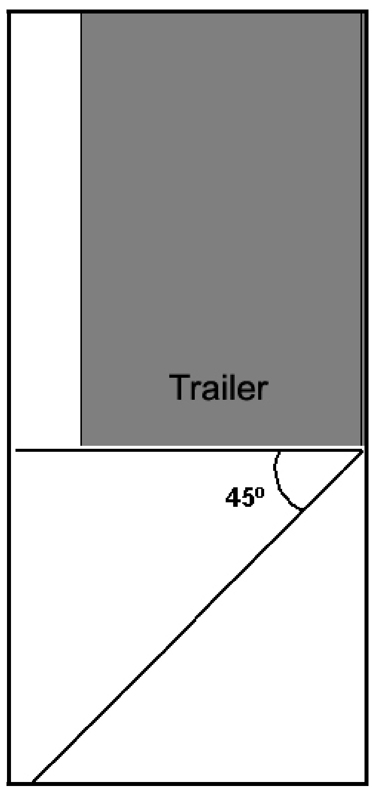

Figure 20. Candidate left merge/re-merge enhancement camera location (early version).

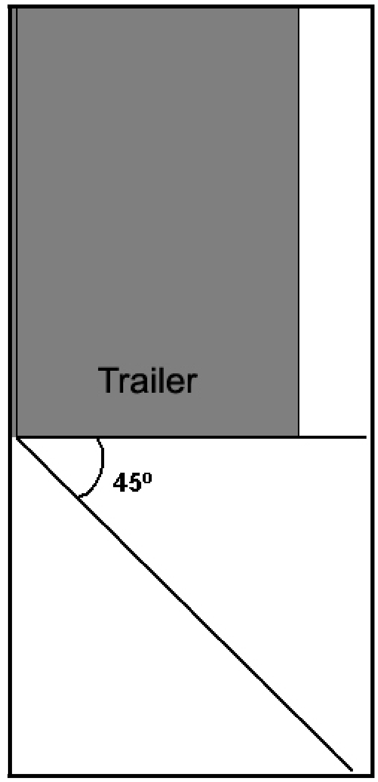

Figure 21. Candidate right merge/re-merge enhancement camera location (early version).

In terms of height of camera location, it is clear that a height of about 7 ft (2.1 m) would provide the most natural view of the adjacent lane. A horizontal FOV of 45^o appeared initially to be most appropriate (but was later increased on the basis of preliminary testing).

The right merge/re-merge monitor could be placed above the passenger door, whereas the left merge/re-merge monitor could be placed above the driver door. These placements would allow the monitor images to be coordinated with the mirrors or mirror surrogates. It should be noted, however, that care must be taken in placing the monitor above the *driver* door. This will put the monitor quite close to the driver, making accommodation to a short visual distance necessary and possibly creating an internal hazard in event of a collision. The monitor location should thus be as far forward on the left header as possible.

Trailer Wide-Angle Rear Multipurpose Look-Down Enhancement

The previous four trailer concepts have been selected to provide specific views and corresponding functions. There is, however, the possibility of combining functions using a single wide-angle camera, as shown in Figure 22. With this arrangement, the camera provides relatively wide coverage of the rear of the trailer. It can therefore be used for all four of the previous functions: rear look down for low-speed backing and maneuvering, rear view for driving (to a limited degree), and passing on left and right. The camera must have a minimum angular FOV of 90° to achieve a 27-ft (8.2 m) lateral coverage on the ground directly across the back of the trailer (this was increased in the preliminary testing). This angular coverage assumes a trailer height above the ground of 13 ft 6 in (4.1 m). If a different trailer height is used, the angular coverage must be adjusted accordingly.

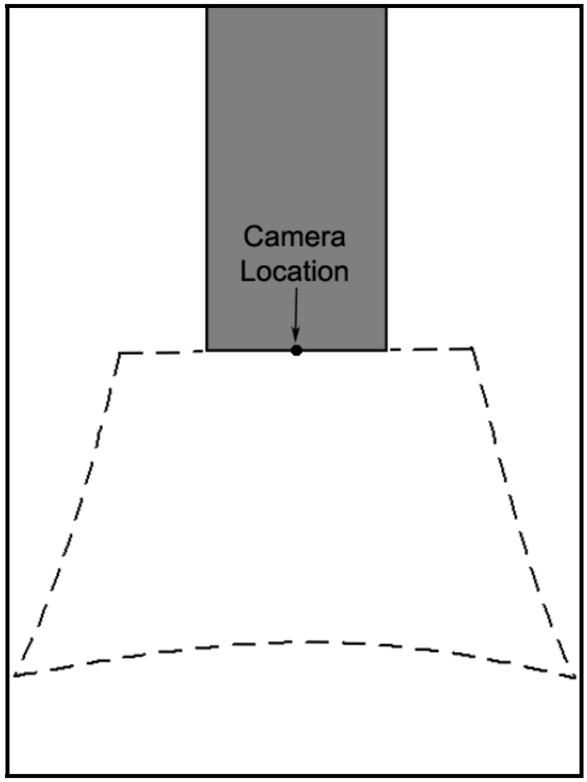

Figure 22. Candidate trailer wide-angle multipurpose look-down camera coverage (early version).

It would be expected that this camera would produce substantial perspective distortions. However, considering that there would be a single display, there is the great advantage of simplicity with this concept. Location of the monitor should be at the top center of the windshield or center IP, and the image should be reversed.

Trailer Rear Multi-Camera Enhancement (early version)

There is the possibility of using more than one camera in a single housing. The idea was to have as many as four small cameras at the center rear of the trailer, with the cameras mounted in a single housing at the top of the trailer. Each camera would have a specific function, similar to one of the first four concepts presented in this section, namely:

- Rear video
- Rear look-down video
- Passing-on-right video
- Passing-on-left video

The four cameras would be aimed to provide the best coverage for the application, and the fields-of-view would, similarly, be selected for best coverage.

The multi-camera system would use a single monitor, which could be switched to the appropriate camera for the view needed. The most likely location would be at the top center of the windshield or directly below in the center of the IP.

Some type of driver control over camera selection would be needed. This could be a simple pushbutton arrangement that would take advantage of direction-of-motion stereotype information. For example, if a driver is merging to the right, the driver would expect to have the "passed" vehicle on the right. Therefore, the pushbutton for the right merge/re-merge camera should be to the right. Figure 23 shows one simple arrangement that appears relatively intuitive. The middle row of pushbuttons uses the abbreviations LR for left rear, CR for center rear, and RR for right rear. The bottom pushbutton uses RV for rear view. Note that these labels have been selected because they would probably be intuitive to heavy-vehicle drivers.

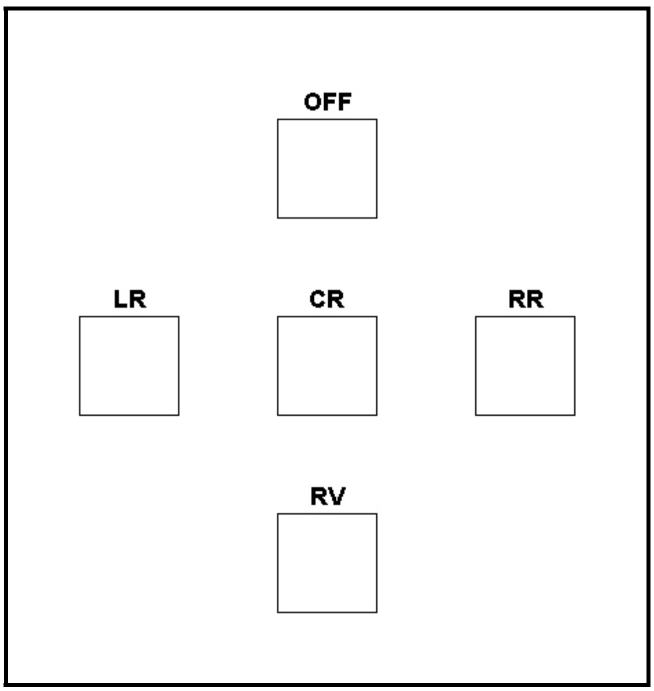

Figure 23. Pushbutton concept for a four-camera rear trailer system (early version).

Straight Truck Enhancements

There are certain instrumentation advantages to using C/VISs in straight trucks. Most importantly, the "cargo box" and the truck itself are never separated. Therefore, the problem of having to deal with different trailers does not exist. Once a straight truck is equipped with cameras, it remains instrumented. Furthermore, there is no need to deal with the connections across the fifth wheel. Once the interconnection wiring is in place, it need not be changed.

Another simplification has to do with turning on city streets. Since the vehicle does not articulate, the geometric relationship between the truck and cargo box remains fixed. This means that the convex-mirror surrogates do not need to take into account the angle between the truck and the box.

Most concepts developed earlier for tractor-trailer vehicles also apply to straight trucks. The one major exception is the backing/bobtailing video. Since the truck and the cargo box are never separated from one another, the need for and reasons for a backing/bobtailing video are eliminated. In addition, most straight trucks are shorter than tractor trailers, which may make some video views less important. There may possibly be some additional video applications for straight trucks; however, no viable concepts have been found.

The trailer concepts presented earlier generally apply only to straight trucks with a cargo box. Flat-bed trucks and other types of trucks that do not have a cargo box represent a totally different application and are not covered in this research, except incidentally.

Issues of Coordination

It is important to note that only selected video systems would be used in any given application. As the number of video systems increases, care must be taken with coordination and time-sharing of displays. Otherwise, the number of monitors in the cab could pose a substantial distraction. Coordination issues and timing issues have not been emphasized in this research; however, these are important and would need to be worked out eventually.

SUMMARY

A summary of initial candidate video applications is presented in Table 6. The table includes four applications that are surrogates (two on each side) and nine applications that are enhancements.

Table 6. Listing of early potential applications of C/VISs and corresponding characteristics.

Description	Application	Camera FOV (degrees)	Camera Location	Monitor Size (in)	Monitor Location	Image Presentation
Left and right West coast (flat) mirror surrogates	Tractor; straight truck cab	Left: 20 Right: 9	Front Fender	8.5 (est) (width)	Left and Right A-pillars	Reverse
Left and right Convex-side mirror surrogates	Tractor; straight truck cab	Left: 45 Right: 45	Front Fender	Variable Size	Left and Right A-pillars or IP	Reverse
Backing/bobtailing enhancement	Tractor	70	Top center rear of cab	Variable Size	Center upper windshield or center IP	Reverse
Front blind-spot enhancement	Tractor; straight truck cab	40	Left front fender or above bumper	Variable Size	(Unknown)	Standard
Right-side look-down mirror enhancement	Tractor; straight truck cab	95	Above passenger door	Variable Size	Right header or right door below glass	Standard
Left merge/re-merge enhancement	Trailer; cargo box	45	Right rear corner, approx. 7ft high	Variable Size	Left header, forward as far as possible	Standard
Right merge/re-merge enhancement	Trailer; cargo box	45	Left rear corner, approx. 7ft high	Variable Size	Right header	Standard
Rear look-down enhancement	Trailer; cargo box	50	Top center of rear	Variable Size	Center upper windshield or center IP	Reverse
Rear-view enhancement	Trailer; cargo box	70	Top center of rear	Variable Size	Center upper windshield or center IP	Reverse
Wide-angle multipurpose look-down enhancement	Trailer; cargo box	90	Top center of rear	Variable Size	Center upper windshield or center IP	Reverse
Multi-camera enhancement system	Trailer; cargo box	(Various)	Top center of rear	Variable Size, switched	Center upper windshield or center IP	All Views reverse

CHAPTER 4: HEAVY VEHICLE DRIVERS' FOCUS GROUP

INTRODUCTION

Focus groups have been found to be very helpful during early phases of research, where they can provide insight into the opinions and needs of individuals affected by the research. In the case of C/VISs, the most important affected group is heavy-vehicle drivers. Correspondingly, a focus group was held using volunteer heavy-vehicle drivers. They provided responses to directed questions as well as their freely given opinions.

The focus group had ten participants who were paid volunteers. The only specific requirements for participation were that the participant had to hold a CDL and had to have at least three years of recent heavy-vehicle driving experience. The group was composed of nine men and one woman and was held in a conference room at VTTI.

The specific objectives of the focus group were to obtain driver opinions of the C/VIS concepts that the research team had evolved and to determine if the participants had additional C/VIS concepts that they would like to have considered. Beyond these specific objectives, the research team was interested in determining any general observations that the drivers felt were important. The fundamental idea was to have the drivers envision a vehicle in which each concept was implemented separately; that is, only one at a time (or possibly in pairs, such as left and right side). They were then to evaluate how well they felt the application would work. Rating scales and a ranking scale were administered to the participants late in the session.

PROCEDURE

Following signing of the informed consent forms and after introductions of the two research team members conducting the focus group, the sequence described below was followed:

1. Lecture Session. One researcher provided a computer-projected lecture of about 20 minutes describing important comparisons between mirrors and C/VISs. This lecture dealt with ideas on how to obtain flat-mirror surrogates which would preserve image perspective and how to increase frame size somewhat to account for increased FOV resulting from "two-eyed" view and "look-around" capability for mirrors. The lecture also defined surrogates and enhancements and described the differences between flat and convex mirrors. The lecture involved explanations of the various optical aspects in ways that heavy-vehicle drivers could understand; that is, in layman's terms.

2. Viewing Needs and Blind Spot Assessment. In this step of the focus group, the participants were invited to suggest ways in which they felt that C/VISs might be used to make their jobs easier or safer. The goal was to obtain their ideas on uses of C/VISs that would be helpful to them as they performed their jobs.

3. Mirror-Surrogate and Enhancement Concepts. Once the drivers had provided their inputs, the research team presented the eleven concepts that had been previously evolved by the researchers. Each concept was described in terms of purpose, camera location, and monitor location. Each concept was explained pictorially using computer projection of images. Drivers also had a handout containing both the lecture session images and the concept images for current and later reference. Drivers were permitted to ask questions during the presentation of the concepts. Following presentation of the concepts, the focus group took a break, with refreshments and snacks provided. During this interval, the research team assembled the new concepts provided by the participants during Step 2 above. Essentially, new or original concepts were codified and presented on flip charts. They were numbered so that they could be evaluated by the drivers along with the concepts evolved by the research team.

4. Discussion/Critiquing of Each Concept by Participants. When the focus group reconvened, the researchers explained the addition of the new concepts as presented on flip charts posted within view of the participants. The participants were asked for their comments on the eleven original concepts and the four new ones. Thereafter, they filled out free form comments on each of the fifteen concepts.

5. Ratings and Ranking of the Concepts by Participants. The drivers were then asked to complete rating forms for each concept, followed by a grand ranking. Note that for surrogates, the drivers filled out scales for Receptiveness and Adaptability; whereas for enhancements, they filled out scales for Receptiveness, Adaptability, Safety Benefit, and Usefulness. (It was believed that driver evaluation of safety benefit and usefulness for surrogates would not be reliable without a field test.)

   The final evaluation by the participants was a grand ranking of concepts from most desirable to least desirable. Drivers were instructed to assume that they were given a new standard tractor (and trailer), but with one change/addition: that is, one of the concepts. They were then asked to rank order how desirable the concept would be under these circumstances.

6. Final comments, payment, thanks, and dismissal. Following completion of the ratings and ranking, drivers were asked for any final comments. They were then thanked, paid, and dismissed. The entire session took about 3 h 15 min.

RESULTS

Step 2 Results**.** During Step 2 it became clear that the drivers wanted to use C/VISs to overcome blind spots that they perceived as troublesome. Specifically, they came up with roughly half the concepts that the researchers had devised, even though at this time the researcher-devised concepts had not yet been presented to them. In addition, they devised several new concepts. During the break, the researchers were able to discern four essentially new concepts; that is, concepts that differed substantially from those already devised by the research team. These four concepts are briefly described.

Concept 12: Left-side/Right-side Trailer Enhancement

Several of the drivers pointed out that in urban turns with tractor trailers they are essentially blind on the side opposite the turn. For example, if they turn to the right, their mirrors on the left turn with them. As a result, they have absolutely no view of the left side of the trailer. Their solution to this problem was to add a camera *at the trailer*. That way, even if the tractor was turned relative to the trailer, they would still have a view alongside the trailer. Figure 24 illustrates this concept.

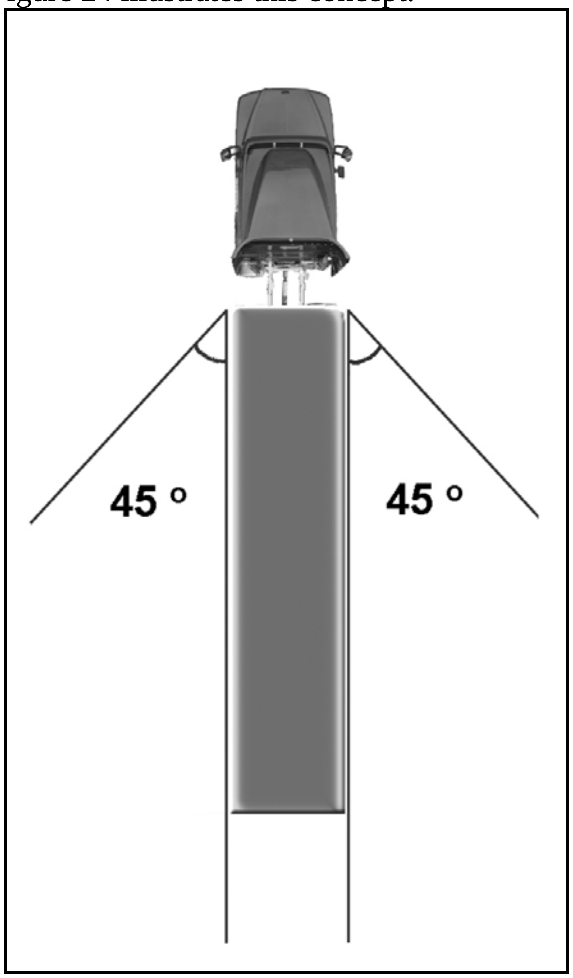

Figure 24. Left-side and right-side trailer enhancement (for enhanced visibility during urban turns).

Some drivers believed that trailers move somewhat in the opposite direction of the turn, relative to the tractor, thereby making clearance estimates very important. However, it appears that, in fact, drivers make wide turns necessitating determination of clearance. Several drivers indicated that they had been involved in minor strikes with other vehicles during these types of turns. Such strikes usually involved collisions with light-vehicle mirrors or other upper body vehicle components.

Concept 13: Right-side Wide-Angle Blind Spot Enhancement

Drivers seemed to be very concerned about the blind spot that exists all along the right side of the tractor, but particularly toward the front. Several drivers mentioned the problem of small vehicles getting under their FOV, particularly toward the right front. While this is certainly not new, they perceived the blind spot to be relatively large and suggested that a camera at the front fender with wide FOV would detect most objects along the right side of the tractor. With researcher input, they decided that the FOV should be about 80^{o}. Figure 25 shows this concept. Note that the concept is quite similar to the convex mirror surrogate (Concept 2), except that the FOV is larger. Additionally, Concept 2 would involve removal of the passenger-side (right-side) convex mirror, whereas Concept 13 would retain the mirror.

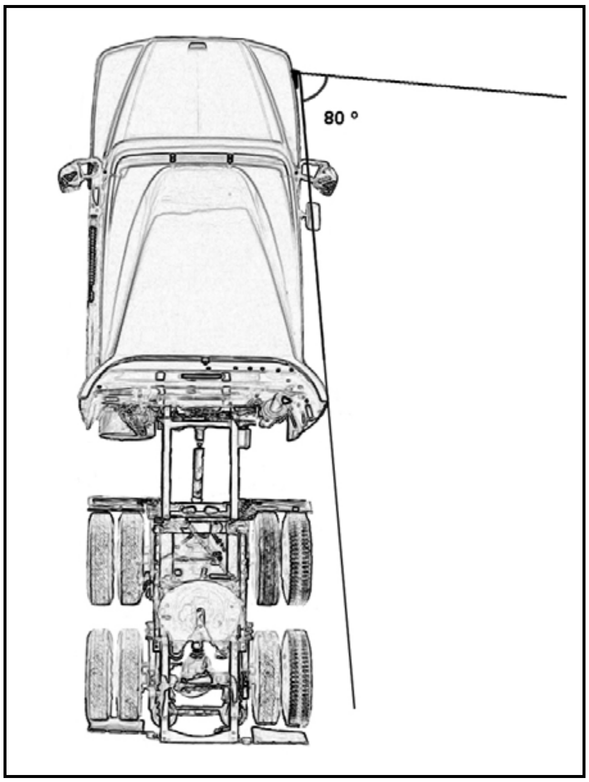

Figure 25. Right-side wide-angle blind-spot enhancement.

It is also worth noting that several drivers indicated they did not feel that passenger-side look-down mirrors were effective. This would explain why they feel vulnerable to blind spots on the right side of the tractor.

Another important point made by the drivers was that convex mirrors mounted on the fenders are prone to producing glare and that these mirrors sometimes miss objects along the right side of the tractor. Specifically, these mirrors pick up headlight and street light glare because of their wide fields of view. (Note that these are the opinions of the drivers.)

It should be remembered that drivers would probably not be familiar with the distortions that exist with wide-angle lenses. A lens with an 80^{o} FOV would have some distortion, and objects would appear to be quite small. There of course would be a tradeoff between FOV and blind-spot coverage. A somewhat smaller FOV would cover the blind spot well while having less distortion.

Concept 14: Left-side Blind Spot Enhancement

Drivers were similarly concerned about the blind spot that they perceived to exist on the left side of the tractor, from roughly the back edge of the driver door to the back end of the tractor. While smaller and somewhat less troublesome, they did feel that this is an important blind spot that could be ameliorated by a C/VIS. It should be noted that Concept 2, as applied to the left side of the vehicle, would similarly overcome this blind spot. Thus, while Concept 14 has a somewhat different emphasis, it could be implemented in the same way as Concept 2; that is, with, say, a 45^{o} FOV camera mounted at the side of the front fender. However, as was mentioned in regard to Concept 13, the main difference is that Concept 14 is envisioned as an enhancement in which the conventional convex mirror would remain, while Concept 2 would involve removal of the driver-side convex mirror.

Concept 15: Trailer Clearance Enhancement

One driver was quite concerned about vertical clearance of the trailer to obstructions such as low hanging tree branches, overhanging loading dock roofs, and low bridges. He felt that a video view of the top front of the trailer would be helpful. The idea would be to slowly approach such obstructions while watching the video monitor to check for clearance. After some discussions among participants and researchers, it was decided that the best location for the camera was at the top of the tractor faring, looking toward the rear and upward slightly. Such a C/VIS would provide some information to the driver regarding clearance at the front of the trailer. Figure 26 shows this concept. While this concept had some advocates, other drivers were not enthusiastic. Apparently, they did not feel that such a concept was needed.

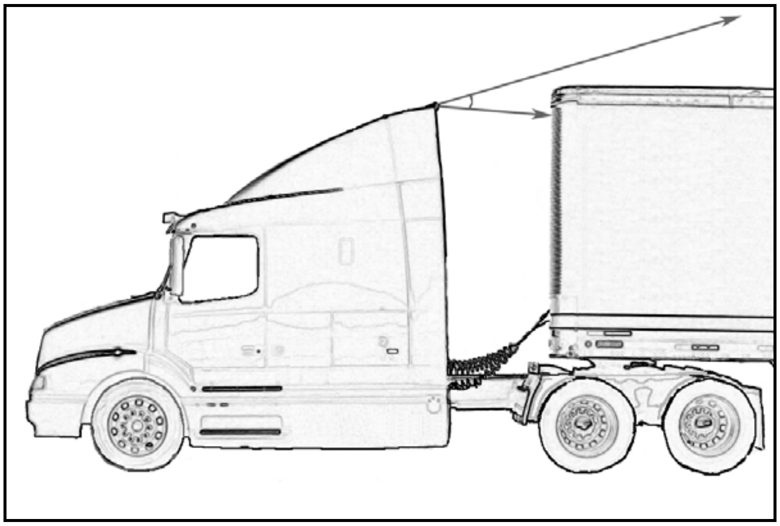

Figure 26. Trailer clearance camera concept.

Once again, it is important to note that during this portion of the focus group, the drivers suggested a variety of other concepts, all of which had been previously evolved by the research team. It can be assumed that, because the drivers came up with these concepts independently, the concepts developed by the research team were largely in line with what the drivers felt would be important.

Step 3 and Step 4 Results

Step 3 involved a lecture by the researchers on the eleven concepts they had developed. Driver participation consisted of asking questions. It appears that the drivers understood the concepts and their intended purposes. Step 4 involved open discussions of all fifteen concepts (the eleven evolved by the researchers, and the four evolved by the drivers) as well as free-form critiquing.

A few important points were made by the drivers during this discussion session. Several of the drivers expressed concern about reliability of C/VISs. These expressions were in terms such as "What about wire corrosion?" and "Trucks get a lot of vibration which could break the cameras and monitors." The drivers clearly recognized the need for "battle hardening" any C/VIS equipment.

Another important comment had to do with cleaning the camera protective glasses over the lenses. As one driver put it, "You're going to need a stepladder to clean the camera lenses." The researchers suggested that, at the very least, a pole-mounted pad or similar simple cleaning device would be needed to clean the protective glass of any camera that is above normal reach. It would be possible to use a pole with adjustable telescoping sections to perform the cleaning. In addition, maintenance, loading, and unloading personnel would need to clean the camera glasses whenever a vehicle was prepared for use.

A creative suggestion made by one of the participants was to combine the backing/bobtailing camera with the trailer rear camera. The concept was that the system would automatically switch between the two cameras depending on whether or not the trailer was connected to the tractor.

A point that the researchers made and the participants agreed on was that there were two categories of applications: over-the-road and yard/urban maneuvering. C/VIS concepts should be considered in both types of applications.

In regard to Concept 3 (the passenger-side look-down camera enhancement), several drivers wanted a larger FOV, one that covered the entire side of the tractor. No doubt these were the same drivers who felt that the current look-down mirror was inadequate and thus suggested Concept 13. Once again, it should be noted that drivers would probably not have been fully aware of the scene distortion that occurs with wide-angle lenses. Therefore, they might not have fully appreciated the tradeoffs that exist between angle of view and scene distortion. If they had been fully aware, it might have changed their opinions somewhat regarding large angles of coverage.

As previously stated, it was generally clear that the drivers were very concerned about their blind spots, and they considered C/VISs as a way of overcoming the problems that blind spots cause. Following the focus group, the *experimenters* developed the top view diagram of blind spots shown in Figure 27. This diagram is the experimenters' assessment of the way that the drivers perceived their blind spots. It helps to explain the responses that drivers provided.

As the discussion ended, drivers filled out the free-form critiquing questionnaire. The questionnaire simply asked for comments on each concept. For the four new concepts, additional handout pages were copied and distributed. There was quite a bit of variability in the responses. Nevertheless, the great majority of responses reflected the discussion points already raised.

Step 5 Results

Immediately following completion of the free-form questionnaires, the drivers were asked to provide ratings for each concept using horizontal summated scales with vertical delineators. There were five descriptors. As mentioned, the drivers rated the surrogates on only two scales: receptiveness and adaptability. It should be mentioned that the passenger-side look-down enhancement was initially treated as a surrogate. As a result, ratings were only obtained for receptiveness and adaptability. Later in the project, this concept was changed to an enhancement. The other enhancements were also rated in regard to safety benefit and usefulness; that is, four scales in total.

To analyze the responses on the rating scales, the vertical delineators on the scales were assigned numerical values. A value of zero was assigned to the left delineator, a value of 1 to the next, and so on, up to a value of 8 for the right delineator (nine delineators in all). Using this scheme, a value of 4 was associated with the center value. This value corresponds to a "moderate" rating. It could be assumed that values less than 4 are associated with an element of negative inclination, whereas values above 4 are associated with an element of positive inclination.

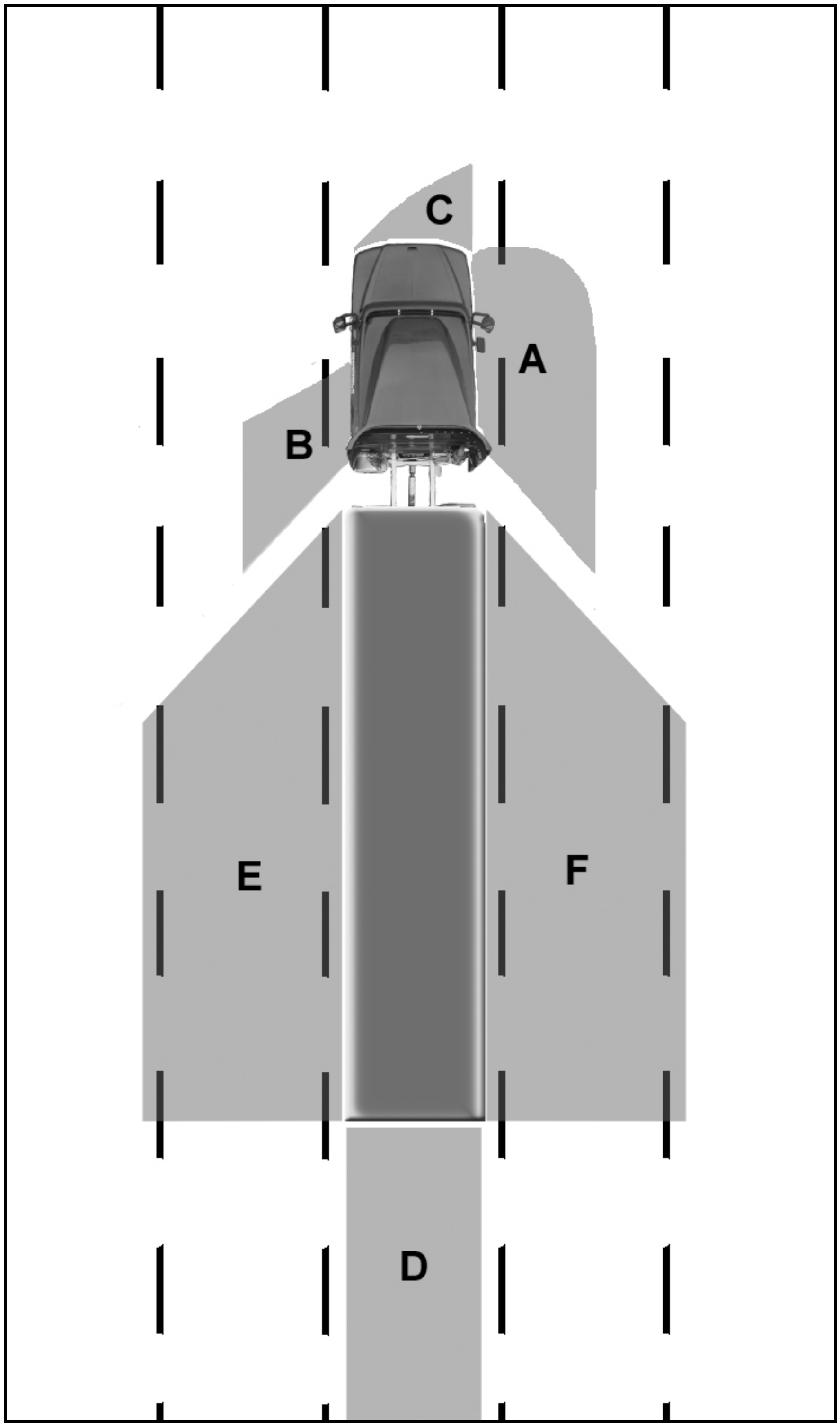

Figure 27. Focus group drivers' perceived areas of blind spots, as depicted by the experimenters. (Note that E and F are associated with turning situations).

Figures 28 through 42 show plots of histograms for each scale used on each concept. Note that for Concepts 13 and 14, one driver left the ratings blank, and for Concepts 14 and 15, one driver failed to hand in a rating sheet. Thus, the total number of responses plotted is nine for Concepts 13 and 15, and eight for Concept 14. All of the other scales contain ten responses. Also, note that in a few cases, drivers placed their ratings on the line between vertical delineators. If so, ratings were recorded as half the value for the lower delineator and half the value for the upper delineator. The figures show that all of the scales are positively biased, since the great majority of responses are either at or to the right of center. Clearly, the drivers as a group favored all 15 concepts. A few concepts received no negative ratings.

To obtain an idea of which concepts had the highest overall ratings, the mean, median, and variance of the ratings were calculated for each scale. Table 7 contains these calculations. Using median values of Receptiveness, the following concepts had values at or above 7.0: Concept 6 (Trailer rear-view enhancement), Concept 7 (Trailer rear look-down enhancement), Concept 9 (right merge/re-merge trailer enhancement), Concept 10 (Trailer rear multi-camera enhancement), Concept 11(Trailer rear wide-angle look-down enhancement), Concept 12 (left and right-side trailer view enhancement), Concept 13 (right-side wide-angle tractor blind-spot enhancement), Concept 14 (left-side blind-spot tractor enhancement) and Concept 15 (Trailer clearance enhancement). These values suggest that drivers would be highly receptive to trying the corresponding C/VISs. Note specifically that none of the surrogates appear in this list. It is believed that the surrogates received somewhat lower ratings because some drivers were reticent to give up their mirrors.

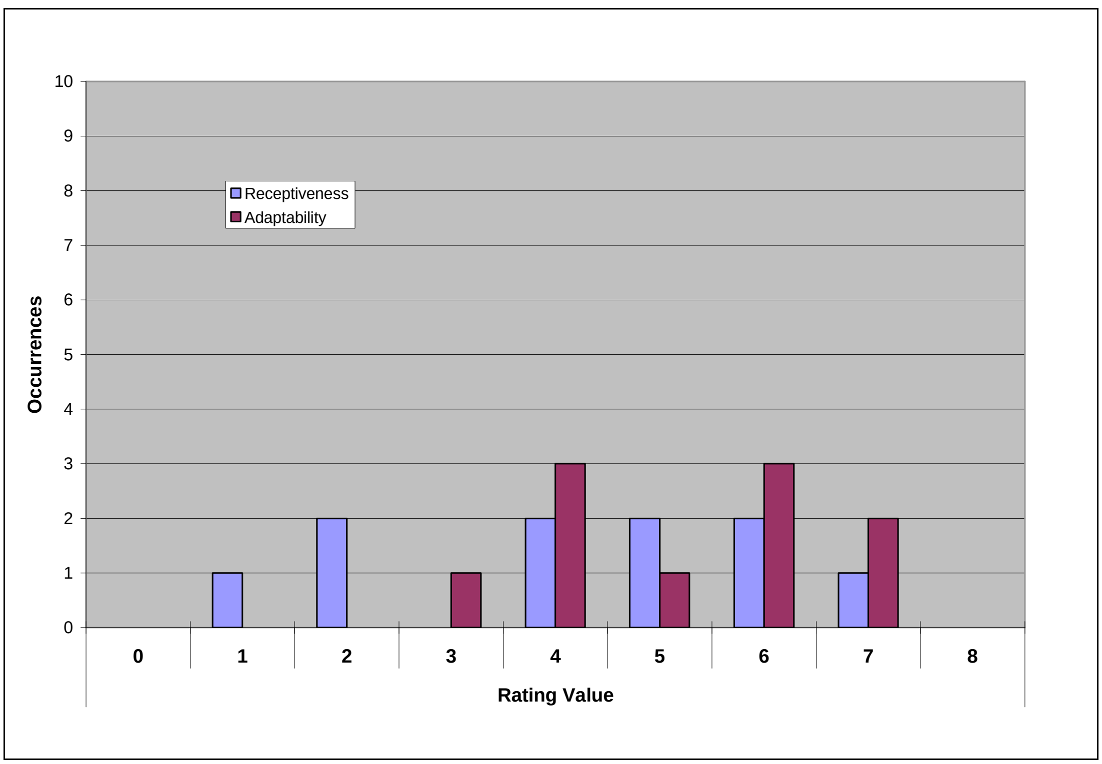

Figure 28. Ratings histogram for Concept 1, Flat/west coast mirror surrogates (10 responses).

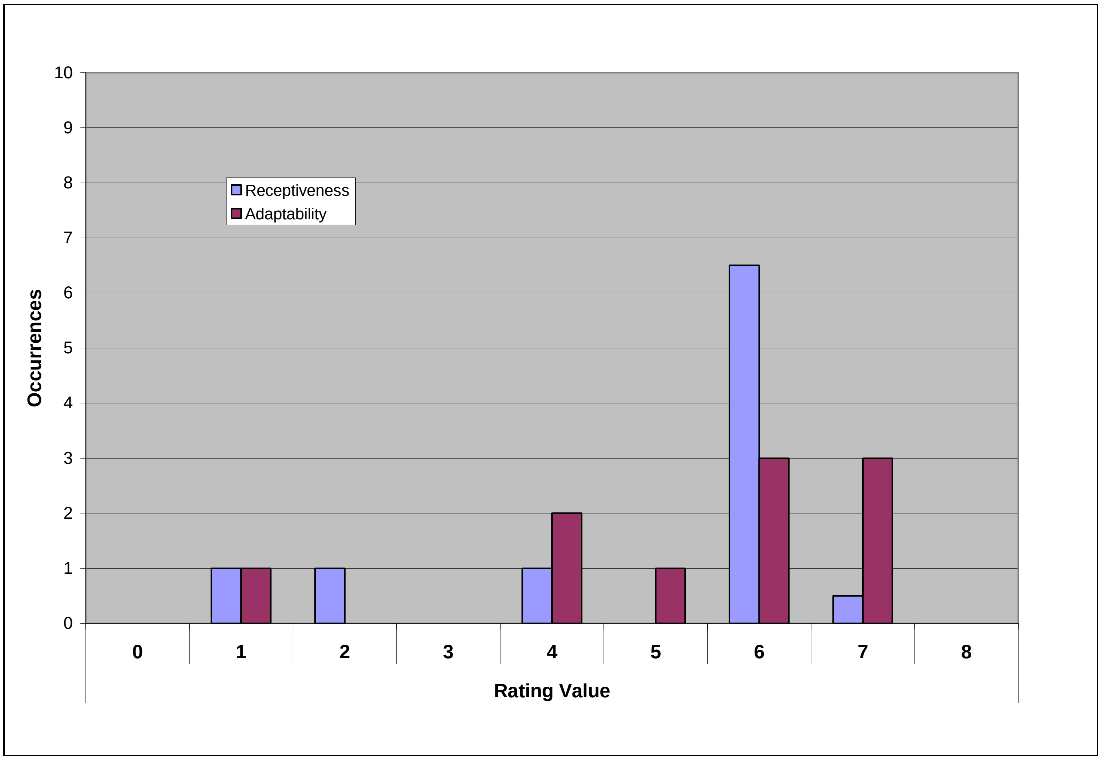

Figure 29. Ratings histogram for Concept 2, convex mirror surrogates (10 responses).

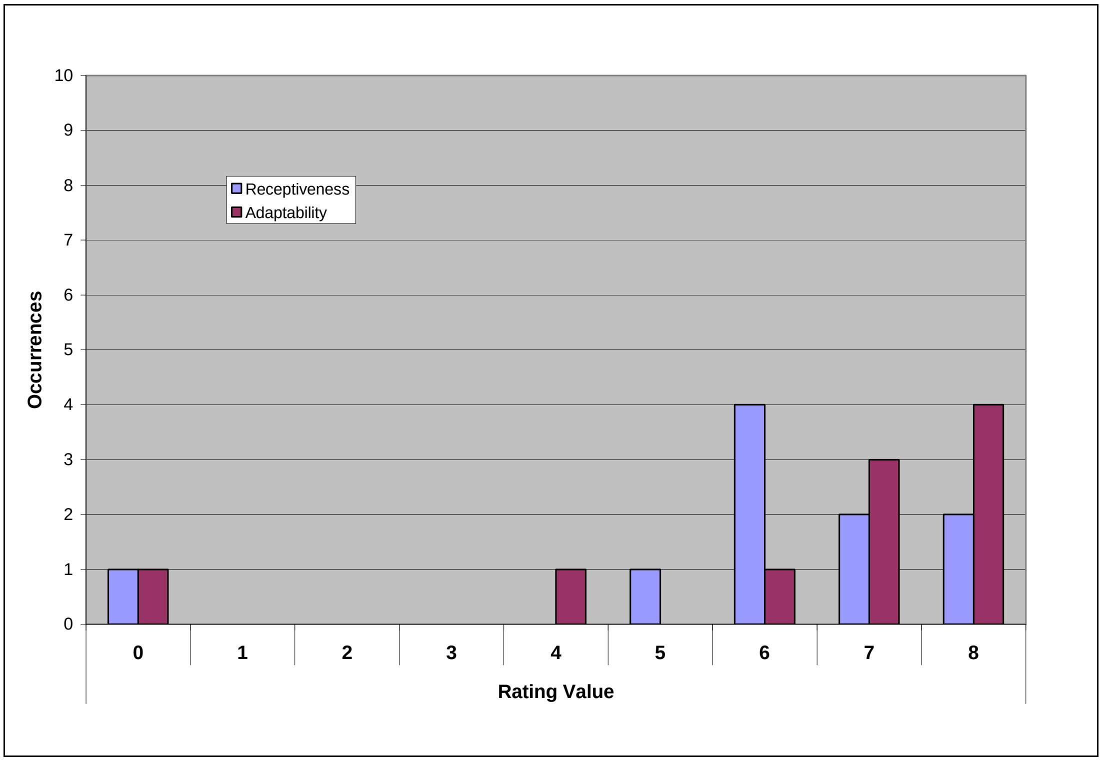

Figure 30. Ratings histogram for Concept 3, passenger-side look-down (tractor) enhancement (10 responses).

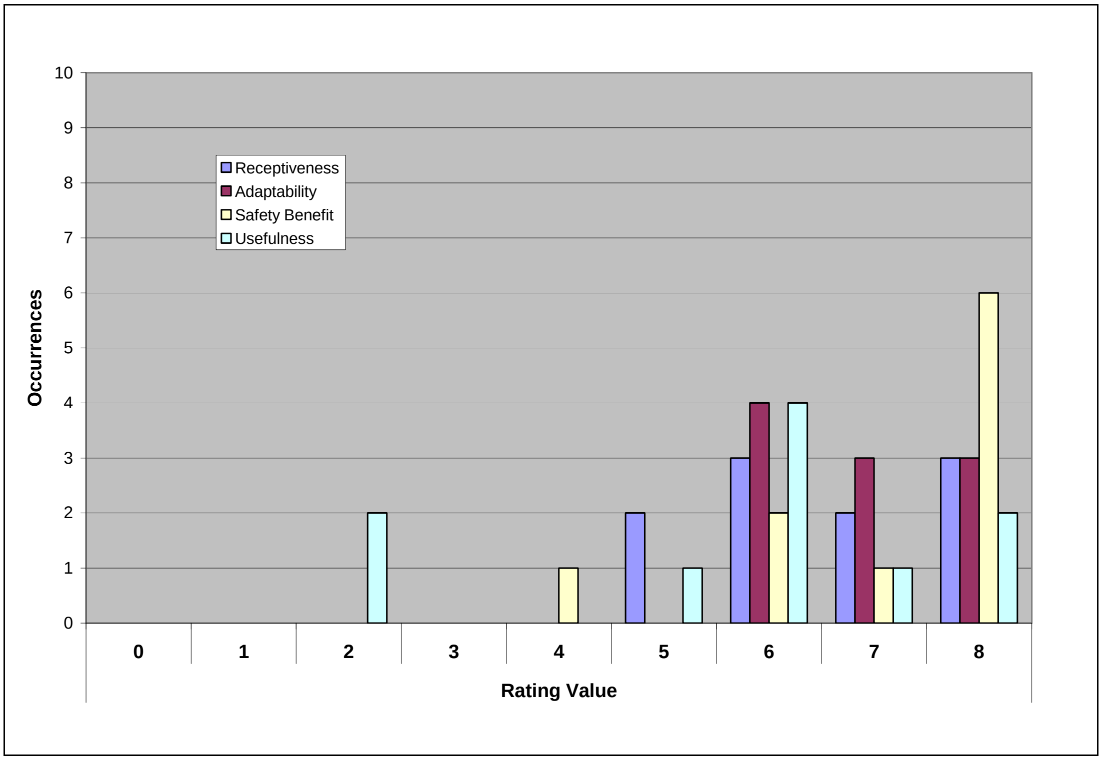

Figure 31. Ratings histogram for Concept 4, front blind spot (tractor) enhancement (10 responses).

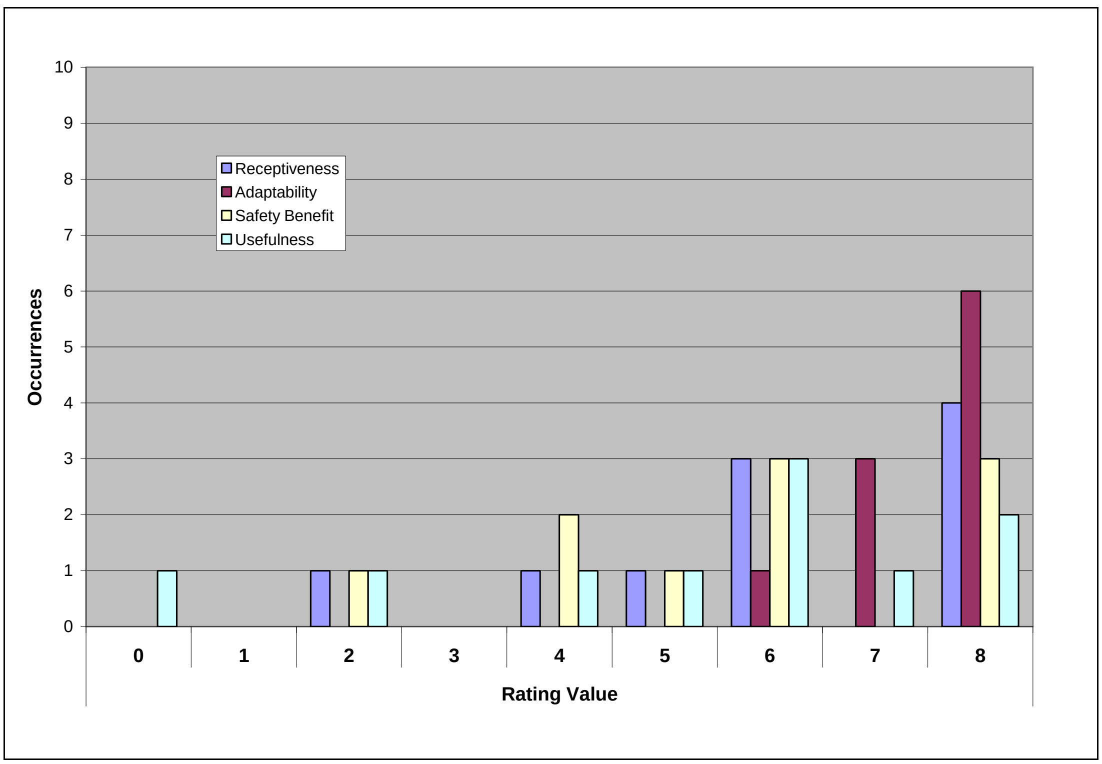

Figure 32. Ratings histogram for Concept 5, backing/bobtailing (tractor) enhancement (10 responses).

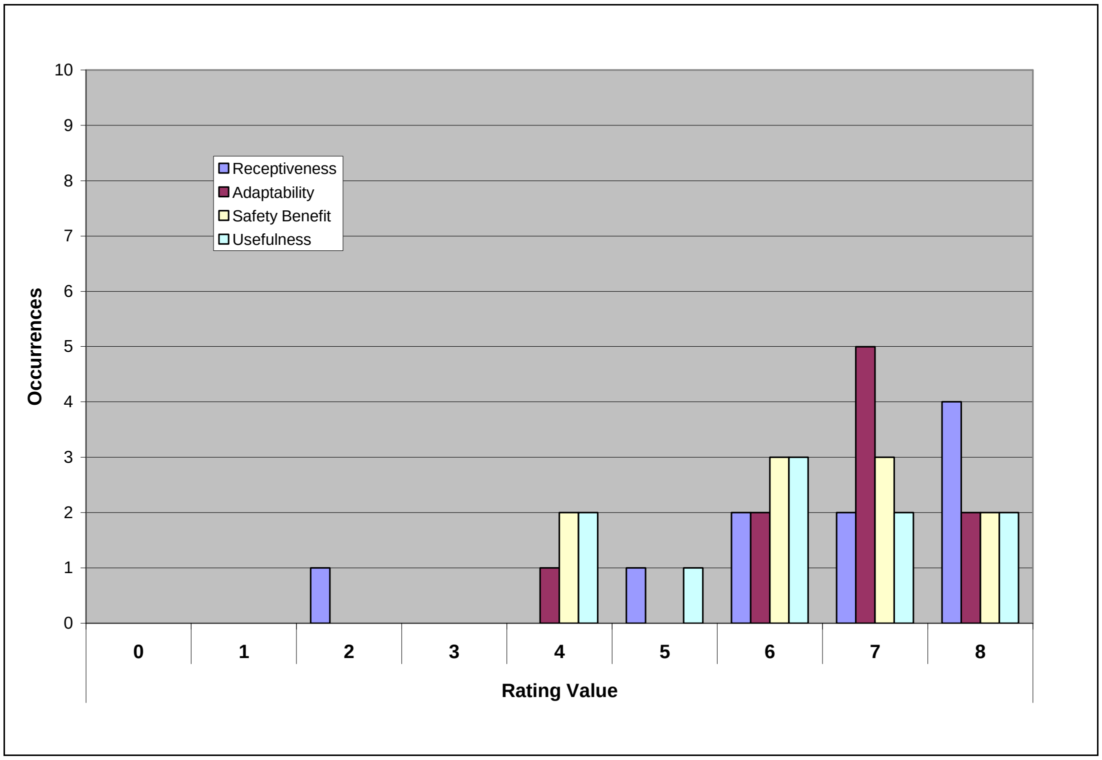

Figure 33. Ratings histogram for Concept 6, trailer rear-view enhancement (10 responses).

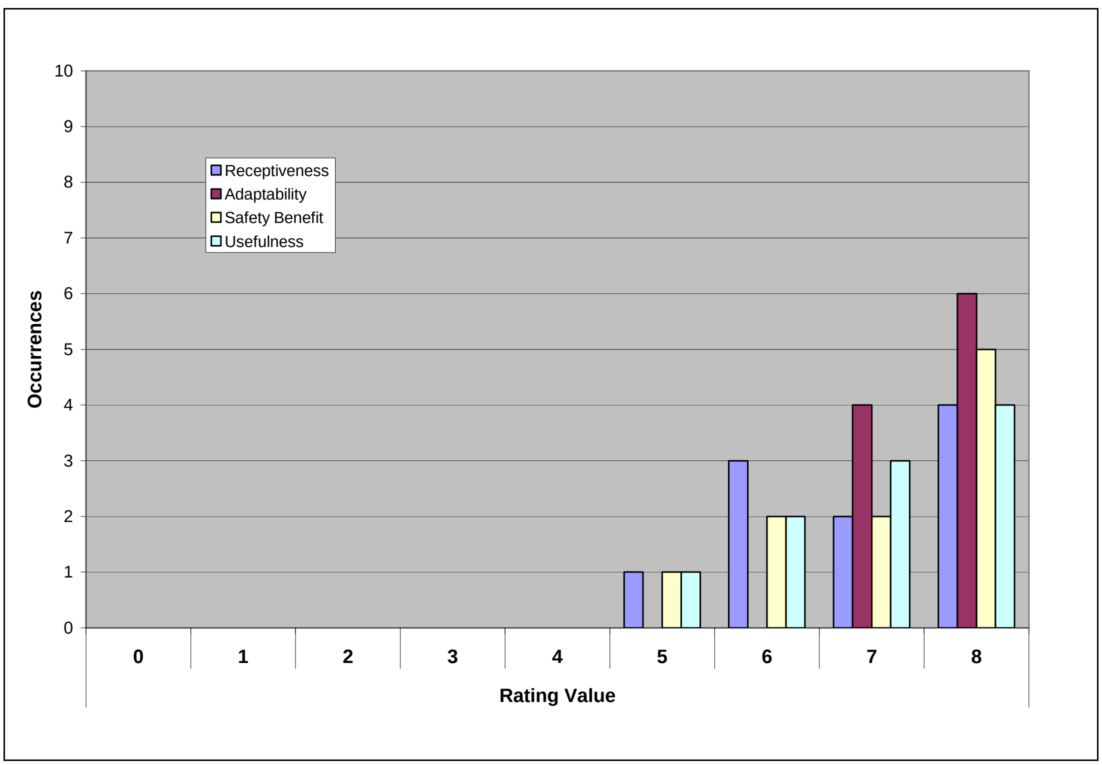

Figure 34. Ratings histogram for Concept 7, trailer rear look-down enhancement (10 responses).

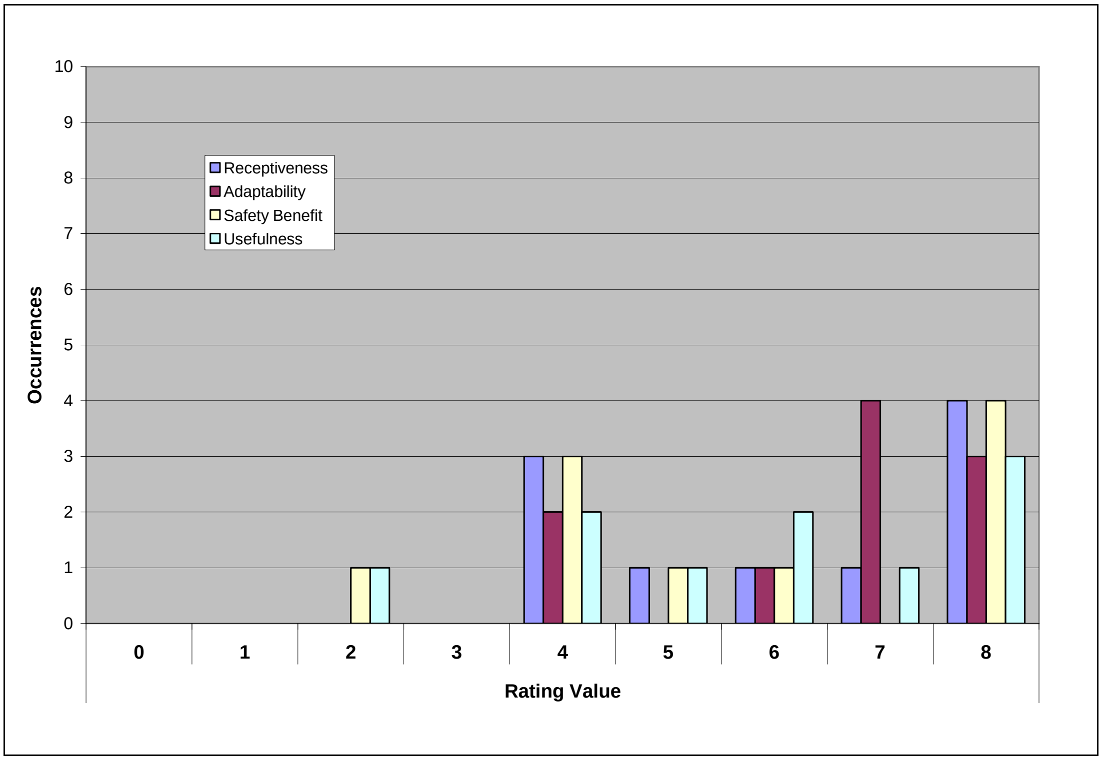

Figure 35. Ratings histogram for Concept 8, left merge/re-merge (trailer) enhancement (10 responses).

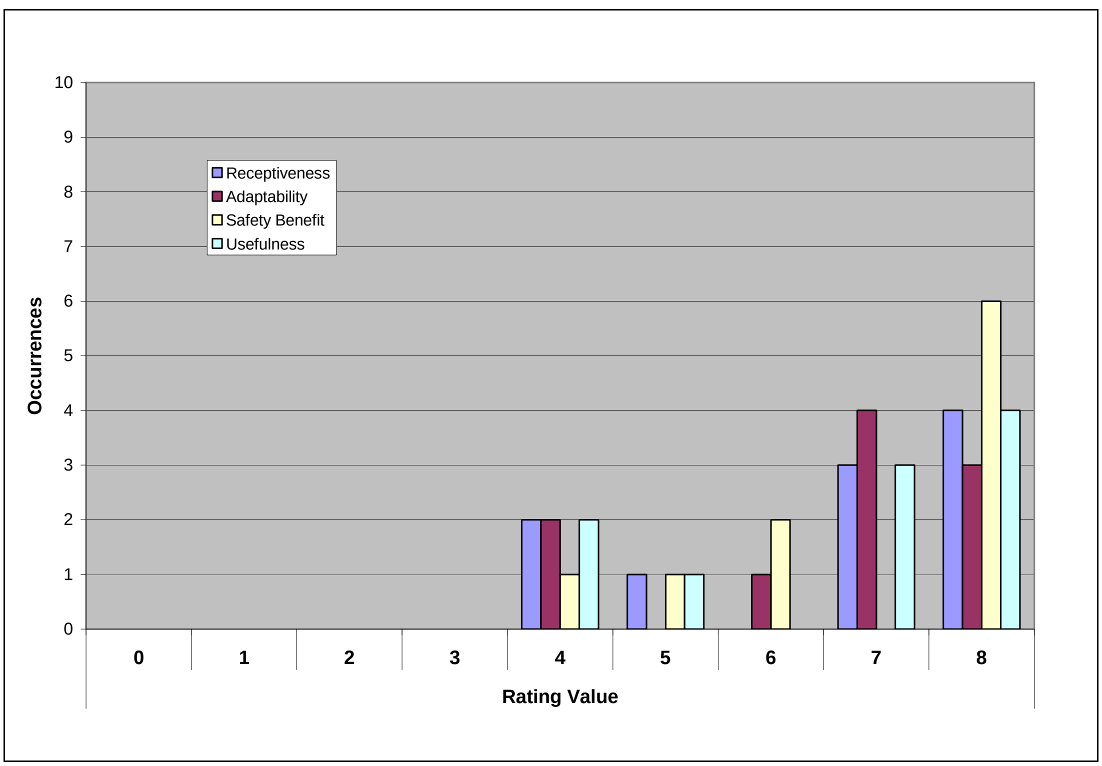

Figure 36. Ratings histogram for Concept 9, right merge/re-merge (trailer) enhancement (10 responses).

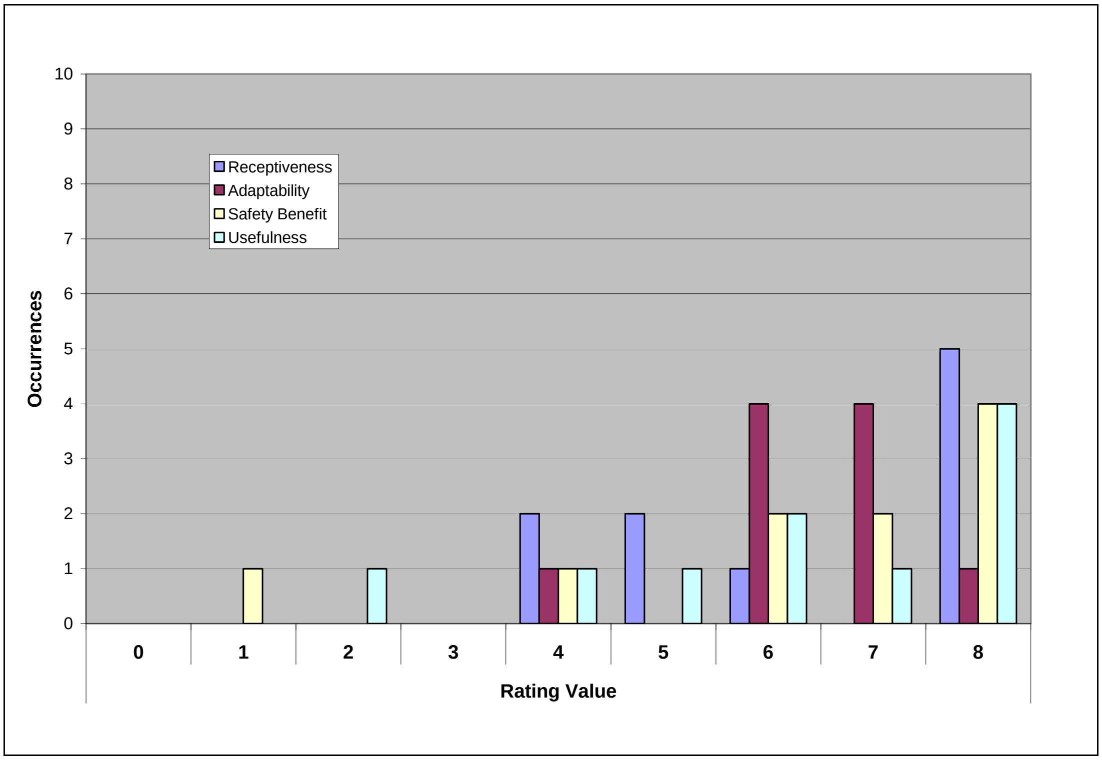

Figure 37. Ratings histogram for Concept 10, trailer rear multi-camera enhancement (10 responses).

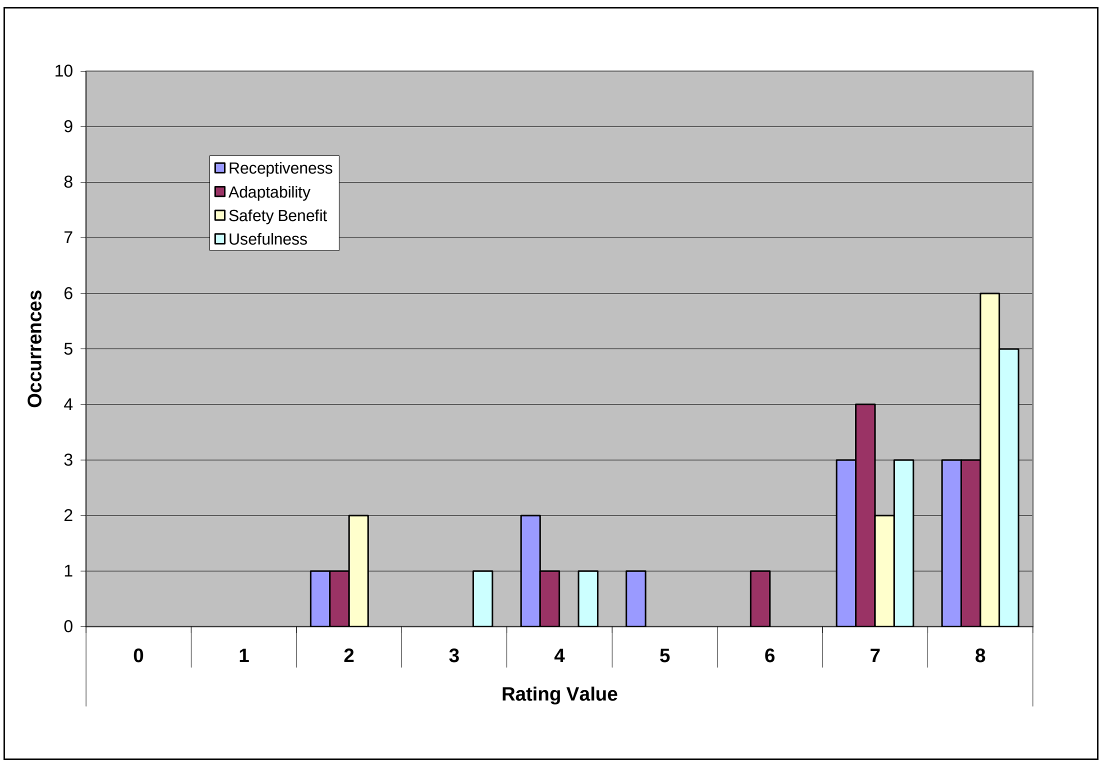

Figure 38. Ratings histogram for Concept 11, trailer wide-angle rear multipurpose look-down enhancement (10 responses).

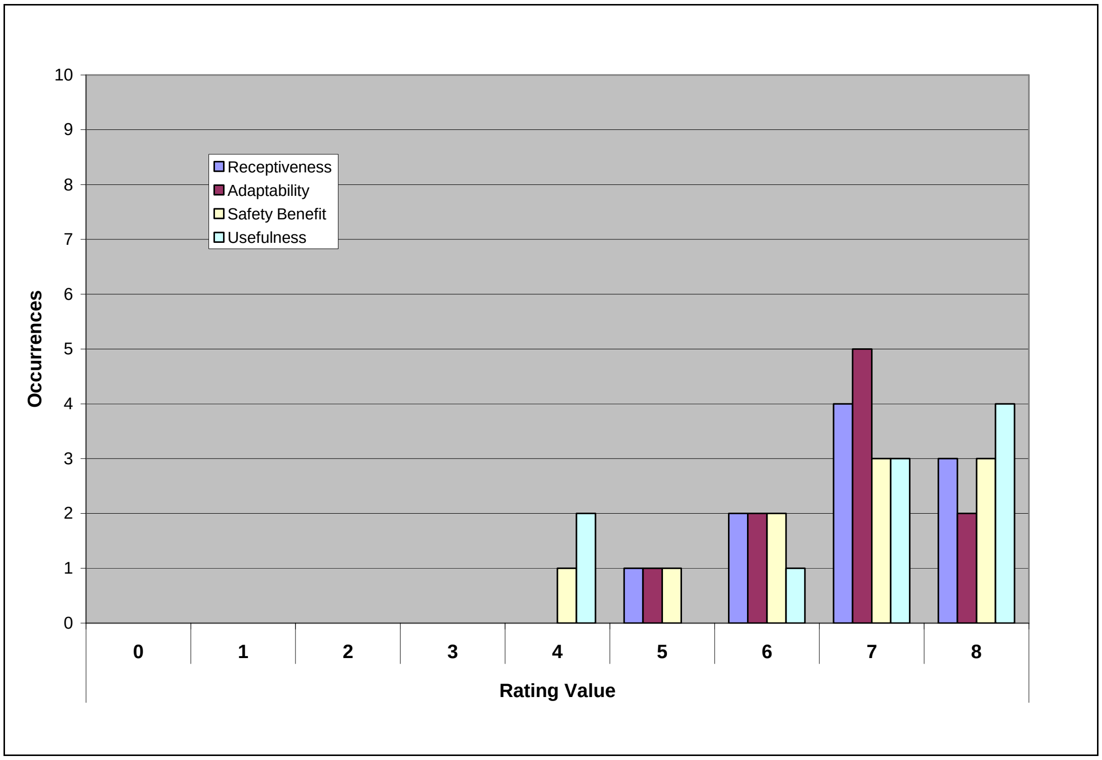

Figure 39. Ratings histogram for Concept 12, left/right-side trailer view enhancements (10 responses).

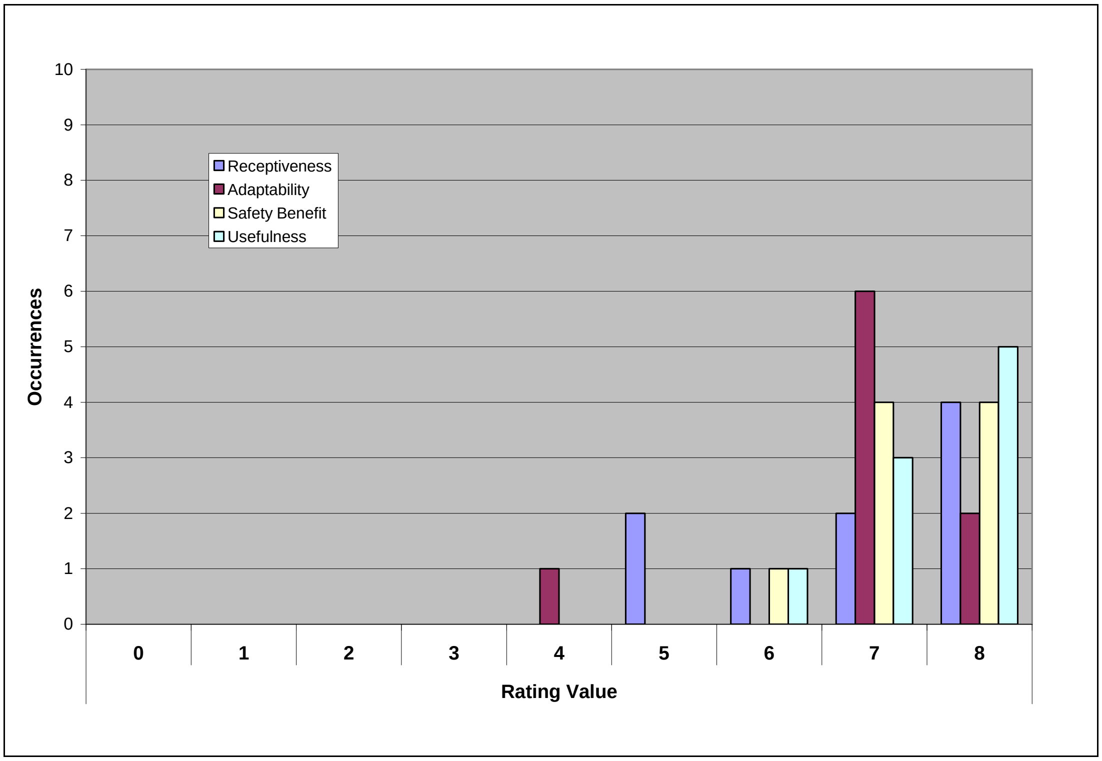

Figure 40. Ratings histogram for Concept 13, right-side wide-angle (tractor) blind-spot enhancement (9 responses).

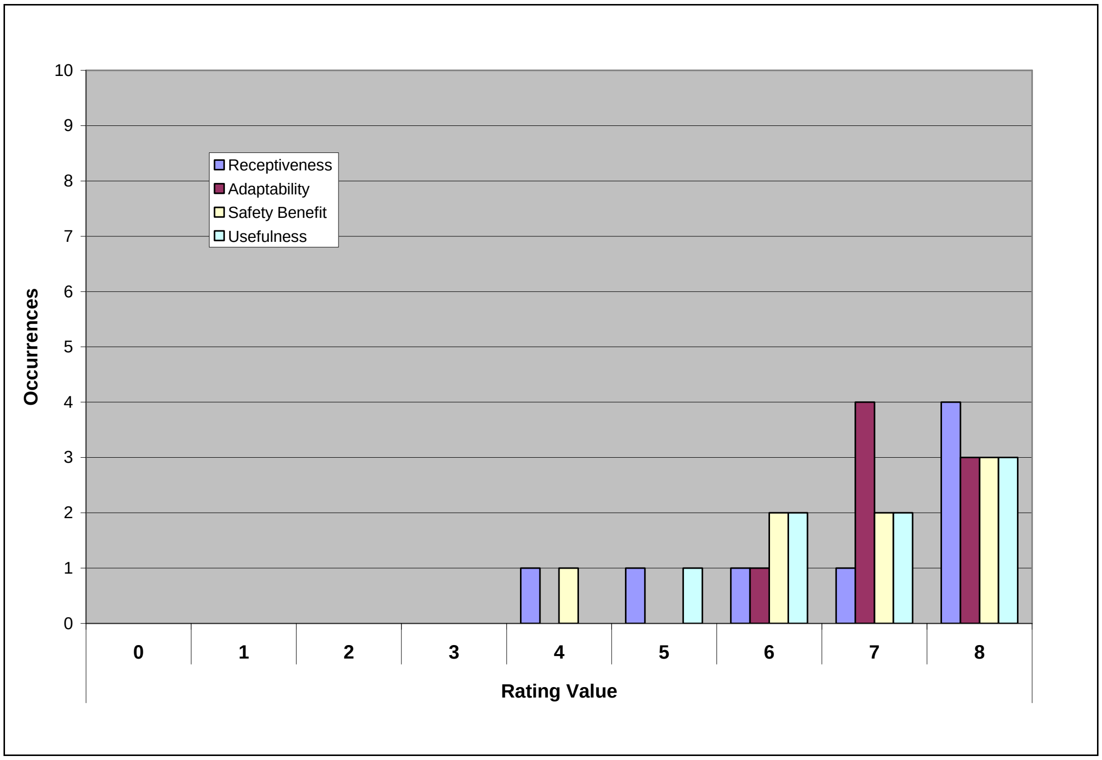

Figure 41. Ratings histograms for Concept 14, left-side blind spot (tractor) enhancement (8 responses).

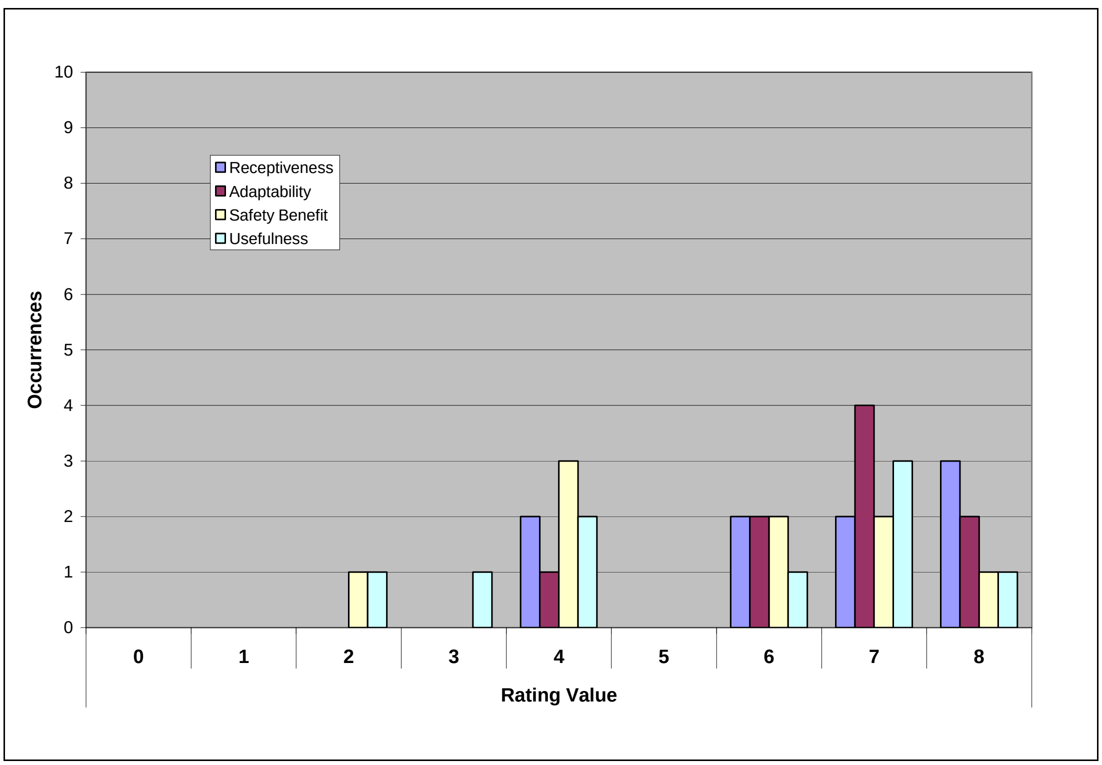

Figure 42. Ratings histogram for Concept 15, trailer clearance (camera on tractor) enhancement (9 responses).

Table 7. Median, mean, and variance calculations for focus group concept ratings.

Statistical Analysis for the Focus Group Response Values					
	Concept	Attribute	Rating		
			Median	Mean	Variance
Surrogates	1. Flat (west coast) mirror surrogates (driver and passenger sides)	Receptiveness	4.5	4.20	1.99
		Adaptability	5.5	5.20	1.40
	2. Convex mirror surrogates (driver and passenger sides)	Receptiveness	6.0	4.95	1.95
		Adaptability	6.0	5.30	1.89
	3. Passenger side look-down enhancement	Receptiveness	6.0	5.90	2.28
		Adaptability	7.0	6.30	2.54
Enhancements	4. Front blind-spot enhancement	Receptiveness	6.5	6.60	1.17
		Adaptability	7.0	6.90	0.88
		Safety Benefit	8.0	7.10	1.37
		Usefulness	6.0	5.60	2.12
	5. Backing/bobtailing (tractor) enhancement	Receptiveness	6.0	6.10	2.02
		Adaptability	8.0	7.50	0.71
		Safety Benefit	6.0	5.70	2.00
		Usefulness	6.0	5.20	2.57
	6. Rear-view (trailer) enhancement	Receptiveness	7.0	6.50	1.90
		Adaptability	7.0	6.70	1.16
		Safety Benefit	6.5	6.30	1.42
		Usefulness	6.0	6.10	1.45
	7. Rear look-down (trailer) enhancement	Receptiveness	7.0	6.90	1.10
		Adaptability	8.0	7.60	0.52
		Safety Benefit	7.5	7.10	1.10
		Usefulness	7.0	7.00	1.05
	8. Left merge/re-merge (trailer) enhancement	Receptiveness	6.5	6.20	1.81
		Adaptability	7.0	6.60	1.51
		Safety Benefit	5.5	5.70	2.21
		Usefulness	6.0	5.80	2.04
	9. Right merge/re-merge (trailer) enhancement	Receptiveness	7.0	6.60	1.65
		Adaptability	7.0	6.60	1.51
		Safety Benefit	8.0	6.90	1.52
		Usefulness	7.0	6.60	1.65
	10. Multi-camera (trailer) enhancement	Receptiveness	7.0	6.40	1.78
		Adaptability	6.5	6.40	1.07
		Safety Benefit	7.0	6.30	2.26
		Usefulness	6.5	6.20	2.04
	11. Wide-angle (trailer) look-down enhancement	Receptiveness	7.0	6.00	2.11
		Adaptability	7.0	6.40	1.96
		Safety Benefit	8.0	6.60	2.46
		Usefulness	7.5	6.80	1.81
	12. Left & right side trailer view enhancement (tractor)	Receptiveness	7.0	6.90	0.99
		Adaptability	7.0	6.80	0.92
		Safety Benefit	7.0	6.60	1.35
		Usefulness	7.0	6.70	1.57
	13. Right side wide angle enhancement blind spot	Receptiveness	7.0	6.89	1.27
		Adaptability	7.0	6.89	1.17
		Safety Benefit	7.0	7.33	0.71
		Usefulness	8.0	7.44	0.73
	14. Left side (tractor) blind spot enhancement	Receptiveness	7.5	6.75	1.58
		Adaptability	7.0	7.25	0.71
		Safety Benefit	7.0	6.75	1.39
		Usefulness	7.0	6.88	1.13
	15. Trailer clearance enhancement	Receptiveness	7.0	6.44	1.59
		Adaptability	7.0	6.67	1.22
		Safety Benefit	6.0	5.33	1.94
		Usefulness	6.0	5.33	2.12

Ratings using the other scales generally tracked the receptiveness scale, but there is variability, particularly with regard to the perceived Safety Benefit. Nevertheless, it can be said that drivers were generally positive in regard to the introduction of various C/VIS concepts.

The final evaluation performed by the drivers was an overall ranking of desirability. In this case, drivers were requested to rank the 15 concepts from “most desirable” to “least desirable.” Because the ranking of 15 different concepts can be quite difficult (because of the high number), the researchers suggested that the drivers might want to first form three groups of 5 concepts: top, medium, and bottom rated. They could then rank within the top 5, the middle 5, and bottom 5. Thereafter, they could make any final adjustments. This approach was only a suggestion, and drivers were totally free to rank the 15 configurations in any way they wished.

The results of the ranking process are shown in Table 8. The configurations are shown in the order of their rank from highest rank (lowest summed score) on the left to lowest rank (highest summed score) on the right. Note that in this table, a score of 1 would indicate a driver’s highest rank and a score of 15 would indicate a driver’s lowest rank, in terms of desirability.

A Friedman nonparametric two-way analysis of variance (ANOVA) was performed on the data with k = 15 (the number of concepts) and N = 10 (the number of drivers.) (Note that there were no missing data for these rankings.) The results were significant ($\chi r2 = 31.6$, $p = 0.01$). They demonstrate that drivers significantly preferred some configurations over others. To determine which concepts were preferred, nonparametric sign tests were performed as follows. The top--ranked concept was compared consecutively with the next-to-top-ranked concept. If not significant ($\alpha = 0.05$), the top-ranked concept was compared with the third-ranked concept. This process was continued until a significant comparison occurred. It was then assumed that all previous comparisons involved concepts not reliably different from one another. The sign tests indicated that the top eight configurations did not differ significantly from one another. In Table 8, these eight are the ones in the first eight columns. Note that the two “surrogates” concepts are included in this grouping; namely, the west coast/flat mirror surrogates and the convex mirror surrogates.

Table 8. Concepts in order of focus group rankings, from left column (most desirable) to right column (least desirable).

Rank: 1 most desirable, 15 least desirable	13	12	8	2	9	4	1	6	14	7	3	11	5	10	15
Participant #	Right side wide-angle tractor blind spot enhancement	Left/right side trailer view enhancement	Left merge/re-merge (trailer) enhancement	Convex mirror surrogates (driver and passenger sides)	Right merge/re-merge (trailer) enhancement	Front blind spot enhancement	West coast/Flat surrogates (driver and passenger sides)	Rear view (trailer) enhancement	Left side (tractor) blind spot enhancement	Rear look-down (trailer) enhancement	Passenger Side lookdown enhancement	Wide-angle (trailer) look-down enhancement	Backing/bobtailing (tractor) enhancement	Multi-camera (trailer) enhancement	Trailer clearance enhancement
1	3	10	6	2	7	11	1	8	4	12	5	13	14	9	15
2	12	5	4	2	10	3	1	8	11	9	6	14	7	15	13
3	10	9	1	5	2	3	13	4	11	14	6	8	12	7	15
4	2	1	5	10	7	12	9	11	3	4	15	6	8	13	14
5	2	1	6	10	7	11	9	12	3	4	15	5	8	13	14
6	4	2	1	7	3	8	6	14	5	15	13	12	9	11	10
7	2	12	8	7	5	1	15	3	11	4	10	6	9	13	14
8	1	6	8	14	5	7	15	9	3	11	2	12	13	4	10
9	3	1	11	5	8	12	4	6	14	7	13	10	15	9	2
10	8	7	9	2	10	3	1	4	14	6	12	13	5	11	15
Sum	47	54	59	64	64	71	74	79	79	86	97	99	100	105	122
Rank	1	2	3	4.5	4.5	6	7	8.5	8.5	10	11	12	13	14	15

Additional nonparametric sign tests suggested that the preferences of drivers were quite broad. For example, comparing the next-to-top configuration with all others of lesser overall rank resulted in a grouping of 13 concepts, that is, all but the top- and bottom-ranked concepts. These results are in line with the rating scales, which showed general receptiveness to all of the concepts.

Since surrogates represent a special class of C/VISs, they were temporarily deleted from the analysis (the passenger-side look-down C/VIS was retained, since it was then considered an enhancement). A Friedman two-way analysis of variance with k = 13 and N = 10 was then performed. Once again, the results demonstrated significance ($\chi_r^2 = 31.53$, $p = 0.01$.) Thus, there was a reliable difference among the enhancements when taken as a group. The same group of nonparametric sign tests showed, of course, that the first six enhancements did not differ significantly. These are exactly the same as those appearing within the top eight configurations shown in Table 8.

Step 6 Results

Payment and dismissal were routine, with several of the drivers commenting that they had enjoyed the focus group and wanted to volunteer for any road tests the researchers might later perform. In addition, one or two additional emphasizing comments were made having to do mostly with ensuring the reliability of any C/VISs that are eventually placed on heavy vehicles. One driver mentioned the problem of condensation and frozen sleet on the camera glass, suggesting the need to heat the glass during winter conditions.

CONCLUSIONS

A number of important conclusions can be drawn from the focus group that was conducted. First, the focus group appears to have been successful in getting heavy vehicle driver input into the process of C/VIS concept development. While an additional focus group might have confirmed the evaluations and recommendations of the drivers, it is unlikely that much in the way of new information would have been generated.

It appears that the drivers were fully engaged in the focus group process and that they fully understood the concepts and importance of what they were doing. Comments were relevant and creative. In addition, the drivers represented important differences in demographics associated with the types of industries that employed them. One pair of drivers was a husband/wife team, one driver came from the furniture industry, and most others were either owner/operators or worked for major trucking concerns.

Indications are that the drivers saw C/VISs as a means of overcoming blind spots, and their selections and preferences were influenced accordingly. While they understood the use of C/VISs for surrogates, they appear to have given a slight preference to enhancements directed at overcoming blind spots; that is, those not currently covered by the main mirrors. Nevertheless, it must be stated that both surrogates (that is, for flat and convex mirrors) ended up in the top eight rankings.

Drivers were generally receptive to all of the concepts; that is, their individual ratings on receptiveness showed a strong positive bias. One or two drivers showed some reluctance in regard to surrogates as well as in regard to some of the enhancements, but in general the overwhelming majority provided ratings at or above the “moderately open” level.

The drivers themselves evolved a group of four new concepts that were directed mainly at blind spots that they felt were not fully covered by the concepts the researchers had devised. There is some overlap between some of these concepts and those devised by the researchers.

The data demonstrate a reliable (statistically significant) preference for some concepts over others. However, this preference is relatively broad.

Table 8 shows the overall preference rankings. As indicated earlier, the first eight of these are not statistically different from one another, nor are the second- to fourteenth-ranked configurations. Therefore, one could consider the first eight as the main preference of the drivers, but perhaps the first 14 are acceptable. These statements are placing interpretations on the data, but are probably justified based on the receptiveness ratings previously described, which showed generally positive values.

Finally, the focus group in general provided the necessary driver perspective in regard to C/VIS concepts and in regard to eventual C/VIS selection and specification. It could be said that the process was successful in meeting project objectives.

CHAPTER 5: REVISION OF C/VIS CONCEPTS BASED ON FOCUS GROUP RESULTS

Following completion of the focus group, a total of 15 applications concepts had been proposed. Several of these are similar, making it possible to consider combinations that would reduce the total number, but retaining and possibly improving the remaining concepts. In this chapter, the logic behind these combinations is provided. In addition, one concept is eliminated on the basis of low desirability, relatively speaking, among the drivers in the focus group.

All of the potential camera positions along with the various angles are shown in Figures 43 and 44. Similarly, all of the potential monitor positions are shown in Figures 45 and 46. The figures will be referred to as the revisions are discussed. It is important to note that the concepts are considered to be relatively independent of one another and that, at most, only a small number would be implemented in any given vehicle. Otherwise, much greater consideration must be given to coordination of the various concepts used.

REPLACEMENT OF CONCEPT 3 WITH CONCEPT 13

Concept 13 is the right-side wide-angle blind-spot camera concept. The camera is placed on the right fender, is pointed rearward, and has an FOV of approximately 80^o (Figure 43, camera location B.) This camera is intended to overcome the blind spot all along the right side of the tractor, including the right side near the front fender. Concept 13 was evolved by the focus group, but there was no discussion of where the monitor should be located.

Concept 3 is the right-side look-down surrogate/enhancement. It was envisioned as including a wide-angle down-looking camera above the passenger-side door and a monitor inside the cab above the door (right-side header area). Several focus group members indicated they did not like the look-down *mirror* and that they did not trust it for detection of objects on the right side of the tractor. Concept 3 would require an extremely wide FOV to cover the entire right side of the tractor, and in addition, the image would provide a top view. This might create some difficulties for some drivers. If the right-side blind-spot camera is moved from above the passenger-side door to the front fender, the image is much closer to that of a wide-angle rear-view mirror. Consequently, the camera image can be reverse-scanned and should then be familiar to the driver.

As mentioned, the monitor location for Concept 13 was not discussed in the focus group. Considering that the camera view is essentially a rear view, it appears that the monitor could be placed in the right front header area (Figure 45, location H.) An alternative would be to place the monitor somewhere in or above the center dash (Figure 45, monitor locations J or K.) One manufacturer has developed a demonstrator vehicle that includes a right-side wide-angle video with a “pop-up” monitor. The monitor is located on the top of the dash to the right of the steering wheel. It can be retracted (into the dash) by the driver, if desired. If C/VIS surrogates are not used for the flat and convex mirrors on the right side of the tractor, the monitor could be placed at the base of the right A-pillar (Figure 46, location D). A smaller monitor could probably be used in this case.

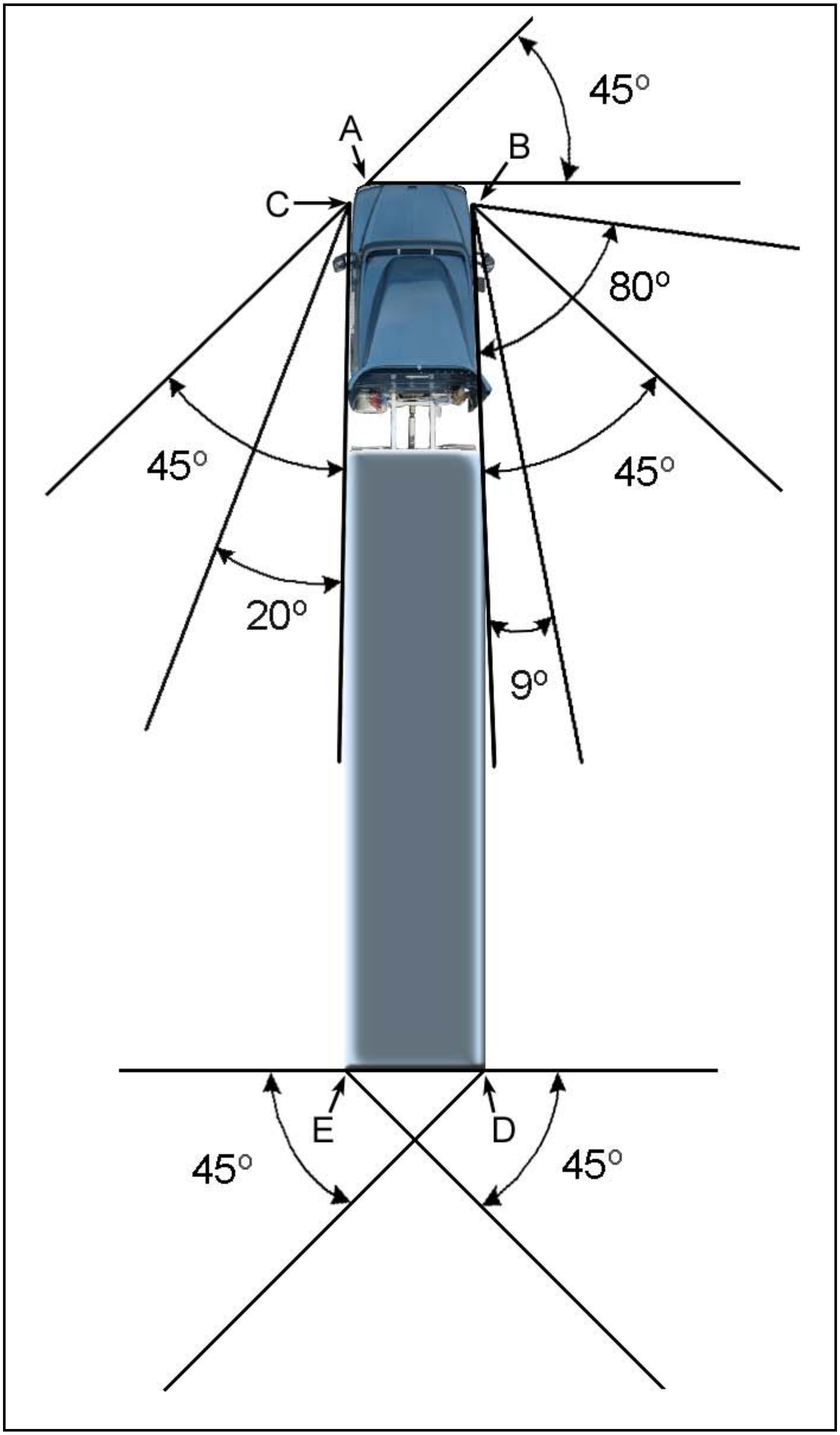

Figure 43. First group of potential camera locations (early version).

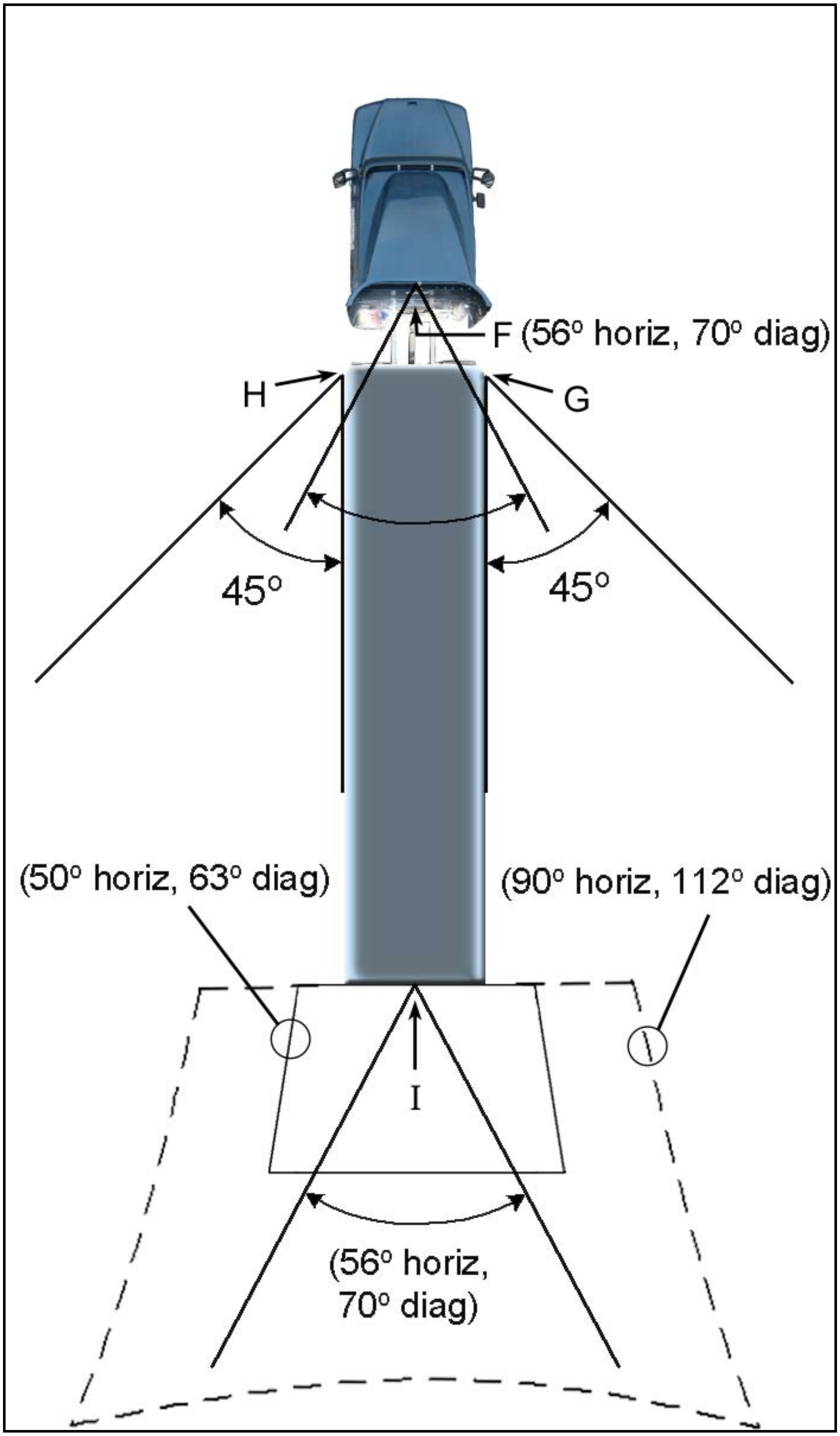

Figure 44. Second group of potential camera locations (early version).

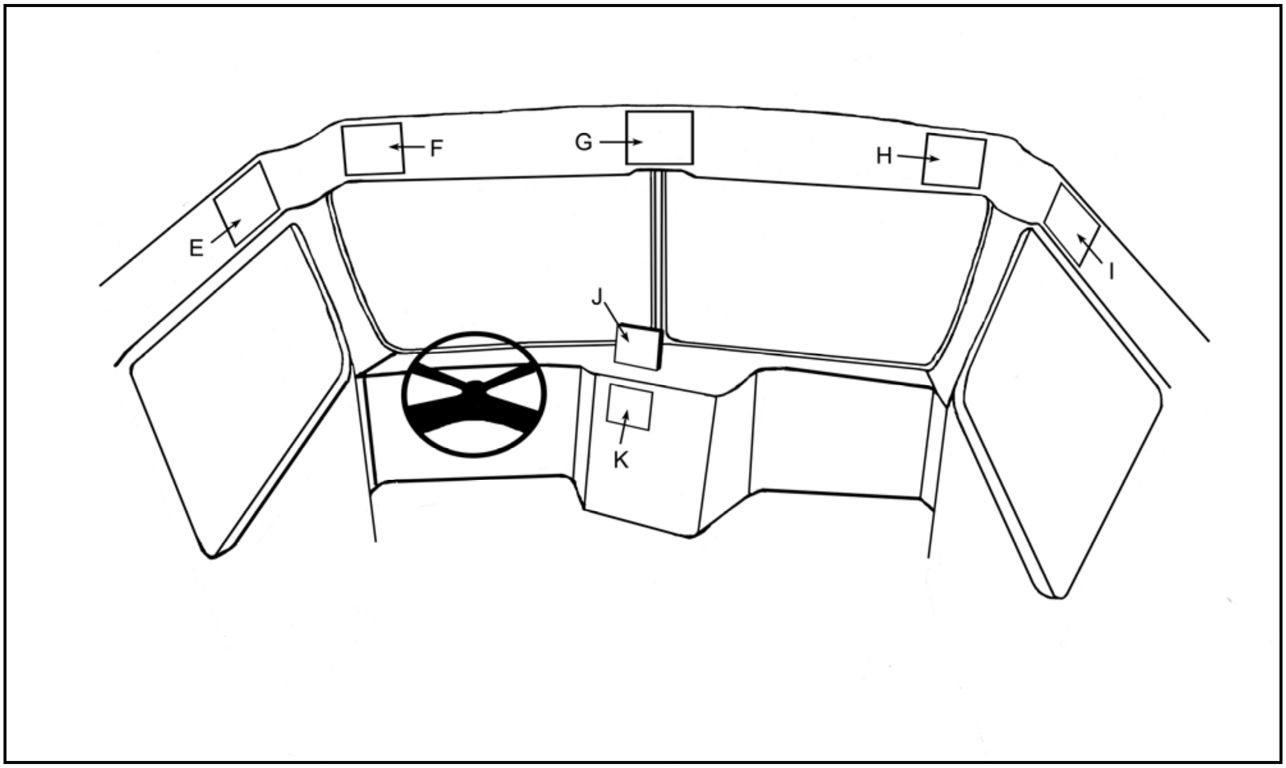

Figure 45. Candidate monitor locations for enhancements (early version).

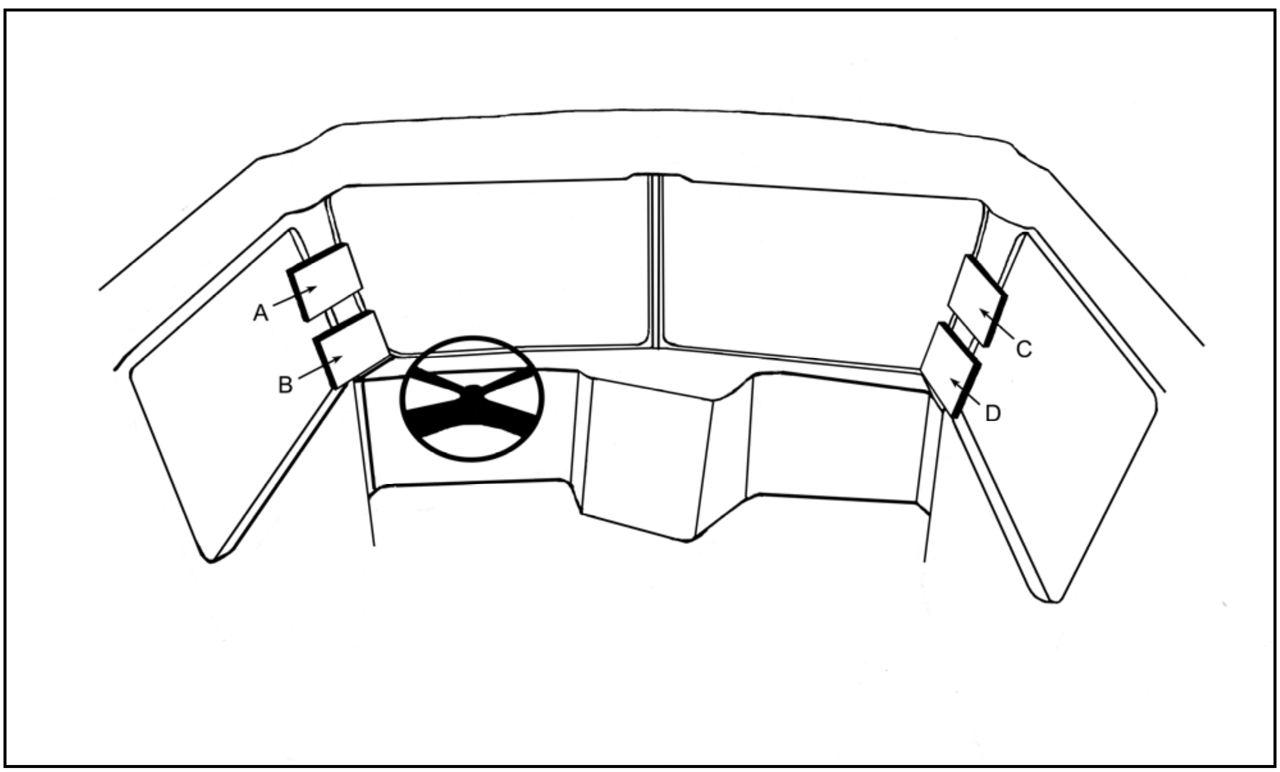

Figure 46. Candidate monitor locations for surrogates (early version).

Are there any disadvantages to Concept 13? One possibility is that an object could be missed at the extreme front outside right, that is to say, approximately 10 ft (3.05m) to the right of the front fender. However, such an object should be within the direct FOV of the driver, particularly if the object extends forward somewhat. Also, Concept 13 may be subject to fender vibration. However, there are several proposed concepts that have this problem. It will be necessary to suppress excessive camera vibration by appropriate design techniques.

All of the above considerations lead to the conclusion that Concept 13 should replace Concept 3. Concept 13 is similar to other concepts in terms of equipment and location and seems to provide a better solution to the problem of blind spots along the right side of the tractor.

MERGING CONCEPTS 14 AND 2L

Concept 14 is the left-side blind-spot camera. It is intended to cover the blind spot that drivers perceive to exist from the left-side (driver) door rearward along the tractor (Figure 47). Concept 2L is the left-side convex mirror surrogate. There is *no* difference in the camera location or FOV for these two applications. The camera is mounted on the left front fender, and the FOV is 30 to 45 degrees. Note that the left-side blind-spot camera does not need to have as large an FOV as the right-side blind-spot camera. The reason for this is that the blind spot on the left starts at the driver door, whereas on the right it begins near the front of the tractor.

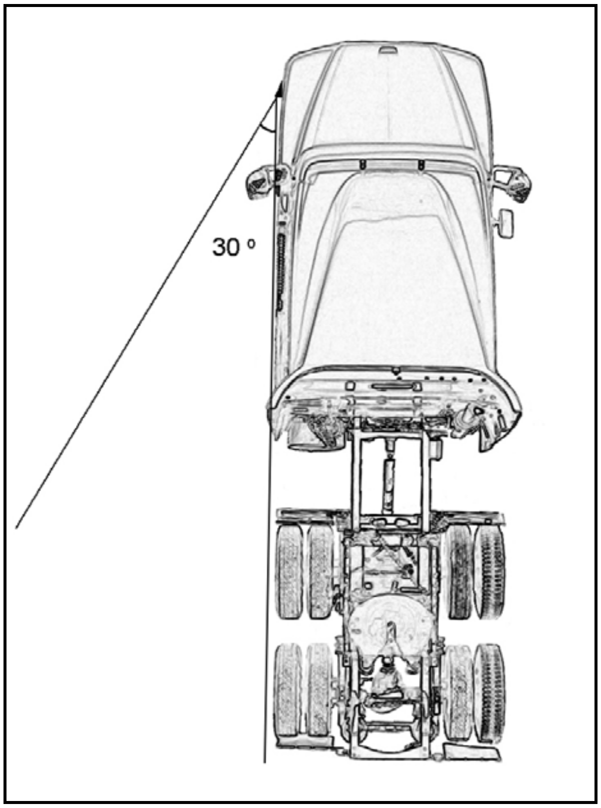

Figure 47. Focus group Concept 14 - left-side blind-spot enhancement.

What are the differences between concepts 14 and 2L? There is one major difference. Concept 2L is a surrogate and would involve removing the left-side convex mirror. On the other hand, Concept 14 is an enhancement that would retain the left-side convex mirror. Any testing to be performed could use exactly the same camera position (Figure 43, Location C).

While it is possible that the same monitor could be used for both Concepts 14 and 2L, the fact that 2L is a surrogate suggests that the monitor should be given a higher priority position. Figure 46 depicts this as location A or B, which is in front of the left A pillar. For Concept 14, the best location appears to be at the left end of the front header (Figure 45, location F). However, if there are no surrogates, the monitor could be placed at location A or B in Figure 46, and a somewhat smaller monitor could be used.

ELIMINATION OF CONCEPT 15

As Table 8 of the focus group results shows, Concept 15 (the trailer clearance camera) did not do well in the desirability rankings, coming in dead last. Examination of the table shows that only one driver gave this camera a good ranking. All other drivers ranked it tenth or lower. Statistical tests confirmed that this concept was considered significantly less desirable than others by the drivers.

The trailer clearance camera is placed at the top of the tractor faring and is aimed toward the top front of the trailer. It would be used to determine clearance between the front top of the trailer and potential obstructions. Apparently, most drivers did not feel that such a concept was necessary or desirable. Consequently, it will not be considered further. However, there really is no reason why such a camera could not be patched into one of the center monitors through a switching arrangement, should a manufacturer or trucking concern desire to do so.

REAR-VIEW COMBINATIONS

As mentioned in the focus group results, one driver had the idea of automatic switching from rear tractor view to rear trailer view when an equipped trailer is connected. This concept is a good one and helps to elucidate other common aspects. It is clear that there are four rear-view combinations that are related; all of which could use the same monitor. They are Concept 6, the trailer rear-view enhancement; Concept 7, the trailer rear look-down enhancement; Concept 11, the trailer wide-angle rear multipurpose look-down enhancement; and Concept 5, the tractor rear backing/bobtailing enhancement. Note that concepts 6, 7, and 11 all have cameras at the center top rear of the trailer, but the cameras have different aim points and fields-of-view. The switching from the backing/bobtailing camera could be to any one of the rear concepts.

The multi-camera rear enhancement similarly contains two of the above four trailer rear views, namely, Concepts 6 and 7. Clearly, there are common components among several of the rear-view concepts.

LEFT/RIGHT-SIDE TRAILER VIEWS (CONCEPT 12; EARLY ANALYSIS)

As indicated in the focus group discussions, drivers are currently blind on the side opposite to turns because, in tractor-trailer combinations, the side mirrors move with the tractor. It is clear that, to overcome the problem, cameras must be attached to each side of the trailer to obtain the necessary view. Such cameras would not turn with the tractor and therefore would maintain the view alongside the trailer. It appears that the cameras should be relatively low, that is, at the bottom edge of the trailer body. Putting the cameras in this position would reduce the likelihood of a small vehicle going undetected. This camera position is not ideal, however, since it would still be possible for an object to be alongside the front edge of the trailer and go undetected. On the other hand, the left-side mirror surrogates (or actual mirrors) might allow detection of such an object on the left side of the trailer, even though the tractor is at an angle. Similarly, the right-side mirror surrogates (or actual mirrors) might allow detection of such an object on the right side, even though the tractor is at an angle.

The monitors for the left and right-side trailer views were not specified in the focus group. However, one important consideration is that since the other cameras may have limited usefulness in an urban turn, one of the same monitors could be switched to the trailer camera view during such a maneuver. These maneuvers are distinguishable by the angle between the tractor and trailer. As an example, assume that the tractor/trailer combination is equipped with a left-side blind-spot camera and a left-side trailer view camera. It would seem that during a moderately sharp turn to the right, the monitor could be switched from the blind-spot camera to the left-side trailer view camera.

It appears that the best monitor positions for the left and right-side trailer views would be at the left and right ends of the front header. These are positions F and H in Figure 45. Note that these are the same monitor positions as those recommended for Concepts 14 (left-side blind spot) and 13 (right-side wide-angle blind spot). As indicated, the left monitor could be switched during an urban turn to the right, and the right monitor could be switched during an urban turn to the left.

It should be re-emphasized that all of the above statements were made prior to the preliminary tests. Those tests showed that the trailer view enhancements were not effective. This is discussed in detail in Chapter 6.

CONFIGURATION SUMMARY

With the changes resulting from analysis of the focus group results, the revised listing of C/VIS concepts can now be written. The list includes those concepts that have been added and it deletes those no longer considered necessary. They are presented in Table 9 in the order of desirability as determined by the drivers, with the most desirable presented first, the second most desirable presented second, and so on.

Table 9. Configuration summary listing of concepts (early version).

Rank	Concept Number	Description
1	13	Right-side wide-angle blind-spot enhancement.
2	12	Left- and right-side trailer view enhancements.
3	8	Left merge/re-merge enhancement.
8	6	Trailer rear-view enhancement.
4	2	Convex left- and right-side mirror surrogates.
5	9	Right merge/re-merge enhancement.
6	4	Front blind-spot enhancement.
7	1	Left and right west coast/flat mirror surrogates.
9	14	Left-side blind-spot enhancement (camera same as 2L).
10	7	Trailer rear look-down enhancement.
11	11	Trailer rear wide-angle multipurpose look-down enhancement.
12	5	Tractor rear backing/bobtailing enhancement.
13	10	Trailer rear multi-camera enhancement.

Writing and Submission of Preliminary Specifications

Once the focus group results were available, work began on writing the preliminary specifications for C/VISs. The specifications were based on a combination of analyses including driver needs and human factors issues, current and future video technology, and systems analyses. The specifications were written in three parts: an introductory section defining terms and stating general requirements, a section providing detailed specifications for 4 surrogate concepts (flat and convex mirror surrogates on each side of the vehicle) and 11 enhancement concepts, and a section providing additional common detailed specifications. The report detailing the specifications was submitted to NHTSA for review (Wierwille, Spaulding, & Hanowski, 2004).

Because the specifications were later revised based on both informal and formal testing results, they are not included in the current report. Instead, the final (that is, revised) specifications are provided in the companion document to current report (Wierwille et al., 2007).

CHAPTER 6: PRELIMINARY ROAD TESTING OF C/VIS CONCEPTS

BRIEF DESCRIPTION OF THE TESTS

Because most of the concepts contained in the preliminary specifications had never been tested, it was decided that preliminary road testing of selected concepts should be performed. The fundamental idea was to determine how well the concepts might be expected to work and also to determine what, if any, changes and improvements were needed. The steps involved in the preliminary road tests were as follows:

- Select concepts typical of the entire set of concepts for preliminary testing. The objective was to obtain enough information so that generalizations could be made to all of the concepts appearing in the preliminary specifications.

- Find and order appropriate video equipment, and design all support hardware, such as power conditioning, bracketing, and wiring interconnection.

- Install the various C/VISs and test them. Perform any early redesign necessary.

- Develop groupings for tests so that drivers could complete their tasks in approximately one hour and so that concepts could be installed that would minimize interference with one another.

- Devise road tests for each concept which would exercise the concept.

- Select VTTI test drivers. Perform the road tests with emphasis on usability procedures. Use several replications of maneuvers to aid drivers in making assessments. Query drivers using a standard questionnaire and also obtain their general impressions and comments.

- Analyze and report the results. Make recommendations for changes in the preliminary specifications.

Four drivers participated in the tests. All were VTTI employees with current commercial driver's licenses (CDLs). All were technically-trained individuals with knowledge of both heavy-vehicle subsystems and trucking operations. During the testing, one of the drivers suffered a bone fracture of a foot (unrelated to the tests) and was unable to continue. Thereafter, tests continued with three drivers.

Five test groupings were developed. With one exception, all groupings tested 2 concepts. The fourth grouping tested 3 concepts. Thus, 11 concepts in all were tested. The highway-related tests were performed on the Virginia Smart Road, located at VTTI in Blacksburg, Virginia. This is an instrumented test facility closed to the public. Those tests involving parking, backing, and other low-speed maneuvers were performed on a large asphalt pad located at VTTI. The pad was private and out of view of public roads.

Tests were performed under daytime conditions during winter. Each test driver was accompanied by two experimenters and an engineer who checked operation of the video equipment and made the changeovers. One experimenter and the engineer sat behind the driver in custom seats. The other experimenter sat in the conventional passenger seat.

In these preliminary tests, the vehicle headers and A-pillar finish panels were replaced with steel panel equivalents that were painted medium low-gloss grey. These modifications allowed development and use of monitor bracketing that could be mounted using strong magnets. The magnets did not interfere with the operation of the monitors, all of which were flat-panel displays (interference was a source of concern because magnets are known to have serious effects on CRT displays). The use of this mounting system allowed rapid changes to be made.

The dash-mounted monitor was held in place by a mounting that was attached to the top of the dash using two-sided adhesive strips. The monitor itself was at the front of the instrument panel to the right of the steering wheel. It overlapped the dash cap (top pad).

Tests were performed using four monitor sizes, as shown in Table 10. These monitors were selected because they covered the range found in the preliminary specifications. Monitors are referred to by their sizes; that is, Size 1, 2, 3, or 4.

All testing was performed using a 1994 Peterbilt (conventional design) tractor. The first two test groupings were performed with the tractor uncoupled, whereas the latter three groupings were performed using a 48 ft (14.6 m) trailer. The actual testing went relatively smoothly. Occasional glitches occurred in the video systems, but were usually easily repaired. Camera vibration for the west coast mirror surrogate required several redesigns of the camera mount before the problem was brought under control. These redesigns made clear that the west coast mirror surrogate represents the largest design challenge.

Table 10. Monitor image sizes used in the preliminary tests.

Size Designation	Height	Width	Diagonal
Size 1	8.35 cm 3.29 in	11.3 cm 4.45 in	14.05 cm 5.53 in
Size 2	9.6 cm 3.78 in	12.9 cm 5.08 in	16.1 cm 6.33 in
Size 3	12.8 cm 5.04 in	17.0 cm 6.69 in	21.3 cm 8.38 in
Size 4	15.8 cm 6.22 in	21.1 cm 8.31 in	26.4 cm 10.4 in

It should be mentioned that several variations of the various concepts were examined during equipment testing. For example, in some cases, cameras and monitors were rotated 90º so that the longer monitor dimension was vertical. However, when these modifications were made, there was usually a compelling reason for not selecting such a configuration. In other words, the disadvantages of this rotation outweighed the advantages. Other types of variations were also tested, but did not result in anything considered to be better.

The results of the preliminary tests are reported in concise form in the following section.

SUMMARY OF FINDINGS OF THE PRELIMINARY TESTS

General Findings

- The concepts were generally successful in providing useful driving information to the drivers. Some of the concepts were preferred over others, and there were two concepts that could probably be eliminated as not being particularly useful. However, considering the number of concepts tested, it is not surprising that a small number were not considered useful.

- The tests served their purpose for the research team, which was to find out how well the various C/VIS concepts worked, and what improvements would be needed. The tests were accomplished with usability testing, which is economical and provides an abundance of information.

- Drivers universally preferred color to monochrome video. However, they wanted accurate color rendition. In some cases, grey pavement appeared slightly blue and skies appeared bluer than they actually were. Drivers indicated that such inaccurate coloring could cause difficulties in identification and in showing things as they really are. Better correction for color balance could be achieved by closer attention to proper settings in camera setup.

- With a few exceptions, drivers *did* like monitor locations at the A-pillars and at the center dash. They generally *did not* like (or at least did not prefer) monitors placed anywhere in the front header. Their reason for not wanting the monitors in the front header was that the monitors were then well above their normal FOV and required large upward head movements. Such movements are not desirable for two reasons: first, the craning of the neck creates a strain and might lead to eventual muscular-skeletal problems; and secondly, peripheral vision cannot be used. It should be noted that the drivers found the side headers to be acceptable locations for the merge/re-merge C/VISs. The A-pillar location was considered satisfactory for west coast and convex surrogates as well as the side wide-angle blind-spot enhancement.

- Several drivers noticed that the image brightness seemed to change relatively quickly for several of the applications. This phenomenon was believed to be a result of rapid auto-iris fluctuations. Whether these fluctuations were caused by mechanical or electronic variations is unknown. The auto-iris feature should have smoothing so that it cannot change too rapidly. In any case, screen brightness should not change too rapidly because such changes are disconcerting to the driver.

- When the FOV of the camera lens is greater than 60º, scene distortion becomes noticeable. In addition, distance cannot be easily judged. Therefore, fields of view should never be wider than absolutely needed for the application. Ideally (assuming image size does not need to be preserved) an FOV of approximately 45 to 55 degrees produces the most natural appearing image with little or no apparent distance distortion.

- Occasionally, the monitor would produce glare at the driver's location for some sun conditions. Appropriate glare shields and hooding should be used to minimize the possibility of glare. However, it should be recognized that glare can also come from mirrors, shiny surfaces, and dash instruments. Therefore, the fact that glare may occasionally occur on a monitor should not be taken as a reason for not implementing a C/VIS. The objective is to take reasonable precautions to minimize glare.

Findings associated with individual concepts (presented in the order in which tests were run)

RIGHT WEST COAST FLAT MIRROR SURROGATE

- The best means of FOV adjustment is to match image size on the monitor screen to that in an equivalent flat mirror (when viewed from the nominal driver's eye position). A viewing distance of approximately 60 ft (18.3 m) from the mirror to an object (probably a light vehicle) should be used. To perform this operation, a variable focal length (zoom) lens must be installed and adjusted. This lens can then be replaced in production with a lens having the same FOV as the setting of the variable focal length lens. This procedure greatly simplifies the problem of obtaining an image with the correct perspective and size. Since the perspective point of view for the C/VIS is lower than for the mirror, the size matching should be done on the basis of the width of the object.

- The Size 3 monitor was preferred and was easier to fit to the A-pillar (as compared to the Size 4 monitor).

- Because the FOV is small (equivalent angle of approximately 9º for the passenger side), a narrow FOV (long focal length) lens must be used. Camera vibration isolation then becomes a severe problem. Even the slightest angular vibration in the camera will appear in the image. Consequently, great care must be taken to determine the sources of vibration and eliminate them. In the preliminary testing, an acceptable camera mount was finally obtained by bolting a welded tubular pipe extension directly to the frame of the tractor. (Image stabilization was not used.) The fender of the Peterbilt tractor simply had too much vibration to serve as a mount for the west coast surrogate camera. Some vibration still existed with the tubular frame, but this was reduced further by adding a metal mass at the camera mounting. In so doing, vibration frequencies were lowered and had less of an effect. It should be possible in future tractor designs to develop fender isolations that will permit camera mounting that is relatively isolated from vibration. Note that this problem becomes less severe as the FOV of the lens increases (focal length decreases).

- It is necessary for this application to have high resolution and color during daytime operations. The high resolution is required so that the driver can gain the maximum information about vehicles alongside. For example, some heavy-vehicle drivers look for head turning by drivers of vehicles alongside to determine if the drivers are attending to their driving or are distracted. Color is helpful in identifying vehicles when there is more than one vehicle present alongside.

- One of the shortcomings of this C/VIS is that drivers cannot ordinarily see the rear end of the trailer (whereas they can sometimes get a partial view when using the actual west coast mirror). The reason for this is that the camera is slightly inboard (laterally) compared with the west coast mirror. One suggestion that should help in estimating the position of the end of the trailer in the monitor view would be to use a horizontal line (delineator) on the monitor corresponding to the projection of the end of the trailer on the ground. Drivers could then look into the monitor and estimate the position of the end of the trailer. Of course, such a system would have to be carefully calibrated on a flat road. Another alternative would be to use some type of proximity sensing with a corresponding indicator system on the monitor. In addition, future vehicle design could make use of fender "flaring" to increase the lateral size slightly. This would help to alleviate the problem of not being able to view the back end of the trailer in the monitor.

- The position of the camera on the fender may subject the camera to debris accumulation. This has already been covered in Chapter 2, indicating that the camera housing should use aerodynamic principles to minimize accumulation of debris. Also, provision should be made for cleaning by the driver and by yard personnel, as previously specified.

- It is clear that using a C/VIS to replace the west coast mirror represents a design challenge. Nevertheless, it is likely that eventually such systems will be used, because they provide a much “cleaner” truck cab structure. Drivers indicate that it will take a while to get used to such a C/VIS, but feel that they could do so.

TRACTOR REAR BACKING/BOBTAILING ENHANCEMENT

- The 70º lens horizontal FOV was considered to be just adequate. The experimenters were reluctant to use a wider field because of the image and distance distortion that accompanies wider fields-of-view.

- The FOV was set so that the rear wheels of the tractor were viewable. This allowed accurate backing. However, the horizon was not in view at the top of the screen, which some of the drivers would have preferred. One possible solution is to move the camera down somewhat on the tractor. This would allow inclusion of both the rear wheels and the horizon. Doing so may cause slightly greater errors in backing, perhaps on the order of 5 in (12.7 cm) but would permit a complete view without additional lens distortion. Tests were run with the camera at the top of the faring. If instead, the camera were placed at the top of the cab, perhaps 3 ft (0.91 m) below the original position, the horizon would be in view. Even lower positions might work well.

- Either a Size 1 or Size 2 monitor can be used, with the monitor mounted in/on the dash. One driver did indicate that the center header position was a bit like a light vehicle's interior mirror. However, as already mentioned, drivers generally preferred not to have monitors mounted on the front header. This suggests that the monitor might be placed at the top center of the windshield, provided that such a position does not block the normal horizontal scan of the driver. Such a position would require less head movement and could provide a modicum of peripheral viewing of the scene to the rear.

CONVEX RIGHT-SIDE MIRROR SURROGATE

- This C/VIS application was the best liked of all tested and was considered to be superior to the convex mirror itself. It provided a superior FOV, a longer viewing range, and less distortion. The Size 2 monitor was considered to be adequate, but some drivers preferred the Size 3 monitor. Put succinctly, this application was a winner.

FRONT BLIND SPOT ENHANCEMENT

- This application had the intended low-speed/standing purpose of improving visibility of the right front corner of the tractor. It succeeded in this respect, but drivers were not satisfied with the camera location.

- After the tests were run, the fronts of tractors were examined with the objective of changing the camera location. However, no reasonable alternative could be found. As an example, placing the camera at the upper right corner outside the cab (above the right corner of the windshield and aimed forward and downward) did not eliminate the blind spot and also required a wide-angle lens with its attendant distortion.

- For the camera in its present position, it should be aimed so that the front bumper and part of the grill appear in the right edge of the scene (a standard, un-reversed view should be used). This provides a reference for the driver in regard to scene orientation and clearance.

RIGHT-SIDE WIDE-ANGLE BLIND SPOT ENHANCEMENT

- Initially, the FOV was changed from 80 to 90 degrees. This provided a view along the entire side of the tractor. Actually, any angle between 80 and 90 degrees appeared to be satisfactory. This application, according to the drivers, worked much better than the look-down mirror and lower side window on the tractors that they had driven.

- Drivers preferred the A-pillar location because it allowed coordination with the outside mirrors, which were in close angular proximity. The Size 2 monitor appeared to be adequate.

TRAILER REAR-VIEW ENHANCEMENT

- The FOV was changed initially to 70º. This produced a more acceptable FOV, but with minor field distortion.

- Drivers found this C/VIS application to be useful because it provided a view behind the trailer that was not available in the mirrors. However, there were differences of opinion regarding camera aim direction.

- Although not tested, it would be possible to lower the vantage point (the vertical location of the camera). This would improve the coverage at the same time that the view would appear more natural. If the camera were placed in or on one of the trailer doors, near the vertical centerline, at a height of perhaps 8 ft (2.4m) above the pavement level, the controversy over aim and FOV could be eliminated.

- The dash location with a Size 2 monitor was preferred by the drivers, although they indicated that a Size 1 monitor would suffice.

LEFT-SIDE TRAILER-VIEW ENHANCEMENT

- This C/VIS application was the least liked of any tested. It was intended to provide a view of the blind spot that occurs along the left side of the trailer when the tractor trailer makes a turn to the right. Drivers did not find it useful in making turns. They also questioned whether such an enhancement is needed, because the trailer does not leave the lane unless the driver first moves to the left before making a turn to the right. If so, the driver assesses lane clearance before moving left.

- Considering that this C/VIS application does not appear to be needed and, in any case, did not provide additional information, it appears appropriate to delete it as a concept in the specifications. The right-side trailer-view enhancement should similarly be deleted as a concept in the specifications.

TRAILER REAR MULTI-CAMERA ENHANCEMENT (CAMERA 4 ONLY)

- This C/VIS provided a usable view of the right adjacent lane behind the trailer. The top edge of view on the monitor was outward toward the rear, and the bottom edge was along a projection of the rear surface of the trailer. This application seemed to fulfill its purpose in showing adjacent lane clearance for lane changes to the right. However, drivers gave the impression that they felt the view, while useful, was odd. One driver suggested that the camera should be moved from the top center of the trailer to a lower, more natural viewing point.

- If the camera is moved downward, it then becomes similar to the right merge/re-merge enhancement. Considering that the right merge/re-merge enhancement was well accepted (as will be described), it should be used to replace Camera 4. Similarly, the left merge/remerge enhancement should be used to replace Camera 3.

- In regard to Cameras 1 and 2, they should use the recommendations given for the trailer rear look-down enhancement and the trailer rear-view enhancements.

TRAILER REAR LOOK-DOWN ENHANCEMENT

- This C/VIS application is intended to be used for backing and parking (not for over-the-road driving). It uses a 50º FOV so that the image has very little distortion. Drivers found the concept useful for its intended purpose, but some felt the view was too narrow. To accommodate these drivers, the FOV should be increased to 60º.

- This application worked well for its intended purpose; that is, backing and parking. Performance, as measured by backing to a barrier, was definitely improved.

- Since other concepts are intended for rear view *while driving*, the present concept should be retained without major modification.

- The camera aim should be such that the bottom edge of the image includes the lower horizontal edge of the trailer. It may be helpful to use a contrasting paint so that the driver can easily distinguish the edge of the trailer. This provides a reference for the driver in regard to scene orientation and clearance.

- The Size 1 monitor at the dash location seemed adequate.

TRAILER REAR WIDE-ANGLE MULTIPURPOSE LOOK-DOWN ENHANCEMENT

- This C/VIS concept performed most intended functions well, but did so with some scene distortion. The application might benefit from scene remapping, as discussed previously. However, the C/VIS seems to be adequate without remapping.

- As in the case of the look-down enhancement, the lower horizontal edge of the trailer should appear in a contrasting color at the bottom edge of the monitor scene. This serves as a reference for the driver.

- Because the camera uses a horizontal FOV of 90º, its vertical FOV is only about 68º. Consequently, if the rear of the trailer is to be in the edge of the image, the scene only extends outward to about 67º. For a camera height of 13.5 ft (4.1 m), the view at the center of the trailer's lane only extends to 32 ft (9.8 m). In adjacent lanes, the view is extended farther because of FOV (pillow) distortion. It seems impractical to substantially extend the vertical FOV to cover a great deal more of the rear area; however, by extending the horizontal FOV to about 102º, the vertical field becomes approximately 76º, and the view is then extended to 54 ft (23.2 m) behind the trailer. This should be sufficient. Again, because of distortion, the view is extended to a greater distance in adjacent lanes.

- One possible alternative is to rotate the camera by 90º. Doing so allows a greater expanse to be seen behind the trailer. However, it would still be necessary to increase the FOV so that the adjacent lanes are covered. This would require a vertical FOV (prior to rotation) of approximately 90º, and a corresponding 120º horizontal FOV (prior to rotation), making distortion even worse. It thus appears that retaining the original orientation and increasing the horizontal FOV to 102º provides the best compromise.

- The Size 1 monitor at the dash location appeared to be adequate. However, drivers were not exposed to the Size 2 monitor in the tests which, based on previous tests, they might have preferred.

MERGE/RE-MERGE RIGHT ENHANCEMENT

- This C/VIS was readily accepted by the drivers. All found it useful, but one felt that he did not need it. Basically, this application allows drivers to check clearance with vehicles in the right adjacent lane when preparing to move to that adjacent lane. Since the left edge of the scene contains the edge of the trailer, the driver has a good reference when viewing the monitor.

- The monitor location in the header over the passenger-side door (with a Size 2 monitor) seemed to work well. It allowed the drivers to coordinate their glances to the mirrors with the monitor view. Accordingly, they could obtain an accurate assessment of clearance. The monitor should be placed as far forward on the side header as possible so as not to increase neck strain over that already present when using the outside mirrors. Using the Size 1 monitor in the dash was also satisfactory, but required drivers to transition their glances across the relatively large angle between the monitor and the mirrors. Therefore, the right header position is preferred.

- Some drivers felt that the camera should have a slightly larger FOV. It appears that a horizontal FOV of 55º would expand the coverage with very little change in view distortion. Consequently, this new FOV is recommended. It would provide a view from alongside to about 25 ft (7.6 m) rearward in the adjacent lane.

- Once possible side effect of this C/VIS is the possibility of abuse, in that it will allow drivers to have a relatively precise indication of clearance. Thus, an aggressive heavy-vehicle driver might use the C/VIS for "sharp cut-ins." The magnitude of this potential problem is unknown. This problem would have to be traded off with the lower likelihood of light-vehicle drivers being forced off the road or out of lane because the heavy-vehicle driver did not have adequate clearance before entering the lane.

FINDING RELATED TO THE COMBINATION OF THE TWO SURROGATES

- Drivers indicated that the angular distance between the west coast mirror surrogate and the actual convex mirror was larger than desired. This occurs because the convex mirror is usually relatively low on the mirror support structure. They also felt very strongly that the convex mirror surrogate was actually superior to the convex mirror itself. Therefore, the recommendation is made that the west coast surrogate should only be implemented if the convex mirror surrogate is implemented. The converse, however, is not required. In other words, the convex mirror surrogate can be implemented by itself.

SUMMARY OF RECOMMENDED CHANGES IN SPECIFICATIONS

The main changes can be summarized as follows:

General recommendations:

- Use color video whenever possible. It should be correctly color-balanced so that it gives an accurate color rendition.
- Avoid use of the front header to mount monitors because this location causes neck strain and also causes the driver to take eyes off the road. One possible alternative is to use the upper center of the windshield, provided the normal road view is not occluded.
- Do not make fields of view wider than necessary, once the camera view exceeds 55º. Beyond 55º, FOV considerations must be traded off against image distortion.
- Camera AGC (automatic gain control) should respond relatively slowly. If it is too fast, monitor luminance changes distract the driver.
- To the extent possible, ambient glare considerations should be included in the placement and shading of monitors.

West coast mirror surrogates:

- Use Size 3 monitors.

- Pay particular attention to angular vibration; consider the use of better isolation mounts and, possibly, electronic image stabilization.
- Determine the correct angle of view by direct comparison with a west coast mirror temporarily installed in the usual location.
- Use a high resolution video chain with accurate daytime color rendition.
- Add a horizontal reference line on the monitor that designates the projection of the end of the trailer on a flat surface (road). The video chain should be calibrated so the line is accurately placed.

Tractor Rear Backing/Bobtailing Enhancement

- Set the lens horizontal FOV at 70º.
- Move the camera location down from the faring to the rear of the cab, so that the coverage is better.
- Use a Size 1 monitor in the center dash location, but consider the alternative of an upper center windshield mount similar to the center mirror in a light vehicle.

Convex Mirror Surrogates

- Use Size 2 monitors at the A-pillar locations.

Front Blind Spot Enhancement

- Aim the camera so that the front bumper and part of the grill appear in the right edge of the scene.

Right-Side Wide-Angle Blind-Spot Enhancement

- Use a horizontal FOV of 80 to 90 degrees.
- Use the center-dash location with a Size 1 monitor, or possibly the right A-pillar location with a Size 2 monitor, if the space is available (not used for surrogates).

Trailer Rear-View Enhancement

- Use an FOV of approximately 70º.
- Move the camera location down on the trailer so that it is near the centerline of the trailer, approximately 8 ft (2.4 m) above the pavement level.
- Use a Size 1 monitor in the center dash location, but consider the alternative of an upper center windshield mount similar to the center mirror in a light vehicle.

Side Trailer View Enhancements

- Delete these enhancements because they are not effective and not needed.

Trailer Rear Multi-Camera Enhancement

- Replace Camera 3 with the left-side merge/re-merge camera, and replace Camera 4 with the right-side merge/re-merge camera.
- Camera 1 should use the recommendations here for the trailer look-down enhancement.
- Camera 2 should use the recommendations here for the trailer rear-view enhancement.
- Note that these changes preclude the use of a single pod at the top center rear of the trailer. The cameras must be located at different positions to get the best views.

Trailer Rear Look-Down Enhancement

- Change the horizontal FOV of the camera to 60º.
- The lower horizontal edge of the trailer should appear in a contrasting color at the bottom edge of the monitor scene.
- The Size 1 monitor in the dash is adequate.

Trailer Rear Wide-Angle Multipurpose Look-Down Enhancement

- The horizontal FOV of the camera should be increased to 102º.
- The lower horizontal edge of the trailer should appear in a contrasting color at the bottom edge of the monitor scene.
- The Size 1 monitor in the dash is adequate.

Merge/Re-Merge Enhancements

- Increase the camera horizontal FOV to 55º.
- Use a Size 2 monitor at the front end of the side header. For the right-side enhancement use the right header, and for the left-side enhancement, use the left header.

Combination of west coast mirror surrogates and convex mirror surrogates

- The west coast mirror surrogate should only be implemented if the convex mirror surrogate is implemented. However, the convex mirror surrogate may be implemented without the west coast mirror surrogate.

CHAPTER 7: FORMAL ON-ROAD TESTS FOR CAMERA/VIDEO IMAGING SYSTEMS (C/VISs)

INTRODUCTION

This chapter describes the formal road tests that were performed using candidate C/VISs. It serves as a follow-on effort to the preliminary road tests that are described in Chapter 6. The on-road tests used 24 CDL-qualified, naïve volunteer drivers, divided into three groups of eight drivers. The fundamental purpose of the tests was to obtain both objective and subjective data regarding C/VIS concepts where questions remained about viability. Tests involving passing and merging were performed on the Virginia Smart Road, located at VTTI in Blacksburg, Virginia. Backing and low-speed maneuvering tests were performed on an asphalt area and access road at VTTI, which were not part of the public roadway system. Each group of drivers performed tasks with two C/VIS concepts as follows:

> Group 1: the tractor backing/bobtailing rear-view enhancement (Concept 5) and the trailer wide-angle rear multipurpose look-down enhancement (Concept 11),
>
> Group 2: the left and right merge/re-merge enhancements (Concepts 8 and 9) and the trailer rear look-down enhancement (Concept 7), and
>
> Group 3: the left and right convex mirror surrogates (Concept 2), and these same surrogates (Concept 2) combined with the left and right west coast mirror surrogates (Concept 1).

The results of the tests were intended to fill in the needed information for revision of the preliminary specifications. This information was primarily of a performance and acceptance nature.

As mentioned, preliminary on-road tests of candidate C/VIS systems were completed and are reported in Chapter 6 of this report. The tests were performed for development and usability testing purposes. The objective of the preliminary testing was to refine the concepts prior to use in formal road tests. The six concepts (nine, counting pairs) used in the formal tests were selected on the basis of importance and the need for additional information. The three groups of two concepts each were arranged so that the tests that each driver performed in each group could be conducted in approximately three hours or less. This length of time was considered appropriate for drivers. It allowed for maximum data gathering without having them become fatigued or lose interest.

COMMON ELEMENTS OF THE THREE GROUPS OF TESTS

To the extent possible, the same procedures were used for each group. Doing so simplified the data gathering and the data processing to follow. This section describes the common aspects of the three groups.

Participants

Each experimental group (that is, Group 1, 2, or 3) consisted of eight CDL-qualified drivers (24 in total). There was a younger age group made up of 12 drivers between 23 and 38 years old (mean: 33.8 and median 36.5), and an older age group made up of 12 drivers between 52 and 71 years old (mean: 59.3 and median 59). The three experimental groups of drivers were reasonably well-matched in terms of age. For the younger drivers the average ages in the three groups were: 33.8, 32.3, and 35.5 years, respectively. For the older drivers the average ages in the three groups were: 56.3, 60.0, and 61.8 years, respectively. Every driver was required to have a current CDL and to have two or more years of experience in driving heavy vehicles. Gender was not considered in selection of drivers for the tests. As it turned out, only male drivers volunteered.

Informed consent

An informed consent form was written and appears as Appendix A of this report. The form was written so that it applied equally well to all three experimental groups. Parentheses were used to show where small differences existed in the final versions used for each participating group.

Hardware Configurations

Generally, the hardware configuration found most desirable for each concept in the preliminary tests was used in the road tests. Three flat-panel monitor sizes were used: sizes 1, 2, and 3 as defined in the preliminary tests. They appear in Table 11. The Size 4 monitor used in the preliminary tests was found to be difficult to fit at the A-pillar location and also was less preferred than the Size 3 monitor by the preliminary test drivers.

One bobtailing configuration was tested. It used VTTI's 1997 Volvo VN series tractor (Figure 48). This tractor had a large windshield, which allowed a monitor to be placed at the top center without interfering with the driver's normal driving FOV. All other concepts were tested using VTTI's 1994 Peterbilt model 379 tractor with 48 ft trailer (Figure 49). Monitors for this tractor were placed at the center dash, at the top center of the windshield overlapping the area above the windshield, at the A-pillars, and on the side headers. The front headers in the two tractors were not used because preliminary tests indicated that drivers preferred other monitor locations.

For highway tests, a 2001 Saab 9-5 served as a confederate automobile (Figures 48 and 49). It was used for several maneuvers intended to bring out differences in passing and merging performance, to be explained later in this chapter.

Table 11. Monitor image sizes used in the formal on-road tests.

Size Designation	Height	Width	Diagonal
Size 1	8.35 cm 3.29 in	11.3 cm 4.45 in	14.05 cm 5.53 in
Size 2	9.6 cm 3.78 in	12.9 cm 5.08 in	16.1 cm 6.33 in
Size 3	12.8 cm 5.04 in	17 cm 6.69 in	21.3 cm 8.38 in

Figure 48. Volvo tractor and confederate automobile (Saab) used for the backing/bobtailing rear-view C/VIS experiment.

Figure 49. Peterbilt tractor with trailer and confederate automobile (Saab) used for all other C/VIS experiments.

Instrumentation for the first group of tests was installed and checked. Thereafter, tests were run for the eight subjects in the given group. Once data were collected, the instrumentation for the next group of tests was installed and checked. This process continued until all three groups of tests were completed.

A parking subtask was incorporated in several of the tests. For this subtask, a parked vehicle was used (Figure 50). This was an older automobile in which the engine, transmission, and driveshaft had been removed. Interior components were also removed to reduce the mass. The springs were compressed so that the parked vehicle had normal curb height at the front and rear. The vehicle had a parking brake release/reapply mechanism to minimize coast if it was pushed.

Figure 50. Tractor trailer backing to parked car.

An artificial loading dock was also constructed as part of the backing subtasks associated with the backing maneuvers for the tractor trailer (Figure 51). This loading dock was capable of being pushed without damage during contact. The dock was 12 ft (3.7 m) wide and had a top height that was approximately the same as the trailer floor.

Figure 51. Tractor trailer backing to loading dock.

In the case of the backing/bobtailing rear enhancement, a traffic cone barrier was used in place of the loading dock, and the driver backed to the cones instead of the loading dock (Figure 52). The cone task was considered to be more difficult for this enhancement because the rear wheels of the tractor obscured the cones to an extent.

Figure 52. Volvo tractor backing to cone barrier.

ORDER OF CONDITIONS

In all cases, drivers performed tests including a baseline for comparison. For enhancements (Groups 1 and 2), the baseline configuration was simply the tractor or tractor trailer without the enhancements. For surrogates (Group 3), they experienced both normal mirrors and the corresponding mirror-surrogate C/VISs. (During surrogate runs, the mirrors that the surrogates replaced were covered.)

Each test group involved baselines combined with two C/VIS configurations (or pairs of configurations). Drivers provided opinion data for baselines and for each C/VIS configuration. For each C/VIS configuration they also provided additional opinion data at the end of participation. These data were used to provide information on the receptiveness of the drivers to the C/VIS. Objective measures were taken during each baseline run and also during runs in which one or more C/VISs were used. Data comparisons were made between baseline and C/VIS run measures. The ordering of conditions always involved the presentation of baseline and corresponding C/VISs in counterbalanced order. Additional details in regard to counterbalancing are presented in the following sections.

TASK A. HIGHWAY DRIVING

Task A included two major subtasks which were performed in a highway setting on the Virginia Smart Road. The first subtask was the Clearance/Overlap Test. In this test, drivers first determined whether a confederate automobile alongside was clear of the rear of the trailer (or the tractor in the case of bobtailing). Immediately thereafter, they provided an estimate in feet of the amount of clearance or overlap (Figure 53). The second major part involved having the tractor trailer (or the tractor, in the case of bobtailing) merge in front of the confederate automobile which maintained constant speed. This test was performed to determine differences in merging distances and variations in merging distances. For Group 1 (only), drivers also observed the confederate automobile directly behind the Volvo tractor in the bobtailing mode and moving away. When instructed by the experimenter, they gave an estimate of distance to the confederate automobile. This test was used so that drivers could provide opinion data regarding observation directly to the rear.

Every highway driving subtask with a given configuration (baseline or C/VIS) was practiced first and then repeated for data gathering. Test procedures were worked out so that all practice for a given configuration was accomplished in one complete loop of the Smart Road. Data gathering then followed with a second complete loop. It is important to note, however, that different clearance and overlap values were used in the practice loop and the data-taking loop.

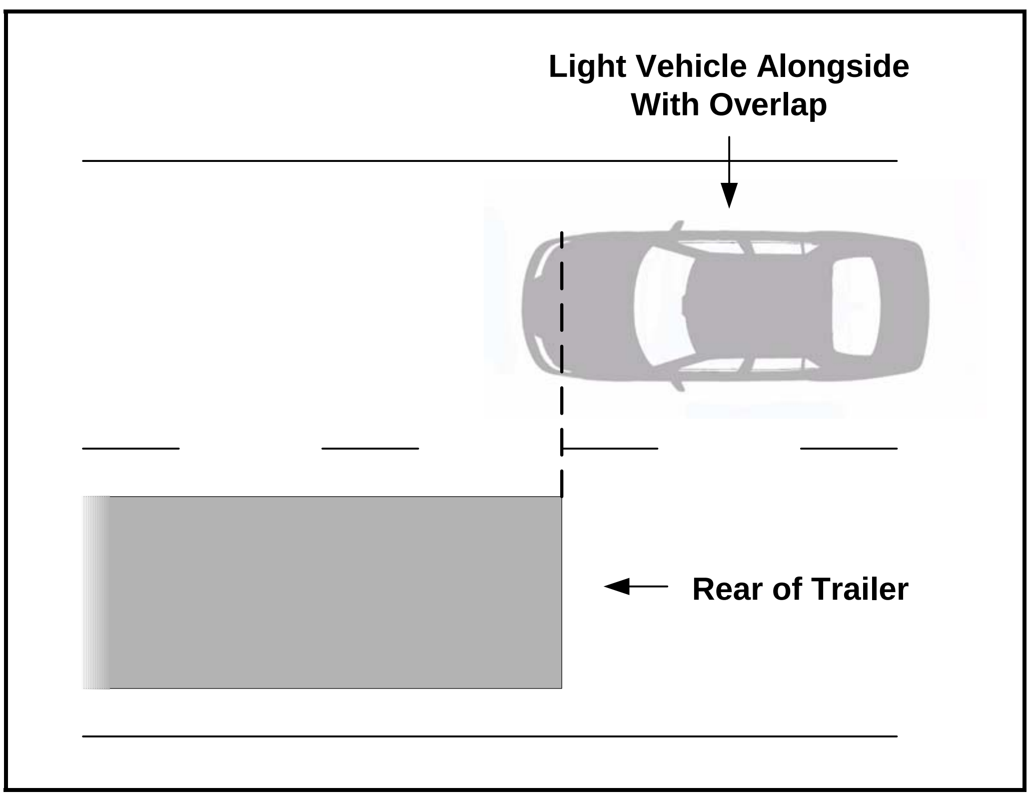

Figure 53. Diagram showing overlap in the clearance/overlap subtask.

TASK B. LOW-SPEED BACKING

Task B consisted of low-speed backing subtasks. Three subtasks were used: Parking, Loading-Dock Backing, and S-Curve Backing. These maneuvers were performed in paved areas adjacent to the Virginia Smart Road.

PARKING SUBTASK

This subtask used a section of the two-lane road (without centerline) as shown in Figure 54. The driver was instructed to back into the right lane, as shown in the figure, and to park 5 ft (1.52m) from the parked vehicle. Final position was measured. In addition, if the parked vehicle was pushed, the distance it was pushed was measured.

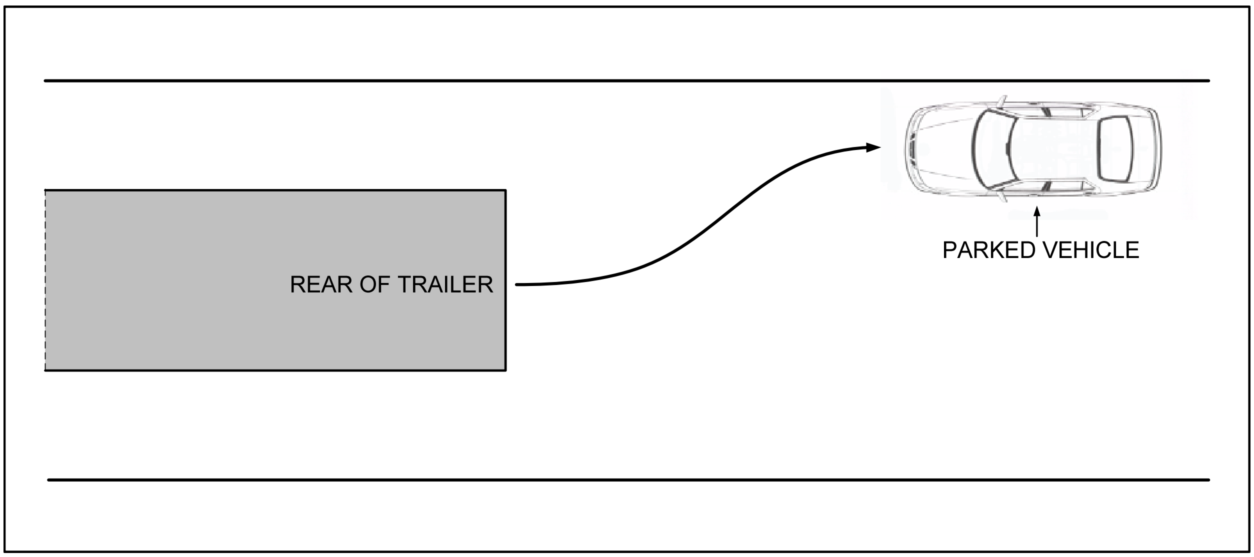

Figure 54. Parking subtask (distances are not to scale).

LOADING-DOCK BACKING SUBTASK

Figure 55 shows a different section of the two-lane road used for the loading-dock backing subtask. Drivers were instructed to stop 1 ft (0.305m) away from the dock. However, if they did strike the dock, measurements were made to determine how far the dock was pushed.

For Group 1, in the bobtailing mode, as mentioned, cones were used instead of a loading dock. The reasons for this were that the cones were lower and might have been more difficult to see, and that drivers seldom approach a loading dock while bobtailing. Drivers were instructed to stop 1 ft (0.305 m) away from the tips of the cones. Measurements were made of final distance as well as any movement of the cones (if struck).

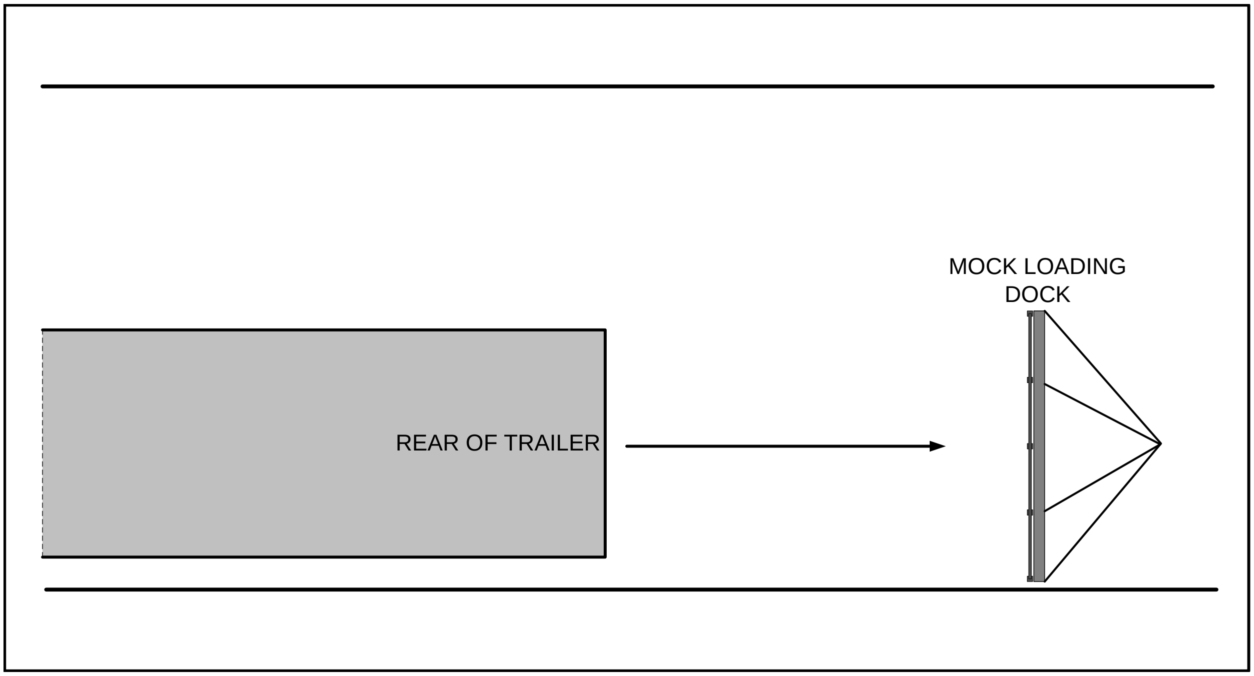

Figure 55. Loading-dock backing subtask.

S-CURVE BACKING SUBTASK

The S-curve backing maneuver was used to determine whether or not a complex backing maneuver would be affected by the C/VIS being tested. In this case, there was the possibility that a given C/VIS might either facilitate or hinder the maneuver. Figure 56 depicts an asphalt area used for the maneuver. Construction barrels were placed so that the maneuver could be accomplished with the correct driving technique. The path laid out by the barrels was approximately 2 ft (0.61m) narrower when used for the Volvo tractor in the bobtailing mode.

All of the backing subtasks (under Task B) for each given configuration (baseline or C/VIS) were performed without practice. In other words, data were gathered during the first attempt. The reasons for not practicing were: 1. The backing maneuvers were performed at low speed and were similar to maneuvers the drivers normally encountered in everyday work (parking and loading dock subtasks) or in driver proficiency testing (S-curve subtask); and 2. Drivers were not time-sharing between maintaining control of the vehicle on a highway and assessing the location of another vehicle (as was the case for Task A). Thus, the backing subtasks were relatively routine and not particularly hazardous.

DGPS Instrumentation of the Tractor Trailer and Confederate Vehicle

Both the tractor trailer (with Peterbilt tractor) and the confederate automobile (2001 Saab 9-5) used in the tests had differential global positioning system (DGPS) capability. The confederate automobile was driven by a confederate experimenter. The data from the two DGPSs were compared to obtain distance between the two vehicles at the times of merge and to determine whether or not there was clearance between the trailer and the confederate vehicle alongside, as will be explained in future sections. In most cases, DGPS distance measurements were backed up by video available to the experimenters (but not the subjects) on a quad-split screen that allowed the estimation of distance. Thus, the video served as a check and as an alternative method of determining distance, if and when necessary.

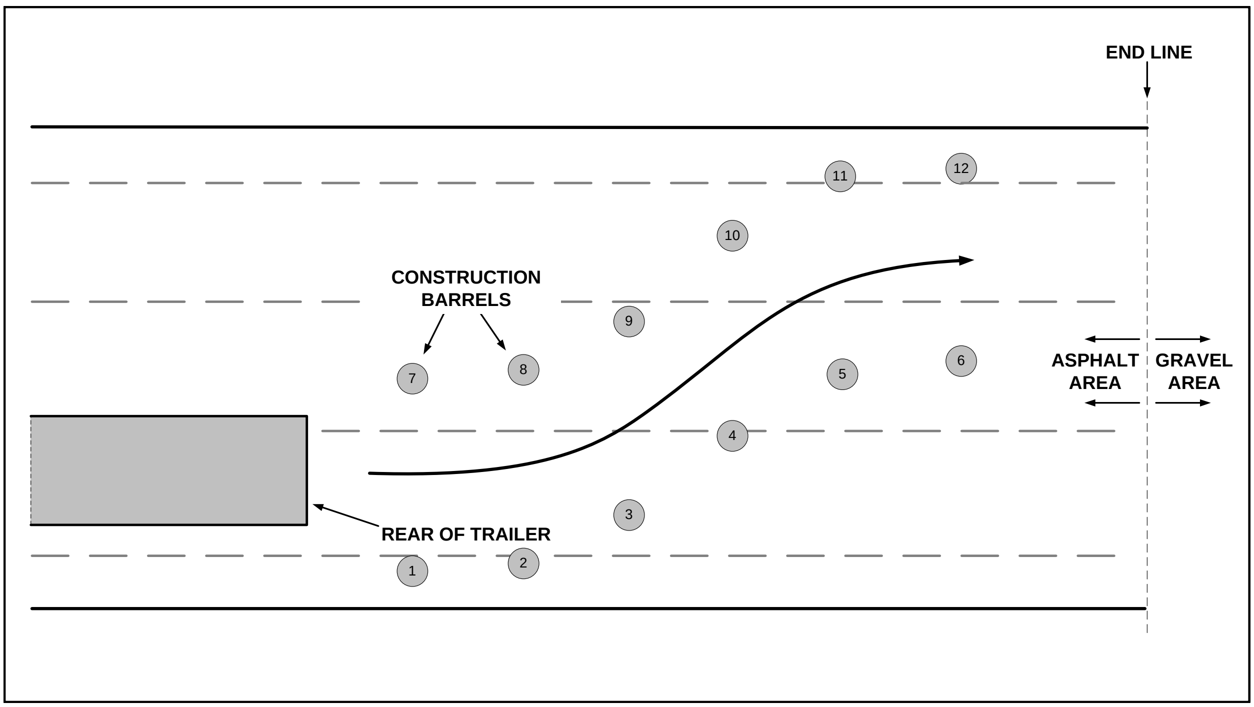

Figure 56. S-curve backing subtask (distances are not to scale).

It should be noted that the DGPS antenna on the tractor trailer was placed at the center-rear of the cab and the DGPS antenna on the confederate automobile was on the center of the trunk. Thus, the longitudinal distance between antennas at the beginning of merge was large, on the order of 70 ft (21.3 m), compared with the lateral separation. Consequently, the lateral separation could be assumed to be 12 ft (3.66m), or one lane width, without introducing appreciable error in calculating longitudinal gap or overlap. To calculate the gap or overlap, the resultant obtained from the DGPS and the 12 ft lateral offset were used to calculate the longitudinal distance. Then, the length from the tractor-trailer antenna to the rear of the trailer was subtracted, and the length from the front bumper of the confederate vehicle to its antenna was subtracted. The result was the gap (for positive values) or the overlap (for negative values). This system was tested and found to be accurate to about + or – 2.5 in (6.35 cm).

OTHER DATA-GATHERING INSTRUMENTATION

In addition to the C/VISs and DGPS, video data on a quad split screen were recorded on digital hard drives. The video images were also available to the experimenters during the runs (but not to the driver/subject, as previously mentioned) as a means of checking that various cameras were working properly and as backup in case problems occurred with the DGPS. Three views were used throughout all experiments, and a fourth varied with the condition. A camera with a 50º FOV was mounted at the center of the windshield and provided a view of the driver's face and eyes. This image was used to determine eye glance positions. Two other cameras provided views that were the same as the merge/re-merge camera views. These cameras allowed determination of the amount of clearance or overlap, based on video image interpretation. Both the Peterbilt tractor with trailer and the Volvo tractor had these cameras. For the Peterbilt with trailer the images served as backup, and for the Volvo tractor the images served as the primary means of determining clearance or overlap, since the Volvo tractor did not have DGPS. The fourth view varied with the particular C/VISs being tested and was used simply as a quality check.

GROUP 1 TESTS

A. Tractor Rear Backing/Bobtailing Enhancement

As indicated, the backing/bobtailing (rear-view) enhancement was implemented in the Volvo tractor, used in the uncoupled mode. The C/VIS camera was placed behind the cab at a height of 10 ft (3.05m) above the road surface (Figure 57). It was aimed so that the top edge of the FOV was slightly above the horizon, and the lower edge included the rear wheels of the tractor. The camera (itself) had a horizontal FOV of 70º. The monitor (Size 2) was placed at the top center of the windshield (Figure 58).

Figure 57. Rear of the Volvo tractor cab showing the rear-view C/VIS camera location.

Figure 58. Monitor in Volvo tractor for the rear-view C/VIS.

The test scenario involved two aspects: Task A, highway driving, and Task B, low-speed backing. The highway driving portion consisted of two separate components. The first involved having a confederate vehicle maneuver along each side (Figure 59, for example) and behind (Figure 58) the tractor. Similarly, the second portion involved the tractor merging to the right and to the left. The primary reason for performing these tests was to obtain opinion data. (The Volvo tractor was not as fully instrumented as the Peterbilt tractor with trailer, which was used for all other tests.)

Figure 59. Confederate automobile passing Volvo tractor in the rear-view C/VIS tests.

The low-speed backing maneuvers (Task B) involved the parking subtask (Figure 54), the backing to cones subtask (Figure 52) and the S-curve subtask (Figure 56). Measures obtained included completion times and final distances for all three subtasks, as well as number barrels (S-curve subtask) or cones displaced. The measures were treated in such a way as to provide an indication of quality of the corresponding maneuver. Figures 60, 61, and 62 show examples of the in-cab monitor for each of these subtasks.

Figure 60. Volvo tractor rear-view monitor during the parking subtask.

Figure 61. Volvo tractor rear-view monitor during backing to cones subtask.

Figure 62. Volvo tractor rear-view monitor during the S-curve backing subtask.

B. Trailer Rear Wide-Angle Multipurpose Look-down Enhancement

This multipurpose enhancement was similarly tested in both highway driving and in backing, using the Peterbilt tractor with trailer. The C/VIS camera was placed at the top center rear of the trailer and had a camera horizontal FOV of 102º (Figure 63). The lower edge of view in the image included the rear bumper of the trailer, so that drivers could judge distance relative to the rear bumper (Figure 64). The monitor was placed at the upper edge of the tractor windshield (with overlap above the windshield) and was Size 2. Although image re-mapping in the display was considered potentially beneficial, these tests were run without image re-mapping. Note that image re-mapping would be desirable because the wide-angle lens caused distortions in the FOV. In particular, the roadway lines appeared curved without image re-mapping (Figure 64). The idea was that if the tests showed the C/VIS to be capable of satisfactory performance, then specifications would not need to require image re-mapping.

Figure 63. Wide-angle rear multipurpose look-down camera at back of trailer.

Figure 64. Peterbilt in-cab monitor for the wide-angle rear multipurpose trailer look-down C/VIS.

The highway driving portion of the scenario consisted of three separate but related components. The first component involved having the confederate vehicle approach from the rear in the adjacent left lane, the adjacent right lane, and in the same lane as the tractor trailer (Figures 64 and 65). The second component of the tests consisted of tractor trailer merges to the right and left. This C/VIS was intended to provide helpful information for merges. The DGPSs installed on the tractor trailer and on the confederate automobile provided distance information that could be used to determine such aspects as clearance at merge. During the "clearance/overlap (no clearance)" tests (Figure 53), the confederate automobile approached in either the right or left adjacent lane. It then moved into a position in which there was some specified amount of lateral overlap with the trailer (no clearance) or some lateral clearance with the trailer (clearance). The driver was queried regarding clearance. Both the DGPSs and an actual recording of video captured the correctness of the driver's responses.

Figure 65. Monitor in Peterbilt with Saab in adjacent lane for the wide-angle rear multipurpose trailer look-down C/VIS.

For the low-speed backing maneuvers, the routines depicted in Figures 54 through 56 were used. The driver performed the parking subtask first (Figures 54 and 66), followed by the loading dock subtask (Figures 55 and 67), and then the S-curve subtask (Figures 56 and 68). Because the driver backed a trailer through the S-curve, the barrels were set to allow greater tolerance in backing.

Figure 66. Monitor of Peterbilt during parking subtask for the wide-angle rear multipurpose trailer look-down C/VIS.

Figure 67. Monitor of Peterbilt during loading dock backing subtask for the wide-angle rear multipurpose trailer look-down C/VIS.

Figure 68. Monitor of Peterbilt during the S-curve backing subtask for the wide-angle rear multipurpose trailer look-down C/VIS.

Group 1. Test Order

By way of review, two C/VIS enhancements were tested in Group 1: the Tractor rear backing/bobtailing enhancement (using the Volvo tractor), and the Trailer rear wide-angle multipurpose look-down enhancement (using the Peterbilt tractor with trailer). It was deemed desirable to test both enhancements using Task A, the highway driving scenario, and Task B, the low-speed backing scenario.

The test ordering for Group 1 was counterbalanced as shown in Table 12. The Task A tests were counterbalanced in terms of baseline and C/VIS runs, and in terms of Task A and Task B. Similarly, the Task B tests were counterbalanced in terms of baseline and C/VIS runs, and in terms of Task A and Task B. In addition, for every younger driver there was an older driver with exactly the same order of presentation.

It is important to note that all drivers drove the Peterbilt tractor with trailer first. Thereafter, they drove the Volvo tractor in the bobtailing mode. This procedure was used so that direct comparisons could be made between the Group 1 results and the Group 2 results in regard to tests using the Peterbilt tractor with trailer. By having drivers drive the Peterbilt tractor with trailer first, the amount of practice for Groups 1 and 2 in regard to the Peterbilt tractor with trailer was essentially the same.

The counterbalancing scheme shown in Table 12 for the four conditions was repeated: the first replication used the Peterbilt with trailer (for the trailer rear wide-angle multipurpose look-down C/VIS tests), and the second used the Volvo tractor (for the rear backing/bobtailing C/VIS tests). The comparisons between Groups 1 and 2 were as follows: the trailer wide-angle rear multipurpose look-down enhancement could be compared to the left and right merge/re-merge enhancements in terms of highway performance; and, the trailer wide-angle rear multipurpose look-down enhancement could be compared to the (regular) trailer rear look-down enhancement in terms of backing performance.

Table 12. Presentation orders for Group 1. (Note that same order was used for each of the two enhancements.)

Subject Number	Age Group	Presentation Order			
		First	Second	Third	Fourth
1	Y	Task A, Baseline	Task A, C/VIS	Task B, Baseline	Task B, C/VIS
2	O	Task A, Baseline	Task A, C/VIS	Task B, Baseline	Task B, C/VIS
3	Y	Task A, C/VIS	Task A, Baseline	Task B, C/VIS	Task B, Baseline
4	O	Task A, C/VIS	Task A, Baseline	Task B, C/VIS	Task B, Baseline
5	Y	Task B, Baseline	Task B, C/VIS	Task A, Baseline	Task A, C/VIS
6	O	Task B, Baseline	Task B, C/VIS	Task A, Baseline	Task A, C/VIS
7	Y	Task B, C/VIS	Task B, Baseline	Task A, C/VIS	Task A, Baseline
8	O	Task B, C/VIS	Task B, Baseline	Task A, C/VIS	Task A, Baseline

GROUP 2 TESTS

A. Left and Right Merge/Re-Merge Enhancements

These enhancements included cameras located approximately 5 ft 10 in (1.78 m) above the roadway, looking across the back of the trailer (Figure 69). The right merge camera was located at the outer left edge of the trailer and was aimed into the right adjacent lane. Similarly, the left merge camera was located at the outer right edge of the trailer and was aimed into the left adjacent lane. The fields of view were 55º, with the edge of the image showing the edge of the trailer. Accordingly, the driver could glance into the monitor and determine the degree of clearance (if any) with vehicles in the adjacent lane prior to performing the merge maneuver. The Size 2 monitors were located on the left and right headers, more or less in line with the outside rear-view mirrors (Figures 70 and 71). Thus, the driver was able to time-share between the mirrors and the corresponding monitor.

Figure 69. Back of trailer showing the three cameras used in Group 2 tests.

Figure 70. Driver-side monitor for the left merge/re-merge enhancement.

Figure 71. Passenger-side monitor for the right merge/re-merge enhancement.

The test scenario for these enhancements included highway driving only; that is, Task A, because the enhancements were not intended for use in backing and parking tasks. In other words, Task B was not performed for the left and right merge/re-merge enhancements. The first set of subtasks involved having the confederate vehicle approach from the rear in the adjacent left lane and the adjacent right lane. Data taking then involved clearance/overlap decisions. The confederate vehicle maneuvered longitudinally alongside the trailer. When requested by the experimenter, the driver indicated whether there was clearance between the back of the trailer and the confederate vehicle as well as the amount of clearance or overlap in feet. The second set of tasks involved actual merges to the left and right, while the confederate vehicle maintained speed. In this case, the driver had to increase speed and merge when he or she felt it was appropriate to do so. These tasks provided measures that indicated any changes in performance associated with the C/VIS as compared with baseline. Position data were gathered from the DGPSs installed on the tractor trailer and on the confederate automobile. The two enhancement camera videos were used as backup in determining clearances and estimating distances.

B. Trailer Rear Look-down Enhancement

This enhancement had the camera at the rear top center of the trailer, 13 ft 4 in (4.06 m) above the road surface (Figure 69). The camera had a 60º horizontal FOV. It was aimed so that the bottom edge of the image included the rear edge (bumper) of the trailer, thereby allowing drivers to judge distance to objects behind the trailer. The monitor was Size 1 and was located at the center dash (Figure 72).

Figure 72. Dash monitor in the Peterbilt tractor used with the trailer rear look-down C/VIS.

This enhancement was intended for backing and parking only. Therefore, tests were limited to backing and parking subtasks (Task B). First, drivers parked in front of a parked car (Figures 54 and 73), with instructions to park five feet (1.52 m) away from the parked car. Thereafter, they approached the artificial loading dock, with instructions to stop 1 ft (0.305 m) from the dock (Figure 55). Measurements were made of final position relative to the loading dock and distance the dock had been pushed if it was struck. Lastly, drivers backed through the S-curve. Barrels were set so that the S-curve maneuver could be accomplished with the correct technique (Figures 56 and 72).

Figure 73. Dash monitor of Peterbilt during backing subtask with the trailer rear look-down C/VIS.

Group 2. Test Order

Both Task A (for the merge/re-merge enhancements) and Task B (for the trailer rear look-down enhancement) in this group had baseline runs, each involving the tractor trailer without enhancements. However, the baselines differed from one another. Thus, the situation, except for the C/VISs being tested, was identical to the Group 1 tests. Consequently, the counterbalancing scheme shown in Table 10 could be used for the Group 2 tests. The only differences were the driver numbers, which ranged from 9 to 16, and the fact that the counterbalancing scheme did not need to be repeated (as it was in the Group 1 tests).

GROUP 3 TESTS

A. Convex Mirror Surrogates

The Group 3 tests consisted of the use of surrogates. Under Group 3A, the convex mirrors were replaced with surrogates. The cameras were placed on the outer edges of the front fenders and had 45º fields-of-view. The monitors were Size 2 and were located at the A-pillars. (The preliminary tests indicated that drivers liked this surrogate and felt it was actually superior to the convex mirrors themselves.) The scenarios for these tests are discussed later in this section.

B. Convex Mirror Surrogates Combined With West Coast (Flat) Mirror Surrogates

Under Group 3B, the west coast mirror surrogates were added to the convex mirror surrogates. Since the recommendation is likely to be made that the west coast surrogates should not be used by themselves, it was the combination that had to be tested. (The reasoning, as explained earlier, is that the convex mirror surrogates perform well and should be used if any surrogates are used.)

For Group 3B, the convex mirror surrogates were the same as in Group 3A. The west coast surrogates also used cameras mounted at the outer edges of the front fenders (there were two cameras on each fender). Image size was matched to that provided by the actual west coast mirrors by adjustment of the zoom lenses. Monitors for the west coast surrogates were Size 3 and were mounted at the A-pillars. It was necessary to stack the two monitors (for the convex and the west coast surrogates) at the A-pillars. Figures 74 and 75 show the stacked monitors mounted in front of the A-pillars. This location was decided upon, as explained earlier, because it minimized blind spots.

The Size 3 monitors (for the west coast mirror surrogates) each had a horizontal line on them corresponding to a vertical plane projected downward from the rear surface of the trailer (onto a flat roadway). This horizontal line indicated the rear end of the trailer (on flat roadway), so that drivers could better judge distances relative to the rear end of the trailer. The camera aim was carefully calibrated prior to data gathering runs to ensure that the horizontal line indicated the end of the trailer on flat roadway. As discussed earlier, a conventional video system does not provide stereographic presentation. Consequently, distances may be more difficult to judge with video. It was deemed desirable to include the horizontal line in the video presentation as a means of helping the driver judge distances in the most critical situations. Note also that such a line is not a function of driver eye height or other aspects of driver viewing position. It is only a function of camera aim and camera FOV, both of which were carefully calibrated prior to data gathering.

Figure 74. Driver-side monitors mounted at the A-pillar. Note the covers over the mirrors.

Figure 75. Passenger-side monitors mounted at the A-pillar. Note the covers over the mirrors, and note also that the upper monitor was hooded to reduce glare.

Figure 76 shows the camera locations on the driver-side front fender. Similarly, Figure 77 shows the camera location on the passenger-side front fender. The round cameras are the convex mirror surrogate cameras and the rectangular cameras are the west coast mirror surrogate cameras. The convex mirror cameras had fields of view of 45º. The west coast mirror surrogate cameras had fields of view creating the same image size in width as the corresponding mirrors themselves, when viewed from the driver's position. As earlier analyses indicated, this meant that the passenger-side FOV was narrower than the driver-side FOV.

Figure 76. Driver-side cameras at the front fender. The round camera is for the convex mirror surrogate, and the rectangular camera is for the west coast mirror surrogate.

Figure 77. Passenger-side cameras at the front fender. The round camera is for the convex mirror surrogate, and the rectangular camera is for the west coast mirror surrogate.

The cameras were each carefully aimed so that when the vehicle was being driven in a straight line, the edge of the trailer could be seen in the image. Since both the horizontal and vertical fields-of-view differed for the convex mirror surrogate camera and for the west coast mirror surrogate, the aim points were quite different, as Figures 76 and 77 show.

Special camera mounts had to be used. The mounts were cubes of mild steel having substantial mass. They can be seen in Figures 76 and 77 (their outside surfaces are painted orange). The cubes helped to reduce high frequency vibration in the west coast mirror surrogate cameras, which were susceptible because they had narrow fields-of-view. The cubes were mounted on a cross bar that went diagonally down from the cubes to the frame of the tractor, where the crossbar was bolted to the frame. It was found that there was simply too much vibration in the fenders themselves to mount the west coast mirror surrogates directly to the fenders. It should be mentioned that, although the mounts worked adequately, additional improvements in mounting intended to minimize vibration effects should be considered in future applications.

Scenario for Tasks A and B

The two tasks used identical scenarios and had a common baseline. Consequently, the situation was somewhat different from the Group 1 and Group 2 tests. In fact, since there was only one baseline in these tests, there are essentially three runs associated with the Group 3 tests, all of which have identical scenarios.

The scenario included both highway and backing tasks (both Tasks A and B). The highway driving portion (Task A) was performed as described earlier and included both the clearance/overlap subtask and the passing subtask. Drivers are often required to perform these using their side mirrors. Therefore, it was considered important to test the surrogates for this capability. The DGPSs installed on the trailer and on the confederate vehicle provided distance information that could be used to determine such aspects as clearance at merge and uniformity of distance at merge. The left and right merge/re-merge enhancement cameras at the back of the trailer (for the Group 2 tests) and corresponding recorded video (not viewed by the driver) were used as backup in case of DGPS dropout.

For the backing subtasks, the routines depicted in Figures 54 through 56 were again used. First, drivers parked in front of a parked car (Figures 54 and 78), with instructions to park 5 ft (1.52 m) away from the parked car. Thereafter, they approached the artificial loading dock, with instructions to stop 1 ft (0.305 m) from the dock (Figure 55). Lastly, drivers backed through the S-curve. Barrels were set so that the S-curve maneuver could be accomplished with the correct technique (Figures 56 and 79). Because the driver backed a trailer through the S-curve, the barrels were set to allow greater tolerance in backing.

Figure 78. Typical view on the passenger-side monitors (for the convex and west coast mirror surrogates) during the task of backing to the parked car.

Figure 79. Typical view on the passenger-side monitors (for the convex and west coast mirror surrogates) during the task of backing through the S-curve.

It should be noted once again that during the surrogate tests the corresponding mirrors were covered so they could not be used. For the convex mirror surrogate runs, the convex side mirrors were covered, and for the convex mirror surrogates combined with the west coast mirror surrogates, all of the side mirrors were covered.

Group 3. Test Order

Counterbalancing for the Group 3 tests involved a single baseline and two tests with surrogates, which were given the temporary names convex C/VIS and combined C/VIS. Counterbalancing was achieved by having the baseline run precede the two C/VIS runs for half the drivers, and follow the C/VIS runs for the other half. In addition, the two C/VIS runs were counterbalanced. These considerations have been incorporated in the counterbalancing scheme shown in Table 13. Using eight drivers, there were four orders for younger drivers (17, 19, 21, and 23) and four identical orders for older drivers (18, 20, 22, and 24). In two of the four runs for each age group, the baseline preceded the surrogate runs, and in the other two runs the baseline followed the surrogate runs. Similarly, the two types of surrogate runs were counterbalanced.

Table 13. Presentation orders for Group 3.

Subject Number	Age Group	Presentation Order		
		First	Second	Third
17	Y	Baseline	Convex C/VIS	Combined C/VIS
18	O	Baseline	Convex C/VIS	Combined C/VIS
19	Y	Convex C/VIS	Combined C/VIS	Baseline
20	O	Convex C/VIS	Combined C/VIS	Baseline
21	Y	Baseline	Combined C/VIS	Convex C/VIS
22	O	Baseline	Combined C/VIS	Convex C/VIS
23	Y	Combined C/VIS	Convex C/VIS	Baseline
24	O	Combined C/VIS	Convex C/VIS	Baseline

It should be noted that the counterbalancing scheme shown in Table 13 does not account for the ordering of Task A (highway driving) and Task B (backing), both of which were performed by every driver in every condition. It was only possible to perform a partial counterbalance for the Task A/Task B ordering. This was accomplished by having drivers 17 through 20 perform Task A first and Task B second, and by having drivers 21 through 24 perform Task B first and Task A second.

EXPERIMENTAL DESIGN

Independent Variables

The experiments were quite similar in design, particularly for the first two groups of tests. The four corresponding enhancements associated with these two groups were analyzed separately. The independent variables were 2 (age groups, between) by 2 (C/VIS conditions: present versus absent, within), with four drivers in each age group. For Group 3, the data for the three conditions were analyzed together. Thus, the independent variables were 2 (age groups, between) by 3 (C/VIS conditions: absent versus convex C/VIS versus combined C/VIS, within), with four drivers in each age group.

Dependent Variables

Dependent variables fell into two major groups: highway driving variables (Task A) and backing and parking variables (Task B). For highway driving (Task A), the following were used where appropriate:

- Percent correctness of answers to the clearance/overlap queries
- Absolute error of clearance/overlap distance estimates
- Glance location probabilities for the clearance/overlap subtask
- Mean cut-in distance in the passing/merging maneuvers
- Glance location probabilities for the passing/merging maneuvers
- Individual ratings of difficulty in determining clearance or overlap in the clearance/overlap subtask (baseline and C/VIS)
- Individual ratings of difficulty in estimating distance in the clearance/overlap subtask (baseline and C/VIS)
- Individual ratings of usefulness, learning time, receptiveness, and blind-spot reduction after completing the clearance overlap and passing/merging subtasks (C/VIS only)

For backing and parking (Task B), the following were used where appropriate:

- Time to complete parking subtask
- Parking subtask final position relative to the parked vehicle
- Glance location probabilities for the parking task
- Time to complete the loading dock (or backing to cones) maneuver
- Loading dock (or cone barrier) distance in final position
- Glance location probabilities for the loading dock (cone barrier) maneuver
- S-curve backing subtask completion time
- S-curve number of direction reversals
- Number of barrels struck in the S-curve subtask
- Glance location probabilities for the S-curve subtask

- Individual ratings of difficulty for the parking subtask (baseline and C/VIS)
- Individual ratings of difficulty for the loading dock (cone barrier) backing subtask (baseline and C/VIS)
- Individual ratings of difficulty for the S-curve subtask (baseline and C/VIS)
- Individual ratings of usefulness, learning time, receptiveness, and blind-spot reduction for the backing subtasks (C/VIS only)

Statistical Tests

Parametric and nonparametric statistical tests were used. As is usually the case, parametric tests were run wherever appropriate and nonparametric tests were used for the remainder of the measures. There were a few cases where parametric tests were considered tentative. Under these circumstances, both parametric and nonparametric tests were used. The main objective of the tests was to determine any statistically significant differences between baseline and the corresponding C/VIS-related conditions. Such differences show reliable changes in performance or opinion for the corresponding C/VISs when compared to baseline. Additional aspects of the tests were intended to show which variables exhibited differences and also whether age group had an effect on driver performance and opinion.

Rating Scales

The rating scales administered to the drivers are shown in Appendix B. These ratings were intended to provide information on the degree of difficulty in performing the various maneuvers and in determining the degree of acceptance of the various C/VISs tested. The performance-related scales were designed so that they could be applied to either baseline or C/VIS runs. Other scales were used for the C/VISs only to determine the degree of acceptance.

For analysis purposes, the rating scale responses were converted to numerical values. Each scale had nine vertical delineators. They were numbered from 1 on the left to 9 on the right. The middle of the scale was then numbered as a 5. A value of 5 would ordinarily correspond to a "moderate" rating, as the scales in Appendix B show. Values greater than 5 would correspond to favorable ratings while values smaller than 5 would correspond to unfavorable ratings.

As mentioned, the Group 1A tests used the Volvo tractor in the uncoupled mode. The loading dock subtask was replaced by the cone-barrier subtask for Group 1A, and the rating scale wording correspondingly was changed, as shown in parentheses in Appendix B. Also, the ratings generally correspond to “tasks.” The word “tasks” is used for the drivers because they did not know that they were part of a larger group of experiments. Thus, “tasks” in the ratings corresponds to “subtasks” in this documentation of the experiment.

Organization of the Test Results

An extremely large set of test results was obtained for the six conditions, which could easily fill a 200-page report. However, to make the results more interpretable, they are summarized here with emphasis on the most important points. In general, the purpose of the tests, as previously mentioned, was to determine performance and opinion benefits/problems associated with the C/VISs tested.

Eyeglance data were analyzed with the goal of supplementing understanding of driver performance and opinion data. These data are presented in the section associated with the particular subtask performed and the particular C/VIS being tested. Eyeglance results were examined by age groups for the various analyses because of the possibility of differences in glance patterns. When substantial differences were found, the plots were included in the presentation of results. Small differences as a function of age are often described, rather than plotted, to keep the presentation within manageable bounds. Otherwise, glance probabilities are presented only as a function of presence or absence (baseline) of the C/VIS.

It should be mentioned that the Group 2 tests were performed before the Group 1 tests. The reason for this was that the Volvo tractor was in use on another project at the time that testing was to begin. To avoid conflicts, the Group 2 tests, which only required the Peterbilt tractor and trailer, were run first. This change in order should not have had any effect on the data because different drivers were used in each of the three groups.

The results are presented in the following six chapters. Chapters 8 through 11 are each dedicated to a particular C/VIS. Each chapter is then labeled with the name of the C/VIS as well as the group in which it was included. Chapter 12 deals with the two surrogates that were tested along with the baseline (Group 3). The reason for this was that comparisons were made relative to a common baseline. In addition, comparisons could be made between the surrogate C/VIS conditions tested. Chapter 13 deals with important performance comparisons between the first and second groups of C/VIS enhancements. In the following chapters, Group 2 results are presented first, followed by the Group 1 results, and then the Group 3 results. This is the order in which the data were gathered. As it turned out, the Group 2 results were somewhat simpler because the right and left merge/re-merge enhancements needed to be tested only in highway conditions (Task A), and the trailer look-down enhancement needed to be tested only in the backing subtasks (Task B).

CHAPTER 8: RESULTS FOR THE RIGHT AND LEFT MERGE/RE-MERGE ENHANCEMENTS (GROUP 2)

These tests were performed using the Peterbilt tractor with 48 ft (14.6 m) trailer. Only on-road subtasks (Task A) were performed and analyzed because the C/VISs were intended for on-road use only.

TASK A (ON ROAD) RESULTS

Clearance/Overlap Subtask Performance and Glance Analyses

In the clearance/overlap tests, results showed that drivers were much better at determining correctly whether there was clearance or overlap when the C/VISs were present. Figure 80 shows that drivers were correct 100% of the time with the C/VISs as compared with baseline in which they were correct 75% of the time. This result was found to be significant using the Cochran Q test; Q = 9.0; df = 1; $p = 0.0027$.

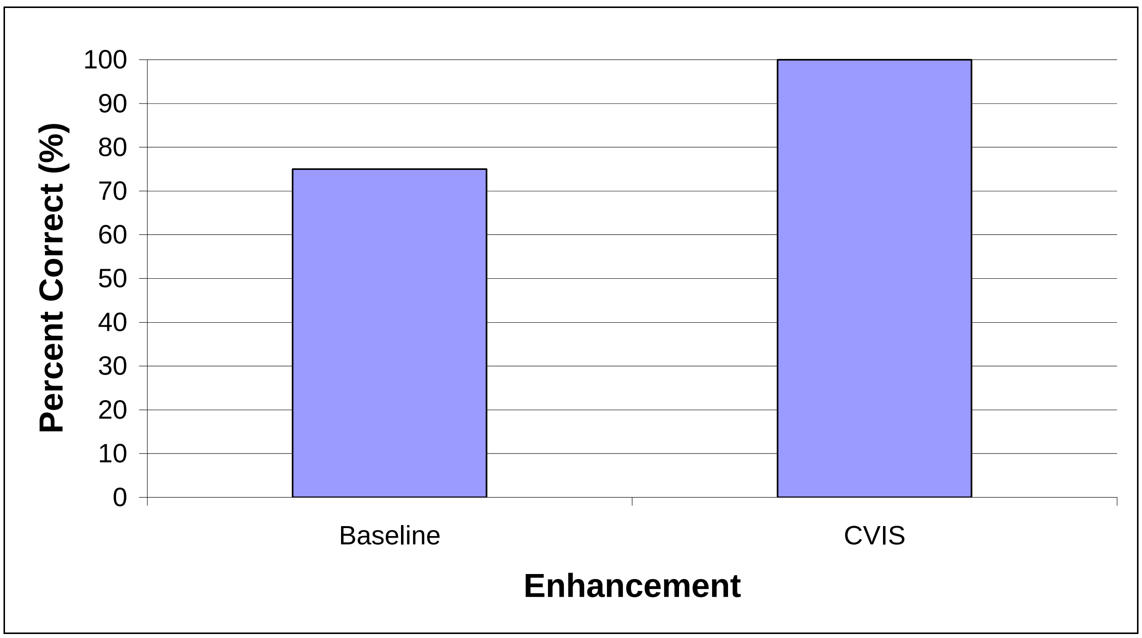

Figure 80. Effect of the merge/re-merge C/VISs on clearance/overlap correctness.

For the clearance/overlap test, a one-way chi-square test on the percent correct for the nested factor of age was not significant. Because there was no appropriate test for interactions between age and percent correct, two additional one-way chi-square tests were run: one for older drivers and one for younger drivers. The results demonstrated a significant effect of enhancement for older drivers ($X^2 = 7.2$; df = 1, $p = 0.0075$). However, the results for younger drivers were not significant. It appears that older drivers were able to obtain greater improvement in their performance when using the C/VIS, mainly because their baseline performance was not as good (Figure 81).

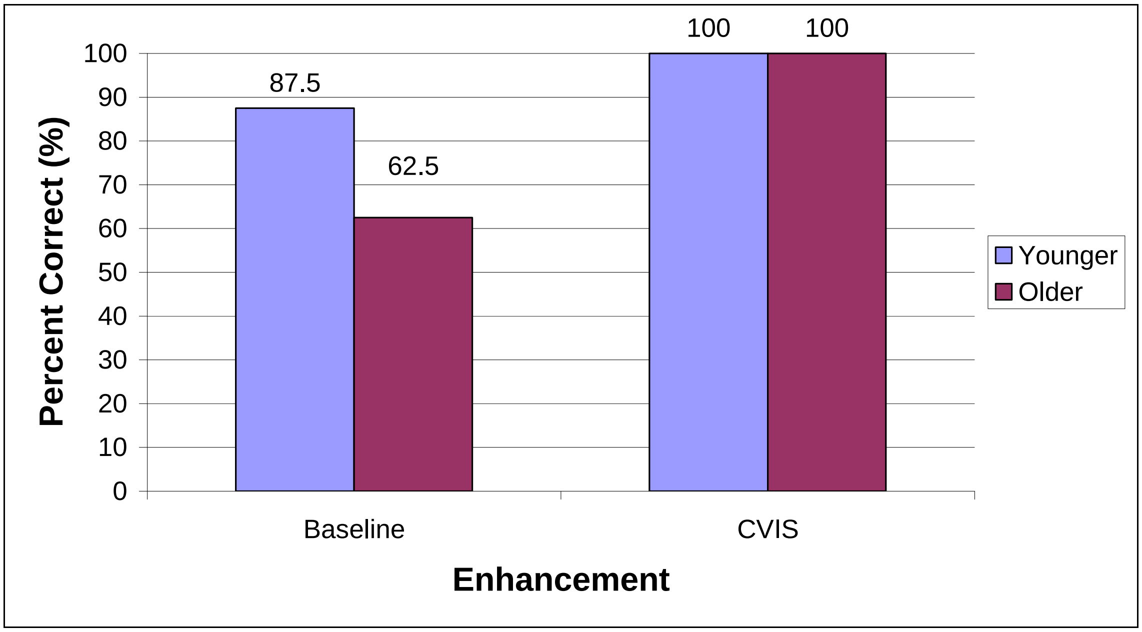

Figure 81. Effect of age and the merge/re-merge C/VISs on clearance/overlap correctness.

Drivers also provided an estimate of the amount of clearance or the amount of overlap in feet. These data were used to determine the relative level of accuracy in estimation. In regard to those estimates with an incorrect statement of clearance or overlap, the estimate of distance was added to the correct DGPS-derived value, rather than subtracted from it. Thereafter, the absolute value of the error was determined. A 2 x 2 x 2 repeated-measures analysis of variance on the absolute error data for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (younger or oolder) revealed that only the main effect of enhancement was significant $F(1,52) = 31.2$, $p < 0.0001$. There were no significant interactions. Figure 82 shows the results for the main effect of enhancement, with standard error bars included. The results indicate that drivers were much better at judging distance when the C/VIS was present.

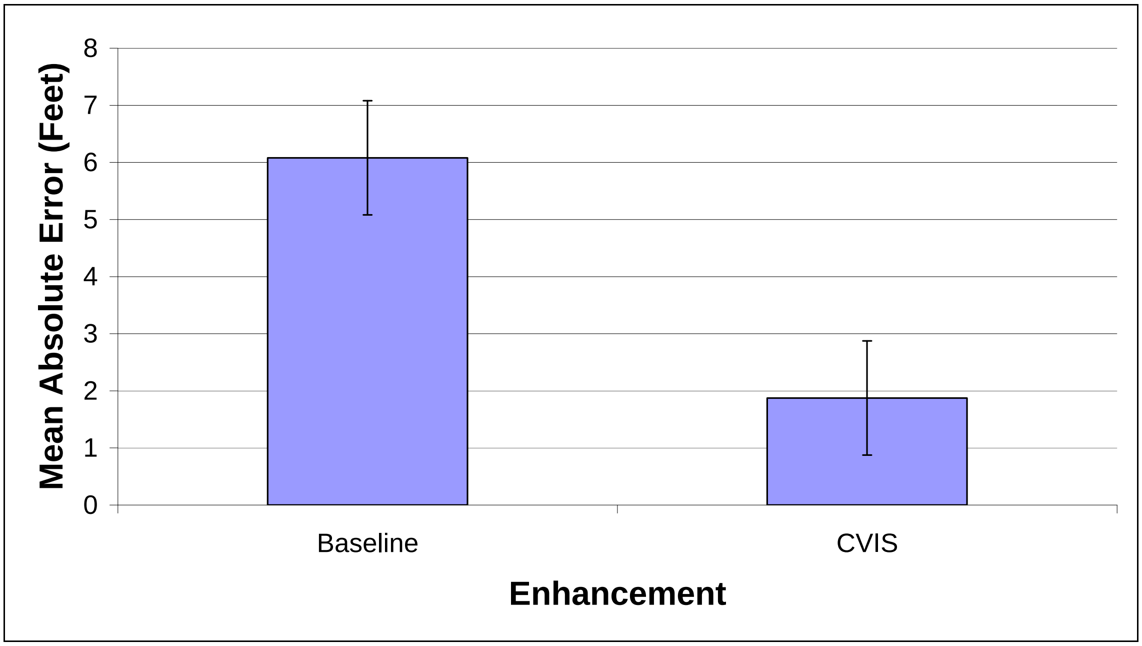

Figure 82. Effect of the merge/re-merge C/VISs on mean error in clearance/overlap distance estimates by the drivers.

Eyeglance data for the clearance/overlap subtask were analyzed for the time interval starting with completion of clearance/overlap instruction by the experimenter and ending when the driver provided the estimate of distance.[1] Note that the driver was first queried regarding clearance/overlap and then in regard to distance in feet. The results are shown graphically in Figures 83 (left side) and 84 (right side). These results show clearly that drivers shifted their visual resources largely from the outside mirrors to the C/VIS on the respective side when the C/VIS was present. Such an indication suggests that drivers could use these C/VISs to determine whether or not they had clearance. Figures 83 and 84 have no appreciable differences from one another, indicating that performance was nearly the same on each side of the vehicle.

[1]Glance location probability was defined as the number of samples in which the eyes were fixated at the given location divided by the total number of samples in which the eyes were fixated. This measure indicates the degree to which the driver fixates on a given location. Note that the sum of all glance location probabilities should be approximately unity.

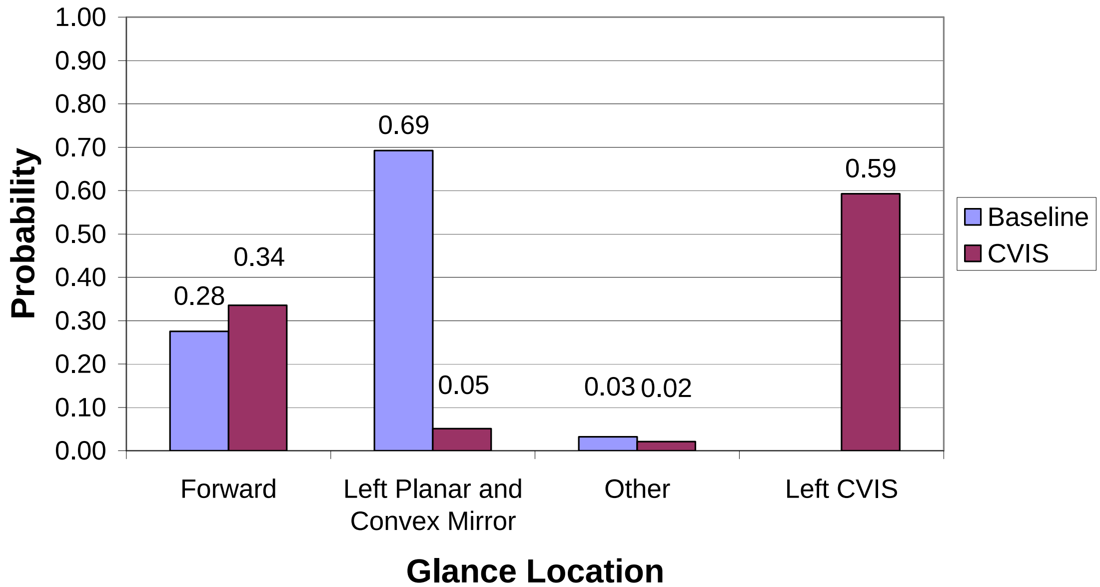

Figure 83. Glance location probabilities for the clearance/overlap subtask, left side.

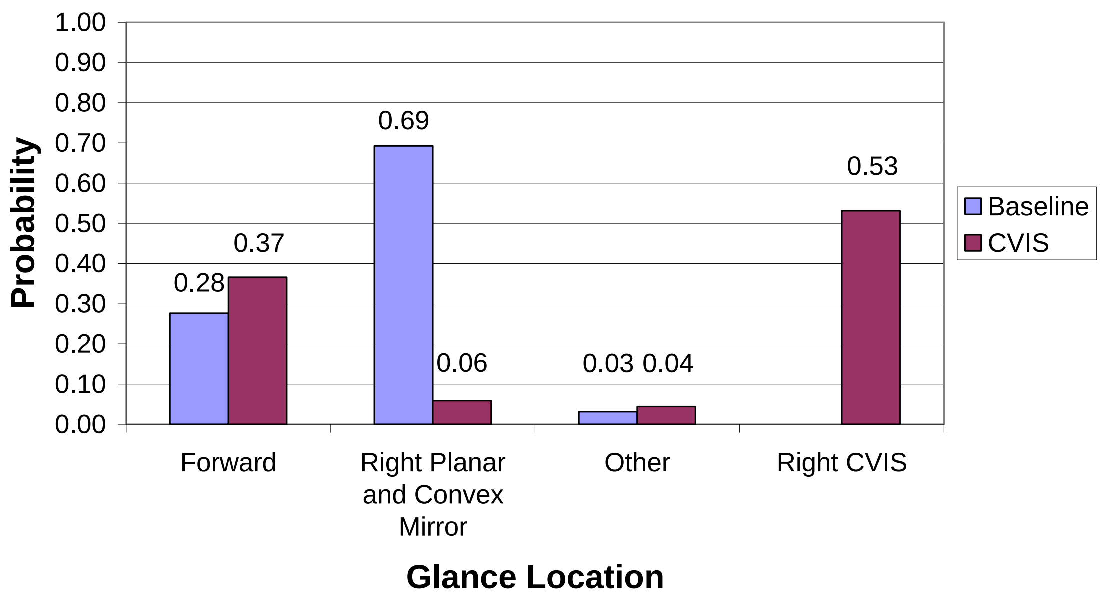

Figure 84. Glance location probabilities for the clearance/overlap subtask, right side.

The glance data were then divided by age group as well as side, resulting in four plots. Close examination of the plots showed no substantial differences as a function of age group for the left side. Similarly, there were no substantial differences as a function of age group for the right side.

Passing/Merging Subtask Performance and Glance Analyses

In the passing/merging subtask, tractor-trailer drivers pulled forward of the automobile and then merged in front of it. Both left-side and right-side merges were accomplished. (Note that in a left-side merge the driver moved to the left in front of the automobile, and in a right-side merge the driver moved to the right in front of the automobile.) There were two replications of passing on each side, for a total of four per driver and condition (C/VISs or baseline). Results were analyzed in terms of re-merge clearance (cut-in distance).

The cut-in distance was defined as the longitudinal component of the distance between the back end of the trailer and the front bumper of the automobile at the initiation of the merge. Initiation of merge was determined by a second experimenter in the tractor who viewed the driver and the roadway. When either the steering input or the vehicle trajectory indicated the tractor trailer had begun a merge, the experimenter pressed a key so indicating. Later, the longitudinal component of distance at that time was calculated and used as the cut-in distance. It should be noted that since the speed difference between the two vehicles was relatively low at cut-in, small errors in the timing of merge initiation would be expected to produce only small errors in longitudinal separation.

Cut-in distance values were analyzed using a 2 x 2 x 2 repeated-measures analysis of variance for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (older or younger). The analysis demonstrated that both side and enhancement main effects were significant: side, $F(1,52) = 4.04$, $p = 0.0495$; enhancement, $F(1,52) = 43.5$, $p < 0.0001$. The main effect of age was not significant and there were no significant interactions. The results for side are shown in Figure 85, and the results for enhancement are shown in Figure 86.

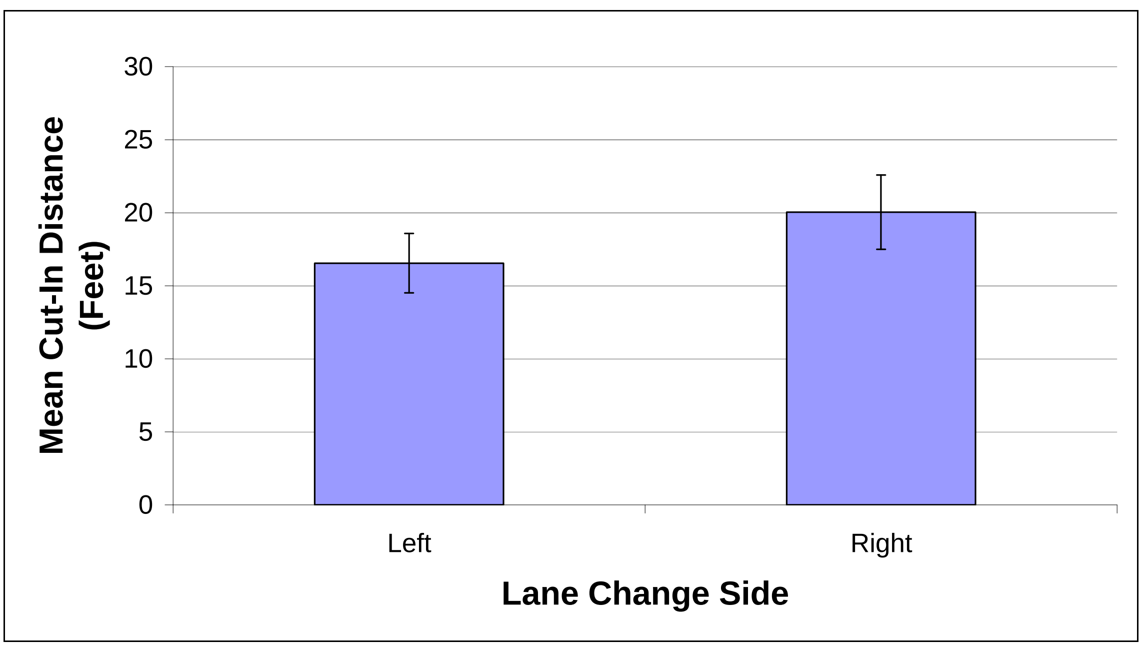

Figure 85. Mean cut-in distance on each side of the tractor trailer for the passing/merging subtask.

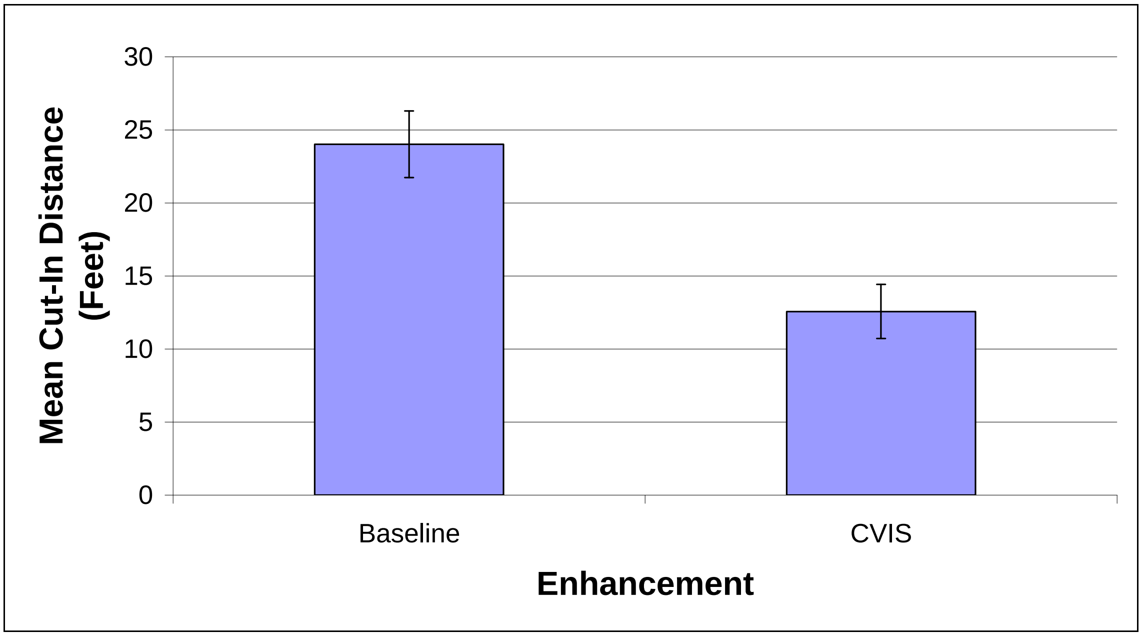

Figure 86. Mean cut-in distance by enhancement (C/VISs or baseline) for the passing/merging subtask.

The results in Figure 86 show that drivers allowed almost twice as much distance before beginning cut-in during baseline. This was probably a result of the greater uncertainty in the position of the automobile when the C/VISs were not available.

Glance data for the passing/merging subtask were analyzed using procedures similar to those used for the clearance/overlap subtask. Glance probabilities were calculated for the interval during which the pass/merge maneuver was performed. Specifically, the interval began when the automobile (confederate) driver moved to the center of the trailer and matched speed to the tractor trailer. It was at this point that the experimenter in the tractor trailer instructed the driver to increase speed and merge in front of the automobile. The interval ended when the tractor-trailer driver began the lateral maneuver to merge in front of the automobile. The results of the glance data analyses are shown in Figure 87 for the left-side pass/merge task and Figure 88 for the right-side pass/merge task. The results indicate, once again, that the two sides were quite similar in terms of glance patterns and that visual resources were taken from the mirror views and used for C/VIS views on the side that the merge was taking place.

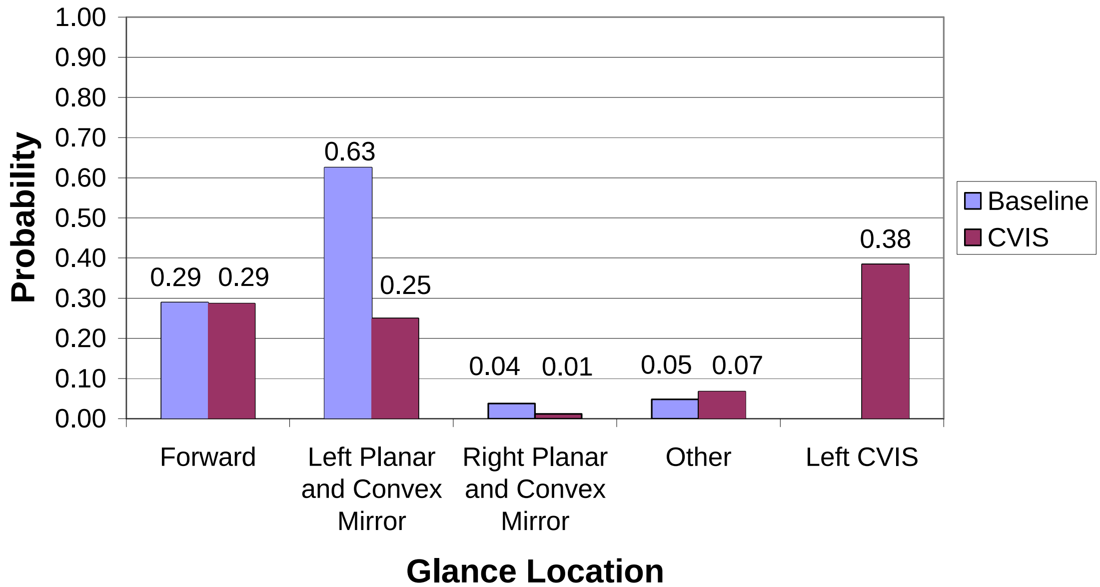

Figure 87. Glance location probabilities for the passing/merging subtask, left side.

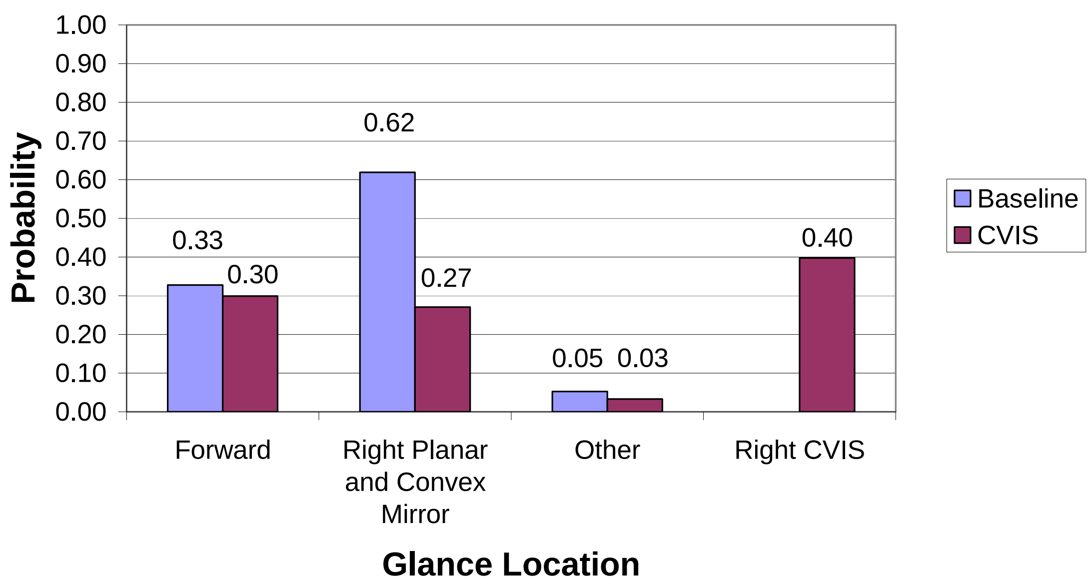

Figure 88. Glance location probabilities for the passing/merging subtask, right side.

The glance data were then divided by age group as well as side, resulting in four plots, following procedures used in the clearance/overlap subtask. Once again, close examination of the plots showed no substantial differences as a function of age group for the left side. Similarly, there were no substantial differences as a function of age group for the right side.

Task A (Clearance/Overlap and Passing/Merging) Opinion Data Analyses

For the opinion data, the *comparisons* involved how difficult/easy it was to perform the clearance/overlap subtask or the passing/merging subtask. In regard to the clearance/overlap subtask, the results are shown in Table 14. The data were first analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. Both main effects demonstrated significance: enhancement, $F(1,6) = 19.44$, $p = 0.0044$; age, $F(1,6) = 7.71$, $p = 0.032$. The interaction was not significant. The main effect of enhancement was also analyzed by a Wilcoxon Signed Ranks Test, an appropriate nonparametric test. The results demonstrated significance for this effect $W = 9$, $N = 7$, $p = 0.02$. Note that the mean and median values of the ratings for baseline and C/VIS are provided in Table 14. Similarly, the age main effect was analyzed by a (nonparametric) Kruskal-Wallace Test. However, the results of that test did not reach significance. The age main effect (in the parametric test) had mean ratings values of 5.75 for the younger age group and 7.25 for the older age group. The enhancement results are plotted in Figure 89 and indicate that the drivers felt that the merge/re-merge C/VISs made the task much easier. Note that many of the ratings for the C/VISs in Table 14 were 9s; that is, the highest possible ratings.

Table 14. Individual ratings for the scale: How difficult/easy was it to estimate clearance/overlap when the other vehicle was alongside near the back of the trailer?

Subject	Baseline	CVIS
9	3	9
10	4	9
11	4	5
12	6	9
13	4	9
14	7	9
15	7	7
16	3	9
Mean Rating	4.75	8.25
Median	4.00	9.00

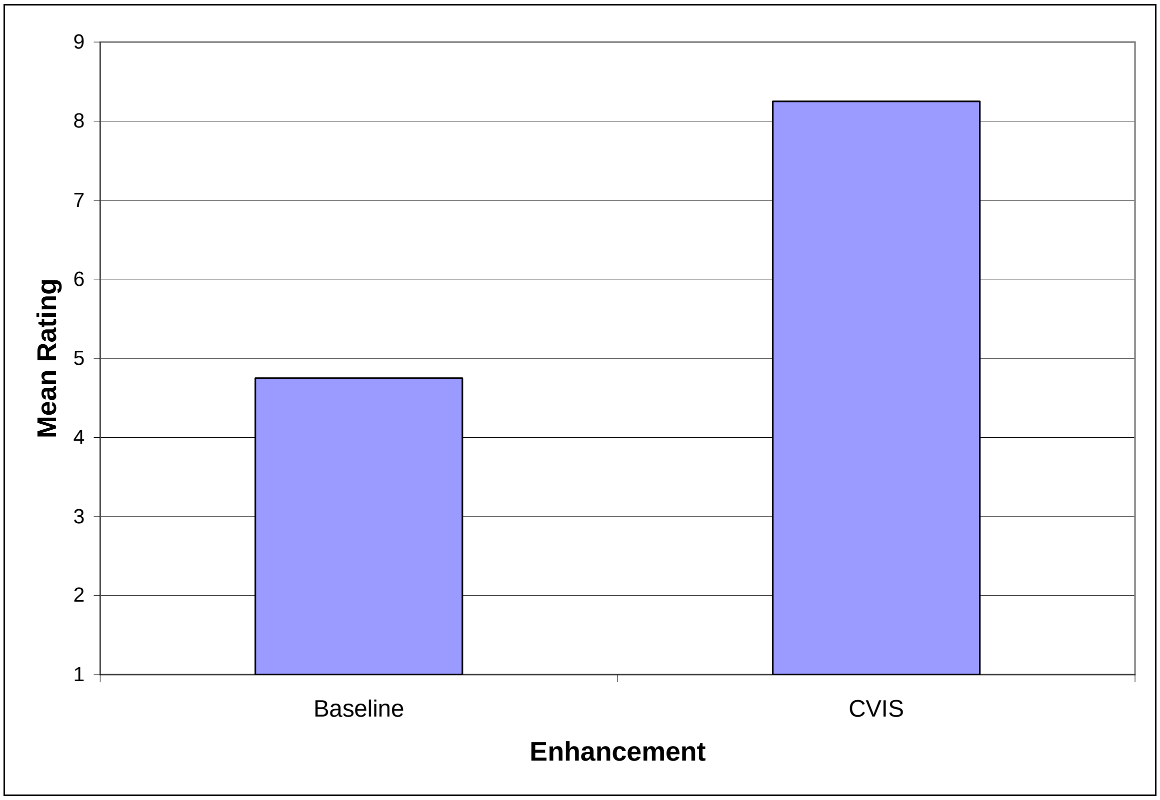

Figure 89. Plot of rating data as a function of C/VIS for ease/difficulty of estimating clearance or overlap.

For the passing/merging subtask, the opinion data are shown in Table 15. The data were first analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. Only the main effect of enhancement demonstrated significance, $F(1,6) = 13.05$, $p = 0.0112$. The interaction of enhancement and age was also not significant. The corresponding Wilcoxon Signed Ranks Test for enhancement similarly demonstrated significance, $W = 21$, $N = 6$, $p = 0.05$. Note that the mean and median values for baseline and the C/VISs are included in Table 15. Figure 90 is a plot of the results. Once again, it is clear that drivers felt that the merge/re-merge C/VISs made the merging task much easier.

Table 15. Individual ratings for the scale: How difficult/easy was it to estimate distance to the other vehicle when merging to the right or left?

Subject	Baseline	CVIS
9	6	9
10	5	9
11	6	9
12	7	9
13	4	9
14	7	9
15	7	7
16	9	9
Mean Rating	6.38	8.75
Median	6.50	9.00

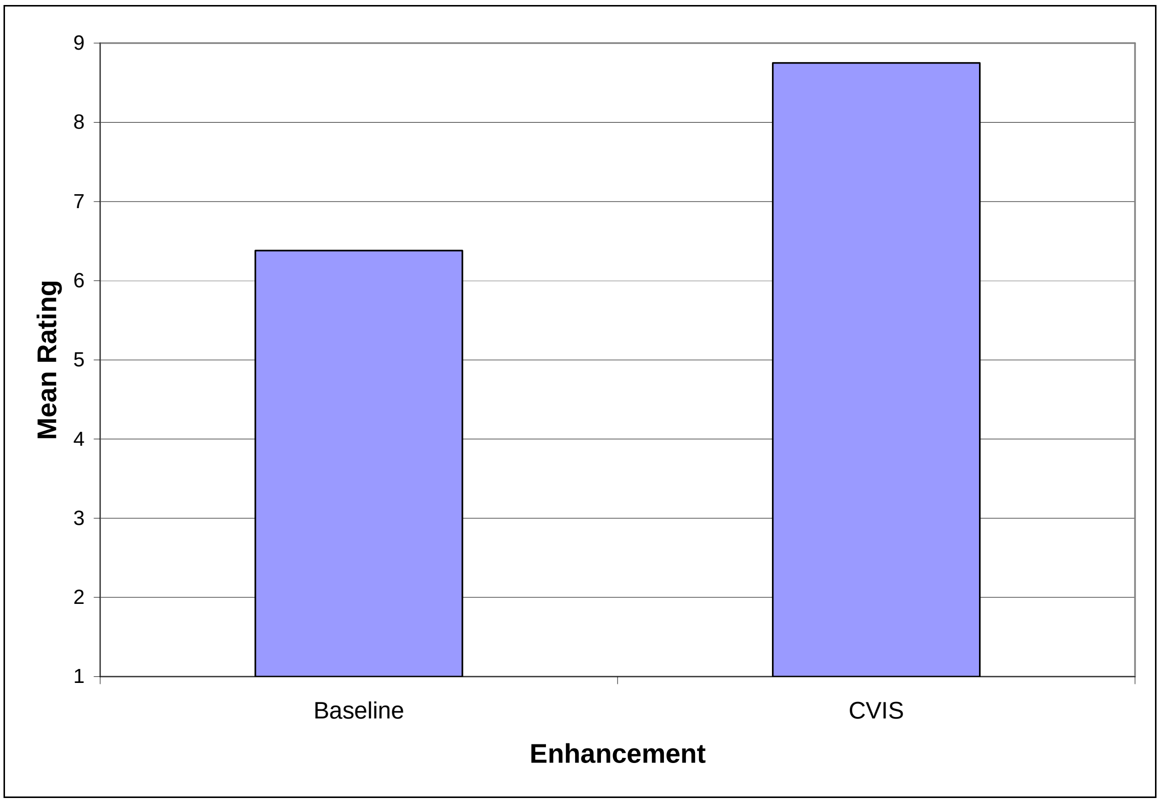

Figure 90. Plot of rating data as a function of C/VIS for ease/difficulty of estimating distance in the passing/merging subtask.

Four additional ratings for the C/VIS enhancements were obtained for the combination of clearance/overlap subtasks and the passing/merging subtasks. The scales were associated with Usefulness, Learning Time, Receptiveness, and Blind Spot Reduction (as described in Appendix B showing the rating scales). These scales were administered after completion of all tasks with the merge/re-merge enhancements. No baseline comparisons were made. The results are presented in Table 16. As the table shows, the drivers generally provided very high ratings on all of the scales for the enhancements. The most prevalent rating was 9, the highest possible.

Table 16. Ratings on various scales for the merge/re-merge enhancements, taken after completing both the clearance/overlap and passing/merging subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
9	9	9	9	9
10	9	9	9	7
11	7	8	8	9
12	9	9	9	9
13	8	7	9	9
14	9	7	7	9
15	9	7	9	9
16	3	5	9	9
Mean Rating	7.88	7.63	8.63	8.75
Median Rating	9.00	7.50	9.00	9.00

The data for each scale reported in Table 16 were analyzed for age effects using one-way analyses of variance with age as the independent variable. None of the scales exhibited a significant age effect on the ratings.

DISCUSSION

Performance data for the merge/re-merge enhancements provide clear evidence of improvement. Correctness in regard to clearance/overlap was 100% with these C/VISs, and sizes of errors in estimation of clearance or overlap were much smaller. For the passing/merging subtask, the cut in distances were shorter, suggesting that drivers were much more certain about the location of the vehicle being passed. Glance data show that the C/VISs were used extensively during the maneuvers. Finally, the opinion ratings for the C/VISs are very high relative to baseline, suggesting that drivers were receptive to the C/VISs.

CHAPTER 9: RESULTS FOR THE TRAILER LOOK-DOWN ENHANCEMENT (GROUP 2)

These tests were performed using the Peterbilt tractor with a 48 ft (14.6 m) trailer. The look-down enhancement was intended to provide a view directly behind the trailer for backing purposes. In particular, the enhancement was designed to allow accurate backing to a fixed object, where distance judgment might otherwise be difficult. Tests were devised to determine whether such an enhancement might be useful in the parking (to a parked car), loading dock backing, and S-curve backing subtasks, particularly in regard to accuracy of the maneuver. These subtasks when combined are called Task B.

TASK B (BACKING SUBTASKS) RESULTS

Backing (to Parked Car) Subtask Performance and Glance Analyses

In regard to the parking subtask (Figure 50), the instructions to the driver indicated that the final position of the trailer should be "5 feet from the front bumper of the car.". First, task completion times were compared with and without the look-down enhancement. The results are presented in Table 17 by driver. A two-way repeated-measures analysis of variance on task completion times with enhancement and the nested factor age as independent variables revealed that there was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 17. Task completion times (seconds) for the parking subtask.

Subjects	Baseline	CVIS
9	152	105
10	65	120
11	132	103
12	124	149
13	69	82
14	141	155
15	85	99
16	66	93
Mean Completion Time	104.25	113.25
Standard Error	12.96	9.29

In regard to final position in the parking subtask, the distance from the end of the trailer to the front bumper of the automobile was measured and recorded. Table 18 shows the measurements as a function of presence or absence of the C/VIS. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. A significant enhancement effect was found $F(1, 6) = 5.94$, $p = 0.0507$. The results are plotted in Figure 91. The figure shows that drivers got closer than the instructed five feet when the enhancement was present and were well beyond five feet for baseline runs. For the C/VIS condition, final positions averaged about 20 in (51 cm) short of the instructed position, whereas for the baseline condition, final positions averaged about 52 in (132 cm) greater than the instructed position. There was no significant age main effect or enhancement by age interaction.

Table 18. Final position distances (inches) for the parking subtask as a function of presence/absence of the look-down enhancement.

Subjects	Baseline	CVIS
9	71.00	53.00
10	101.00	37.75
11	122.75	4.50
12	243.00	63.50
13	202.00	25.00
14	109.50	43.50
15	2.00	47.00
16	49.50	35.00
Mean Distance	112.59	38.66
Standard Error	27.77	6.39

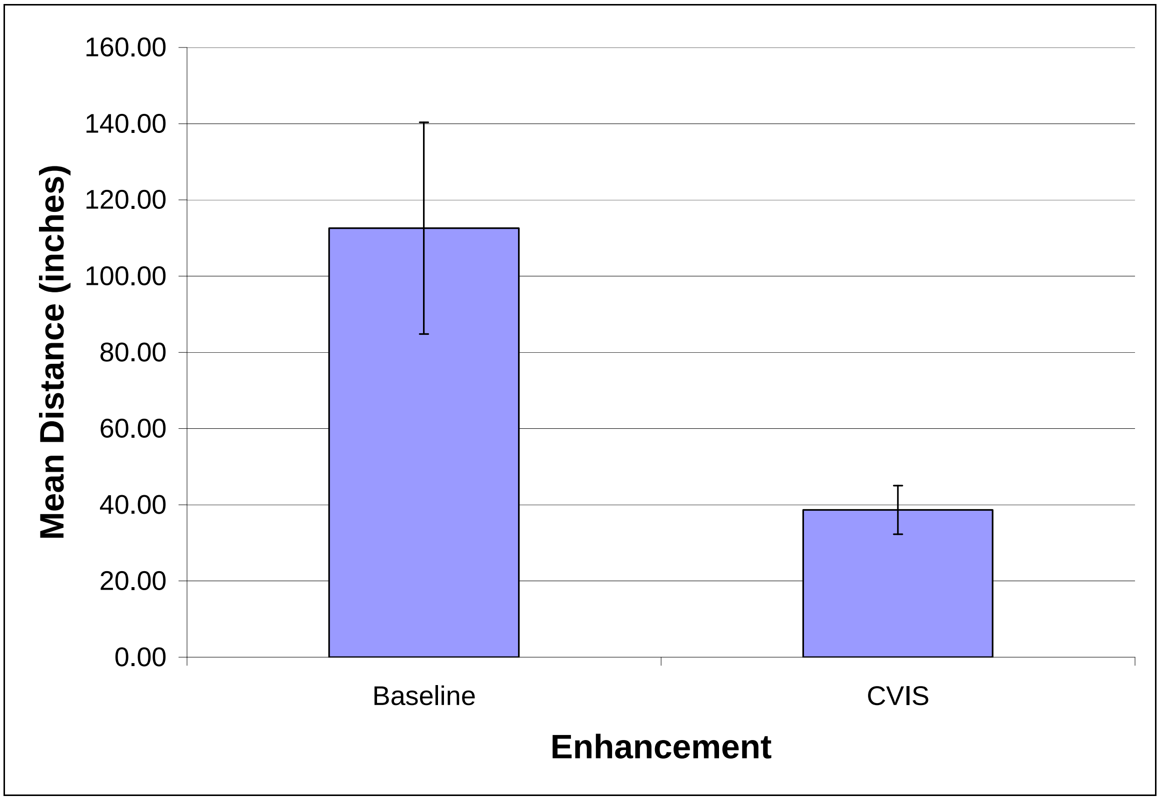

Figure 91. Final position distances (inches) for the parking subtask as a function of presence/absence of the look-down enhancement.

It should be mentioned that one driver in the baseline condition struck the structure in front of the bumper of the automobile. This released the brake and caused the automobile to move about 2.5 in (6.4 cm) to the rear. Since the bumper itself was not struck, the measurement of final position was taken from the original position of the automobile.

Table 19 shows the absolute errors from the 5 ft (1.53 m) goal by subject as a function of enhancement. Values in the table are in inches. An analysis of absolute error was performed. Once again, a two-way repeated-measures analysis of variance with enhancement and the nested factor of age as independent variables was carried out. The results indicated that neither of the main effects nor the interaction was significant; however, for the main effect of enhancement, it was found that $F(1,6) = 4.22$, $p = 0.086$. The values plotted in Figure 92 show that there was a large difference between means as a function of enhancement. The difference in standard error is also quite large, suggesting that the data might not meet the assumptions of parametric analysis. As a result, a Wilcoxon (nonparametric) test was carried out. It demonstrated a significant effect of enhancement, $W = 33$, $p = 0.02$. A Mann-Whitney test performed on age was not significant. Thus, the results for enhancement shown in Figure 92 can be considered to be reliable.

Table 19. Absolute error (in) from the 5 ft goal as a function of enhancement for the backing (to a parked car) subtask.

Subject	CVIS	Baseline
9	7	11
10	22.25	41
11	55.5	62.75
12	3.5	183
13	35	142
14	16.5	49.5
15	13	58
16	25	10.5
Mean	22.22	69.72
Std. error	5.94	21.73

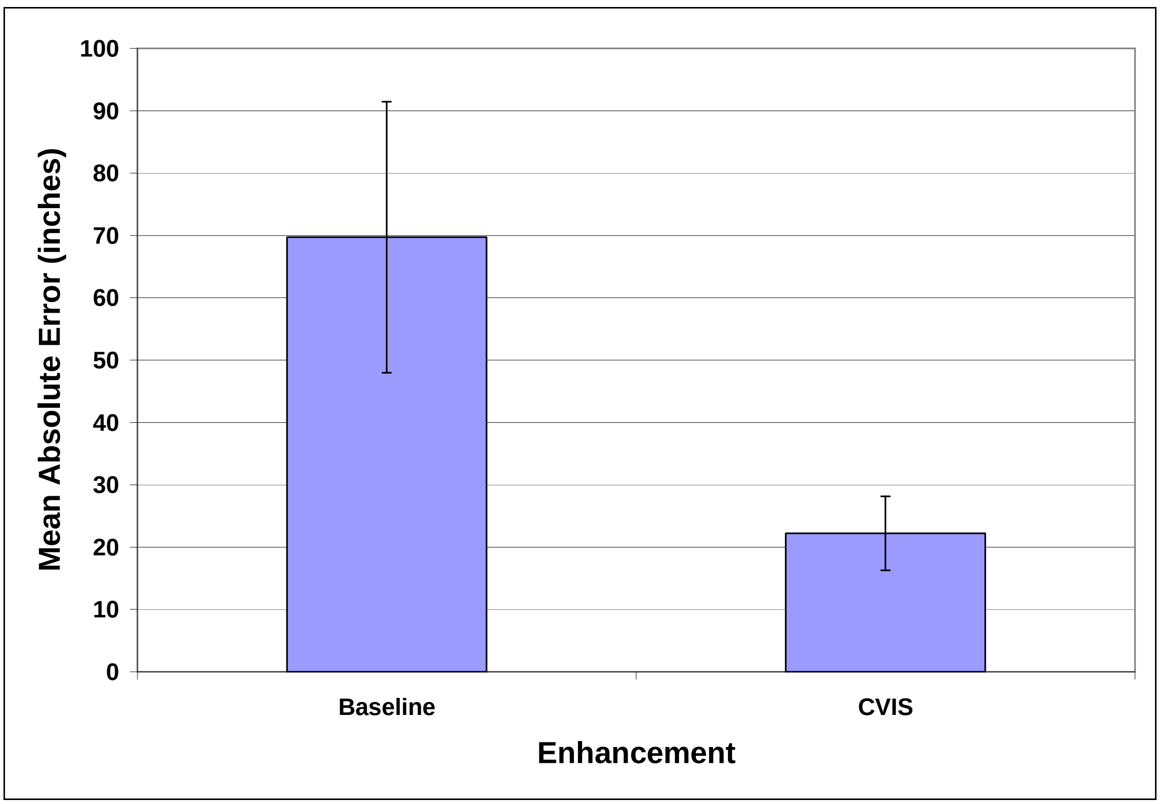

Figure 92. Mean absolute distance error (in) from the 5 ft goal as a function of enhancement for the backing (to a parked car) subtask.

Glance data for the last 30 seconds of the parking subtask were analyzed to obtain glance probabilities with and without the look-down C/VIS. The results are shown in Figure 93. The plot shows that the C/VIS once again was heavily relied on (when available) during the last 30 seconds. Visual resources were taken from the left- and right-side mirrors at about the same level.

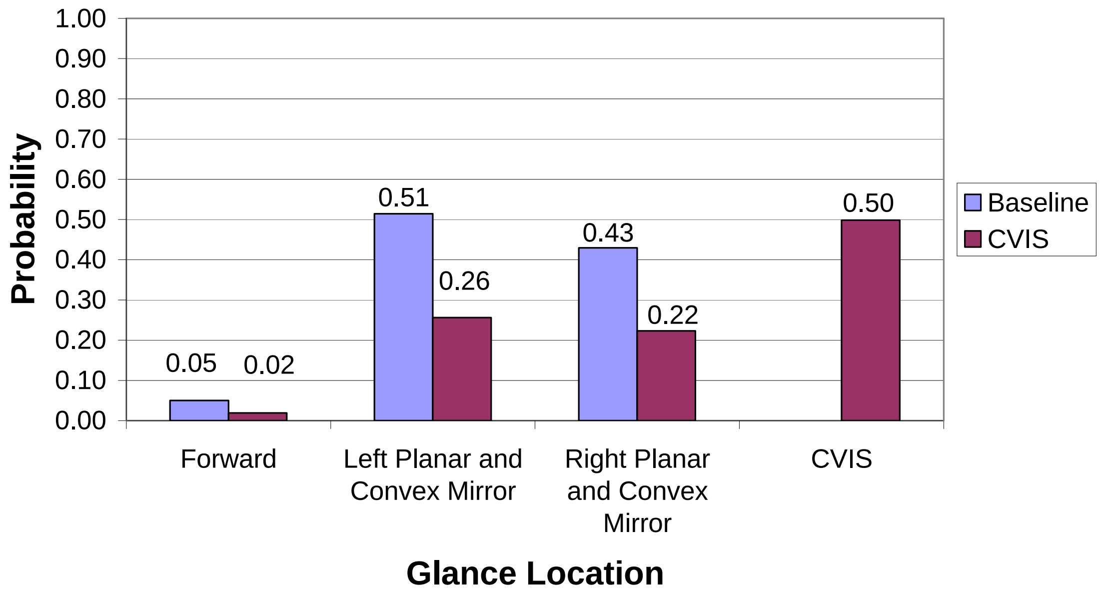

Figure 93. Glance probabilities for the parking subtask with and without the look-down C/VIS.

The glance data were then split according to age group. There were several differences, which appear in Figures 94 and 95, for younger and older drivers, respectively. The plots show that younger drivers relied a bit more heavily on the rear look-down C/VIS than did the older drivers. In addition, younger drivers relied more heavily on their right mirrors in baseline runs while older drivers relied more heavily on their left mirrors in baseline runs.

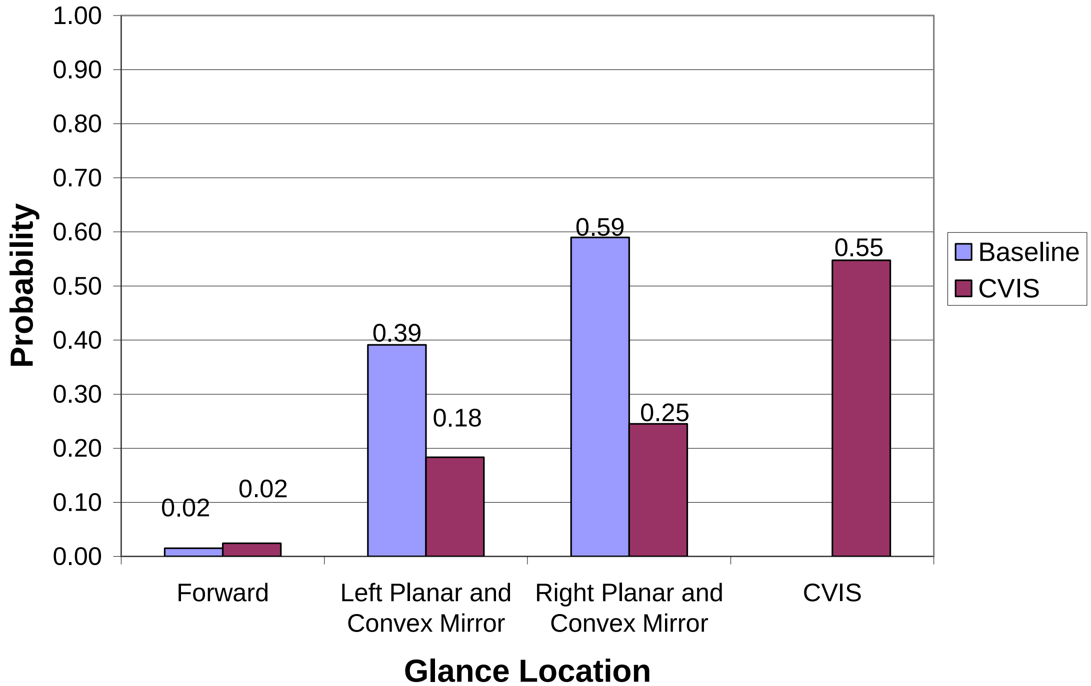

Figure 94. Glance probabilities for the parking subtask with and without the look-down C/VIS, for the younger driver age group.

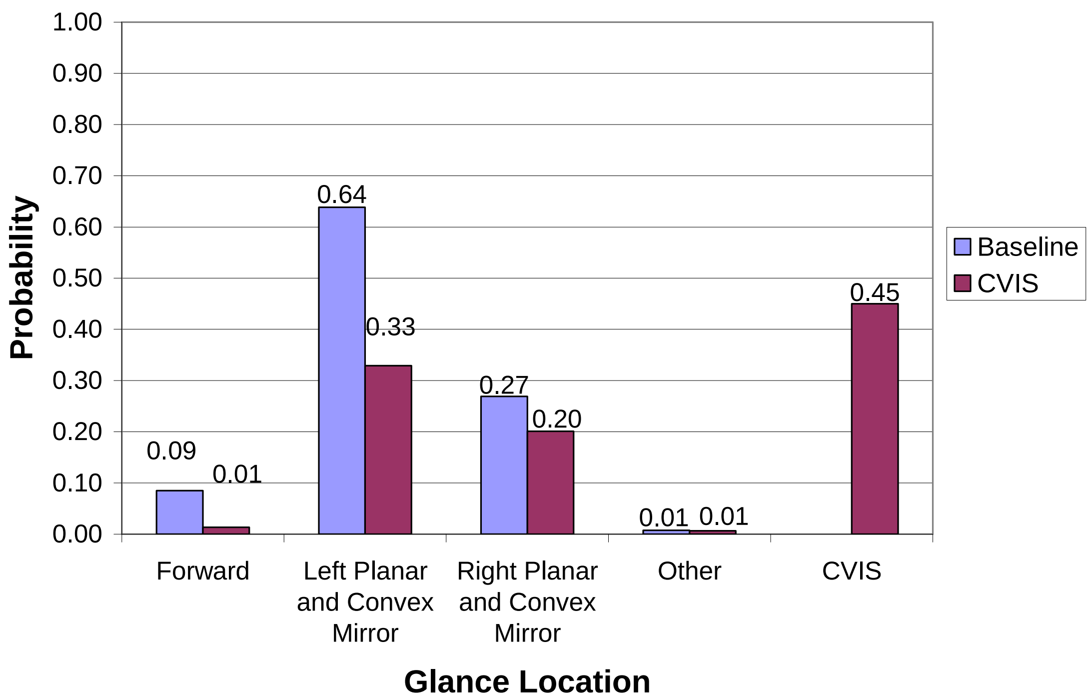

Figure 95. Glance probabilities for the parking subtask with and without the look-down C/VIS, for the older driver age group.

Loading Dock Subtask Performance and Glance Analyses

In regard to the loading dock subtask (Figure 51), recall that drivers were requested to bring the trailer to "1 foot away from the loading dock." A two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables demonstrated that neither enhancement nor age was significant. The interaction of enhancement and age was also not significant. The results are shown in Table 20 by driver.

Table 20. Task completion times (seconds) for the loading dock backing subtask.

Subjects	Baseline	CVIS
9	93	97
10	84	99
11	103	105
12	75	99
13	72	81
14	101	96
15	94	93
16	78	130
Mean Completion Time	87.50	100.00
Standard Error	4.21	4.93

To assess final position distance, the distances in inches between the closest corner of the trailer and the loading dock were analyzed. Table 21 shows the results. A two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables demonstrated that drivers parked significantly closer to the instructed target using the C/VIS compared to the baseline condition $F(1, 6) = 6.27$, $p = 0.0462$. There was no significant age effect or enhancement by age interaction. The results are plotted in Figure 96.

Table 21. Final position distances (inches) for the loading dock subtask.

Subjects	Baseline	CVIS
9	27.5	8.5
10	56.5	11
11	10	13.75
12	146.5	15
13	42.75	4.5
14	19	17
15	29	0.5
16	49	13
Mean Distance	47.53	10.41
Standard Error	15.16	1.98

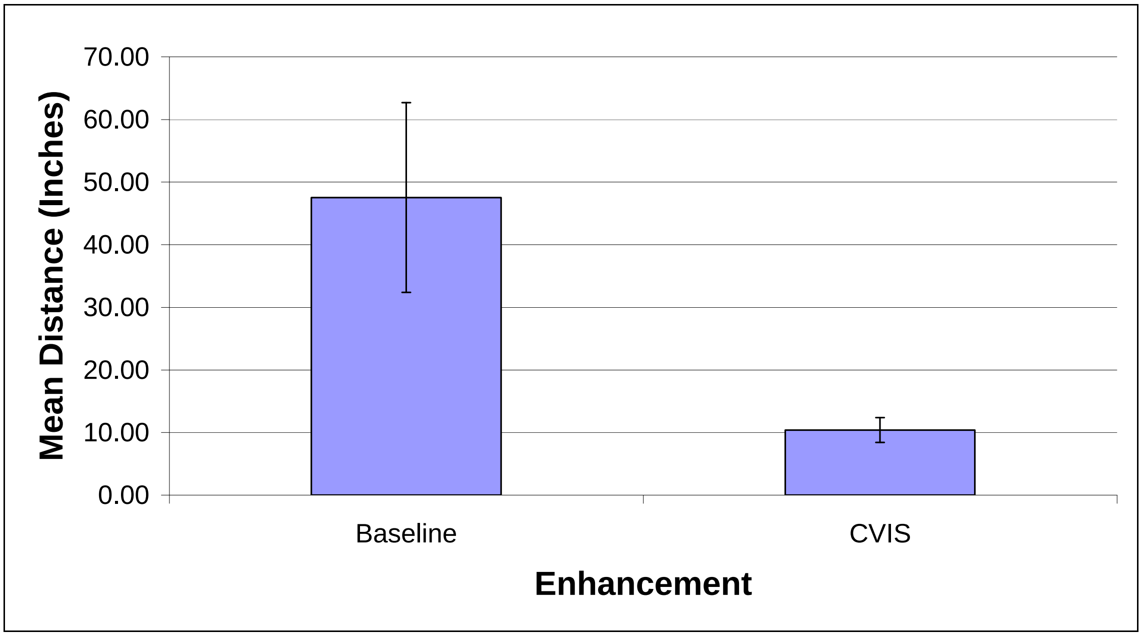

Figure 96. Final position distances (inches) for the loading dock subtask as a function of presence/absence of the look-down enhancement.

It should also be mentioned that there were no cases where the loading dock was struck by the trailer.

Absolute error from the instructed 1 ft (0.305 m) goal was also examined using a two-way repeated-measures analysis of variance with enhancement and the nested factor of age as independent variables. Neither of the main effects nor the interaction was significant; however, for enhancement, $F(1,6) = 4.17$, $p = 0.087$. Table 22 shows the errors in inches by subject. In addition, the results are plotted in Figure 97. The table and plot show that there is a large difference in means. Also, the standard errors are quite different, suggesting that a nonparametric test should be run. A Wilcoxon test indeed demonstrated a significant effect of enhancement $W = 36$, $p = 0.004$. age was found not to be significant using a Mann-Whitney test.

Table 22. Absolute error in inches from the 1 ft goal as a function of enhancement for the loading dock subtask.

Subjects	CVIS	Baseline
9	3.5	15.5
10	1	44.5
11	1.75	2
12	3	134.5
13	7.5	30.75
14	5	7
15	11.5	17
16	1	37
mean	4.28	36.03
std error	1.290	14.99

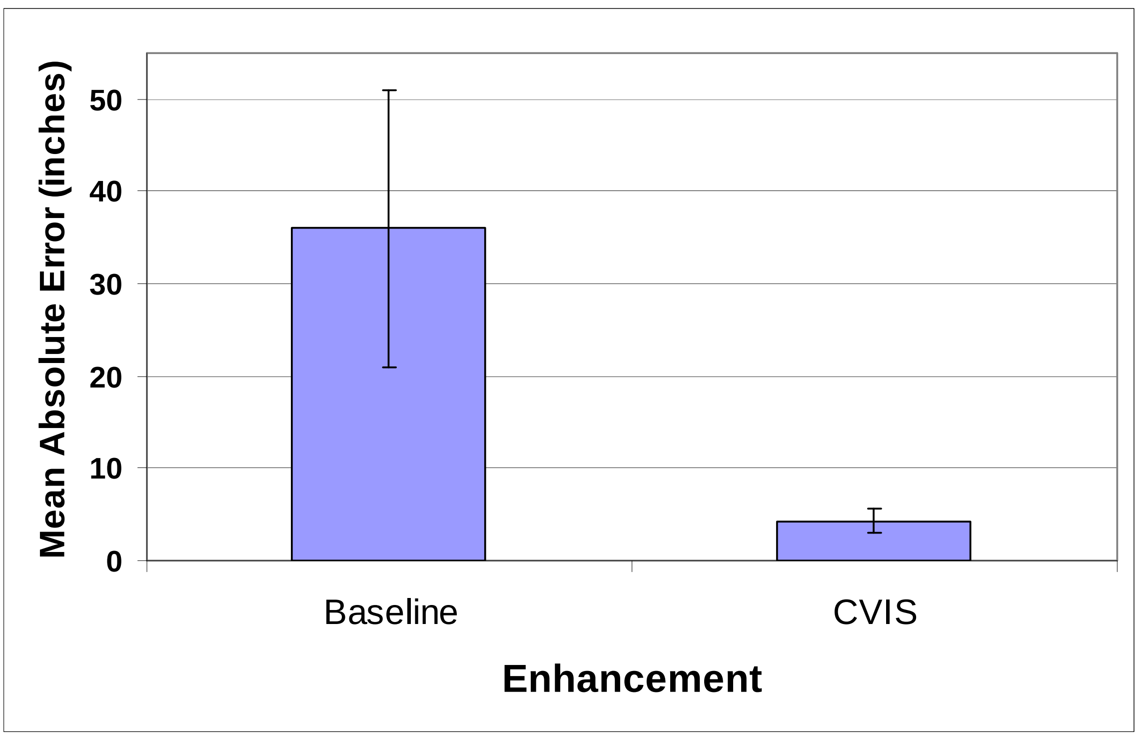

Figure 97. Mean absolute error (in) from the 1 ft goal as a function of enhancement for the loading dock subtask.

Glance data for the last 30 seconds of the loading dock subtask were analyzed to obtain glance probabilities with and without the look-down C/VIS. The results are shown in Figure 98. The plot shows that the C/VIS was heavily relied on (when available) during the last 30 seconds. Visual resources were taken largely from the left-side mirrors and to a smaller extent from the right-side mirrors.

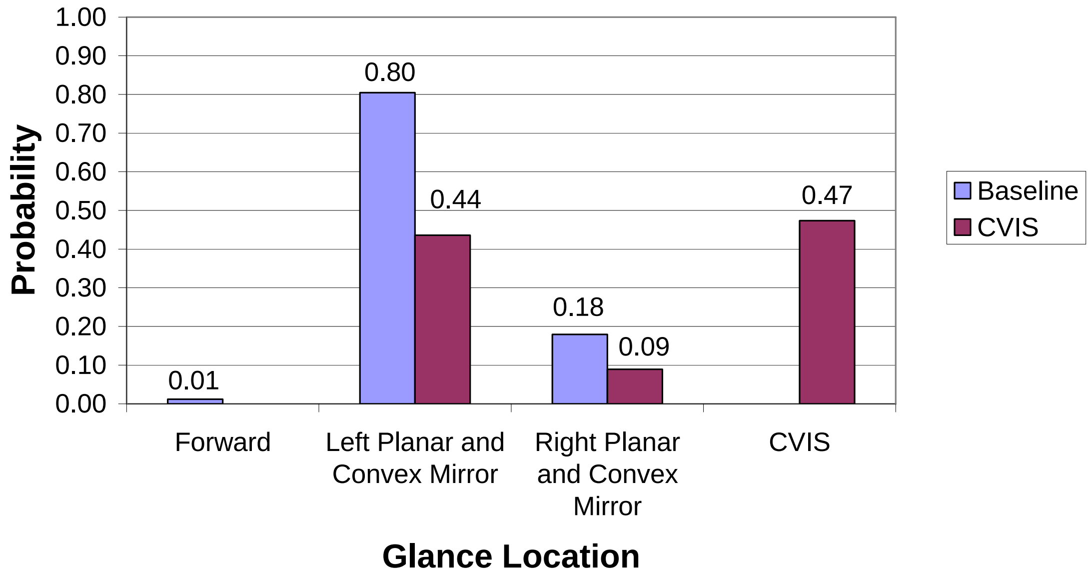

Figure 98. Glance probabilities for the loading dock subtask with and without the look-down C/VIS.

Glance data were then split by age group. The results showed that the C/VIS was used a bit more by the older drivers than by the younger drivers (0.58 versus 0.37). Older drivers took the resources for this change from left mirror views (0.35 for older drivers versus 0.52 for younger drivers).

S-curve Backing Subtask Performance and Glance Analyses

The S-curve subtask results were analyzed using several measures that would indicate the "quality" of the S-curve maneuver (Figure 56) by the driver. The first analysis was for task completion time.

Table 23 shows the task completion times in seconds. A two-way repeated-measures analysis of variance of task completion times for enhancement and the nested factor age was performed. There was no significant difference in task completion time with and without the rear look-down C/VIS. There was no significant age effect or significant enhancement by age interaction.

Table 23. S-curve subtask completion times in seconds.

Subjects	Baseline	CVIS
9	91	110
10	241	131
11	88	87
12	145	123
13	83	135
14	189	293
15	78	82
16	86	114
Mean Completion Time	125.13	134.38
Standard Error	21.54	23.64

The number of direction (forward/backward) reversals by each driver was also analyzed. Table 24 shows the results. A Wilcoxon Signed Ranks test on the data in the table indicated that differences with and without the C/VIS were not significant. To investigate Age effects, the data were arranged categorically such that drivers either reversed or they did not. A one-way chi-square test revealed that older drivers reversed significantly more often than younger drivers (six reversals compared to two) $X^2(1) = 4.3316$, $p = 0.0374$.

Table 24. Number of direction reversals in the S-curve subtask.

Subjects	Baseline	CVIS
9	0	0
10	2	0
11	0	0
12	2	2
13	0	2
14	4	18
15	2	0
16	0	2
Total Number of Reversals	10	24

The number of barrels struck in the S-curve task was investigated. Table 25 shows the total number of barrels struck by each driver. A Wilcoxon Signed Ranks test indicated that differences with and without the C/VIS were not significant. A one-way chi-square test indicated that age was not significant.

Table 25. Number of barrels struck in the S-curve subtask.

Subjects	Baseline	CVIS
9	0	2
10	3	1
11	0	0
12	0	0
13	2	4
14	1	1
15	0	0
16	0	0
Total Number of Barrels Struck	6	8

Glance data from the time that the trailer passed a line between the first two barrels to the time that the trailer passed a line between the last two barrels were used to calculate glance probabilities. The results are plotted in Figure 99. The results suggest that the look-down C/VIS (when available) was used sparingly and that resources were drawn primarily from the left planar and convex mirrors.

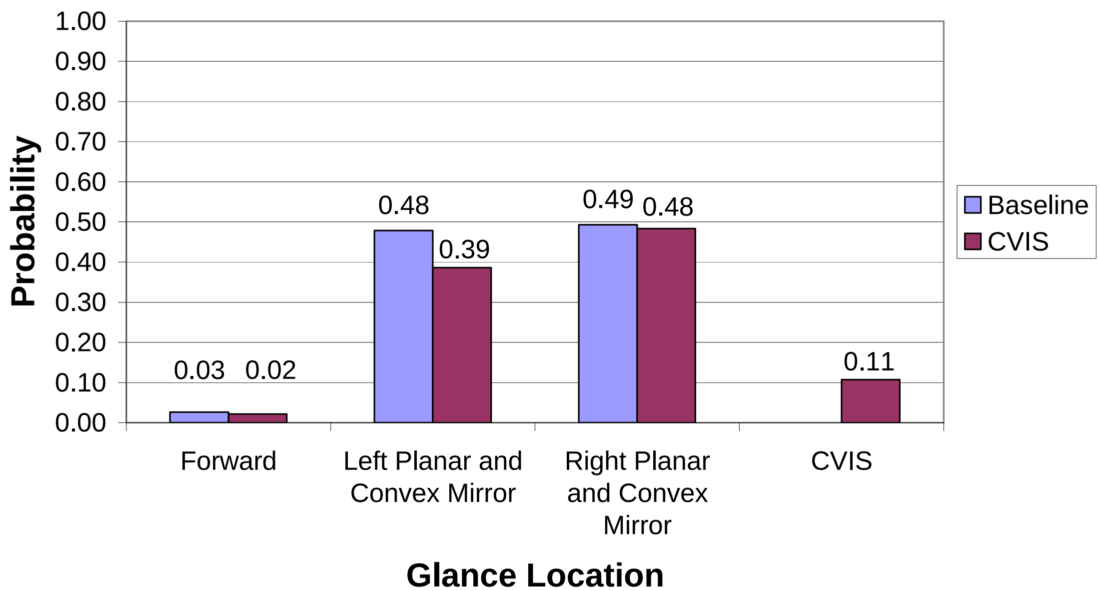

Figure 99. Glance probabilities for the S-curve subtask with and without the look-down C/VIS.

When the glance probabilities were examined as a function of age, differences were noted, as shown in Figures 100 and 101 for younger and older drivers, respectively. The plots show that older drivers used the C/VIS somewhat less than younger drivers. The plots also show that older drivers relied on their right-side mirrors more than younger drivers, whether performing in baseline or with the C/VIS.

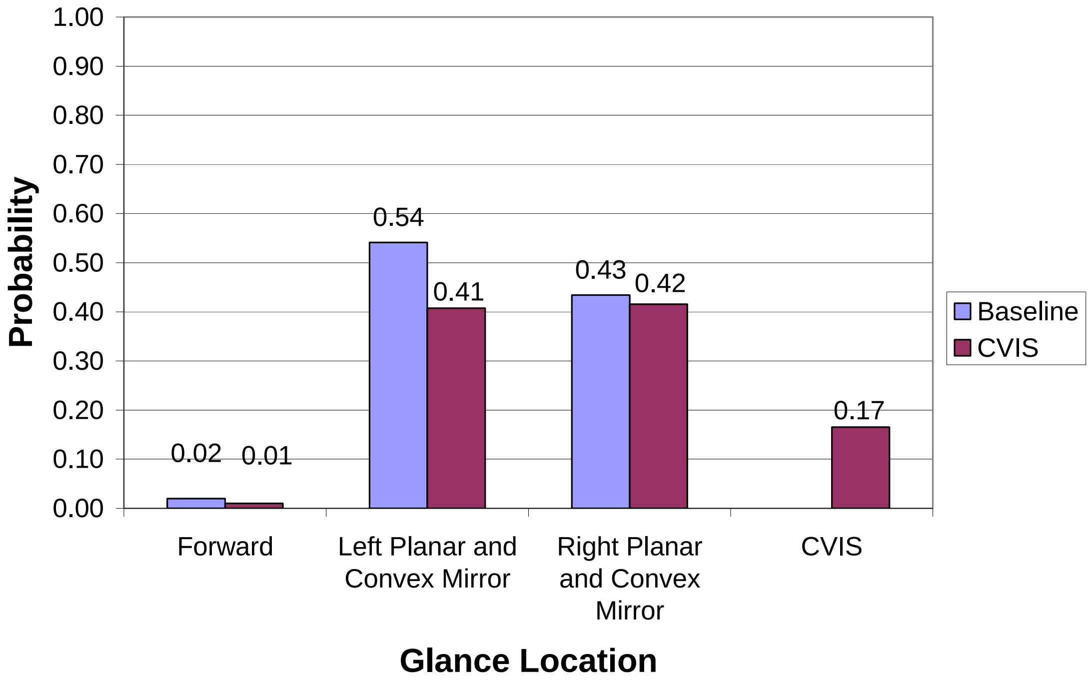

Figure 100. Glance probabilities for the S-curve subtask with and without the look-down C/VIS, for the younger driver age group.

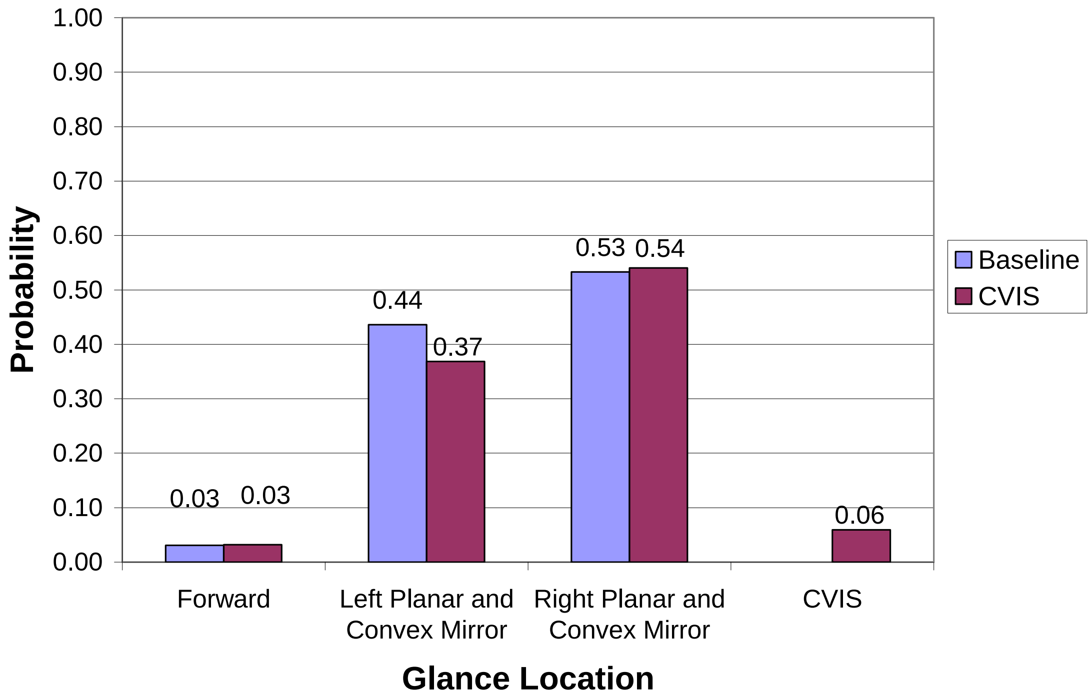

Figure 101. Glance probabilities for the S-curve subtask with and without the look-down C/VIS, for the older driver age group.

Task B (Backing Subtasks) Opinion Data Analyses

Opinion data comparing ease/difficulty of performing the various maneuvers was compared for baseline and look-down C/VIS. In the parking subtask, drivers (in baseline) could not see the parked car once they were close to it. Thus, when the look-down C/VIS was available, they used it. The opinion ratings comparing baseline and C/VIS are presented in Table 26. The substantial increase in the ratings for the C/VIS condition resulted in significance for both the two-way repeated-measures analysis of variance ($F(1,6) = 26.09$, $p = 0.0022$) and the Wilcoxon Signed Ranks test ($W = -15$, $N = 5$, $p < 0.05$). Although age was not a significant main effect, there was a significant enhancement by age interaction $F(1,6) = 21.13$, $p = 0.0037$. Older subjects gave a mean rating of 6.25 for the C/VIS and 6 during the baseline, while younger subjects gave a mean rating of 8 during C/VIS and 3.25 during baseline. The enhancement main effect is plotted in Figure 102 and enhancement by age interaction is plotted in Figure 103.

Table 26. Individual ratings for the scale: How difficult/easy was the parking subtask?

Subject	Baseline	CVIS
9	2	7
10	3	3
11	3	9
12	7	8
13	7	9
14	7	7
15	7	7
16	1	7
Mean	4.63	7.13
Median	5.00	7.00

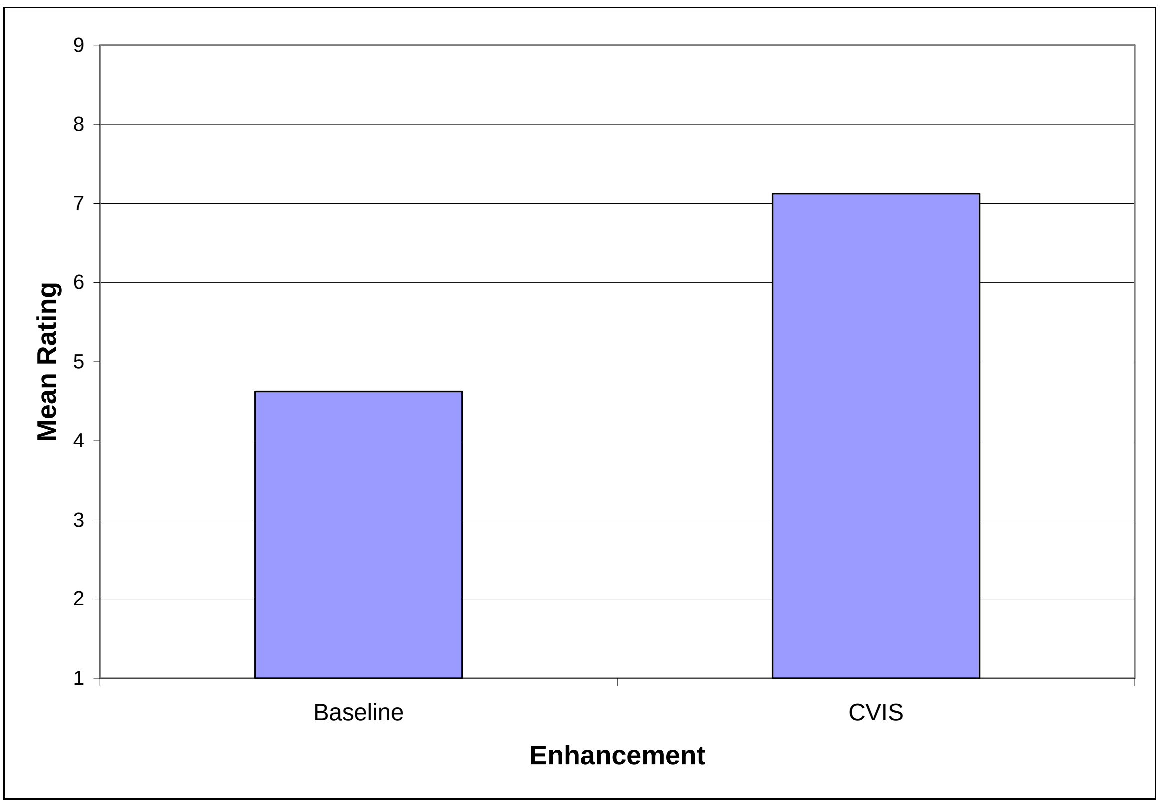

Figure 102. Plot of the enhancement main effect on rating of ease/difficulty of performing the parking (to a parked car) subtask.

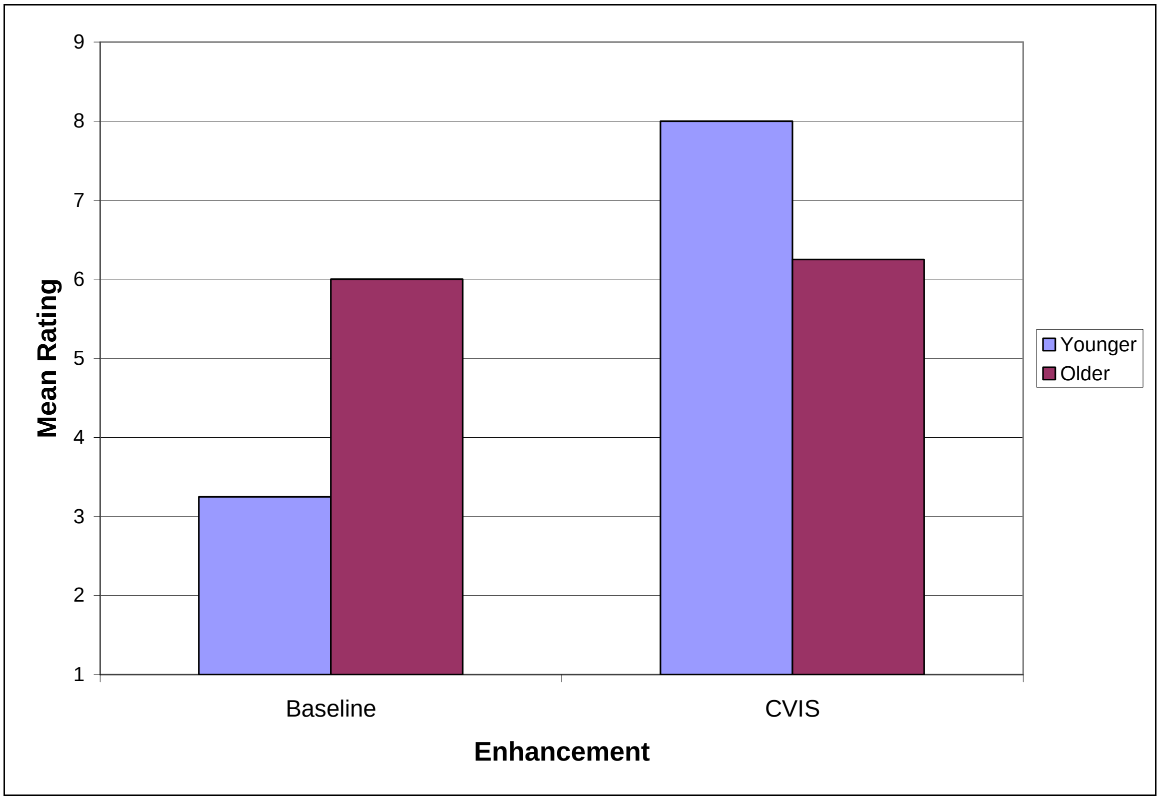

Figure 103. Plot of the enhancement by age interaction for rating of ease/difficulty of performing the parking (to a parked car) subtask.

The opinion data comparing the ease/difficulty of performing the loading dock subtask with and without the look-down C/VIS are shown in Table 27. As can be seen, the C/VIS condition resulted in only slightly higher average ratings when compared with baseline. Statistical tests similar to those performed on the parking data showed that the changes were not sufficient to be reliable; that is, both the two-way repeated-measures ANOVA and the Wilcoxon Signed Ranks tests did not result in significance. There was no significant age effect or enhancement by age interaction.

Table 27. Individual ratings for the scale: How difficult/easy was the loading dock subtask?

Subject	Baseline	CVIS
9	7	9
10	3	3
11	7	7
12	6	9
13	9	9
14	7	7
15	7	9
16	8	8
Mean	6.75	7.63
Median	7.00	8.50

For the S-curve subtask, the results are shown in Table 28. The table shows that drivers judged the ease/ difficulty to be about the same with and without the C/VIS. A two-way repeated-measures Analysis of Variance with enhancement and the nested factor age as the independent variables showed that the opinion data ratings were not significantly different between C/VIS and baseline. Additionally, there was no significant age effect or enhancement by age interaction. The Wilcoxon Signed Ranks nonparametric test also showed enhancement to not be significant.

Table 28. Individual ratings for the scale: How difficult/easy was the S-curve subtask?

Subject	Baseline	CVIS
9	7	8
10	1	1
11	5	5
12	7	7
13	3	2
14	7	5
15	7	7
16	8	5
Mean	5.63	5.00
Median	7.00	5.00

Once the parking, loading dock, and S-curve subtasks had been completed, drivers were asked to complete additional ratings for the look-down enhancement. Results are shown in Table 29. The table shows that drivers were generally favorable to the enhancement, ranking it well above a neutral value of 5. One-way analyses of variance revealed that there were no age effects for any of the scales.

Table 29. Ratings on various scales for the rear look-down enhancement, taken after completing the parking, loading dock, and S-curve subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
9	8	7	9	9
10	9	9	9	9
11	5	7	9	9
12	9	9	9	9
13	7	7	9	9
14	7	5	7	7
15	9	7	9	9
16	7	5	8	9
Mean Rating	7.63	7.00	8.63	8.75
Median Rating	7.50	7.00	9.00	9.00

DISCUSSION

In general, the data for the look-down enhancement suggest that this enhancement was useful when backing to an object that is directly behind the trailer and hidden from view in the mirrors. The enhancement did not appear to be useful in the S-curve subtask, it was moderately useful in the loading dock subtask, and it was quite useful in the parking subtask. It should be noted that the loading dock was wider than the trailer and therefore could be seen in the mirrors during the latter stages of the backing maneuver. Thus, the driver could use both the mirrors and the C/VIS in this task. On the other hand, in the parking subtask, the driver had to rely on the C/VIS to determine distance to the automobile in the latter stages of the maneuver, assuming there were no useful shadows.

CHAPTER 10: RESULTS FOR THE TRAILER REAR WIDE-ANGLE MULTI-PURPOSE LOOK DOWN ENHANCEMENT (GROUP 1)

These tests were performed using the Peterbilt tractor with 48 ft (14.6 m) trailer. Both on-road subtasks (Task A) and backing subtasks (Task B) were performed and analyzed as previously explained.

TASK A (ON ROAD) RESULTS

Clearance/Overlap Subtask Performance and Glance Analyses

The percent of correct responses in the clearance/overlap task was analyzed using the Cochran Q test. The result was not significant, however, it was close: Q = 3.098; p = 0.078. The percent correct is plotted in Figure 104 for baseline and for the C/VIS. The results suggest a slight improvement when using the C/VIS, if the results can be assumed to be reliable.

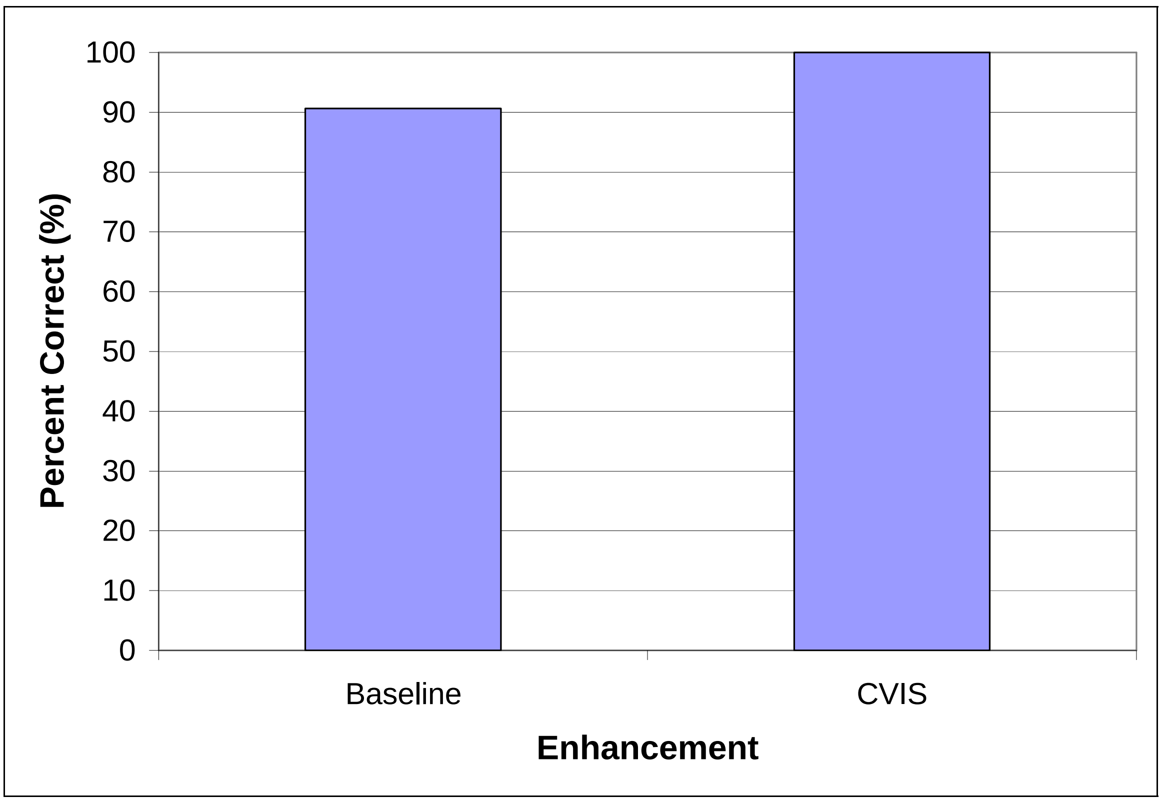

Figure 104. Tentative effect of the trailer wide-angle rear multipurpose look-down enhancement C/VIS on clearance/overlap correctness. (Note that *p* = 0.078)

Also, for the clearance/overlap subtask, a one-way chi-square test on the percent correct for the nested factor of age was not significant. Because there was no appropriate test for interactions between age and percent correct, two additional one-way chi-square tests were run: one for older drivers and one for younger drivers. The results did not demonstrate a significant effect of enhancement in either case.

Drivers also provided an estimate of the amount of clearance or the amount of overlap in feet. These data were used to determine the relative level of accuracy in estimation. In regard to estimates with an incorrect statement of clearance or overlap, the estimate of distance was added to the correct DGPS value, rather than subtracted from it. Thereafter, the absolute value of the error was determined. A 2 x 2 x 2 repeated-measures analysis of variance on the absolute error data for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (younger or older) did not reveal any significant main effects or interactions. In particular, the main effect of enhancement was not significant with $F(1,51) = 1.78$, $p = 0.188$.

Eyeglance data for the clearance/overlap task were analyzed for the time interval starting with completion of clearance/overlap instruction by the experimenter and ending when the driver provided the estimate of distance. Note that the driver was first queried regarding clearance/overlap and then in regard to distance (in feet). The results are shown graphically in Figures 105 (left side) and 106 (right side). These results show clearly that drivers shifted their visual resources largely from the outside mirror to the C/VIS when the C/VIS was present. Such an indication suggests that drivers would use these C/VISs to determine whether or not they have clearance. Figures 105 and 106 are quite similar, indicating that performance was nearly the same on each side of the vehicle.

Eyeglance data was also plotted separately for younger and older drivers, and for left side and right side. The two age group plots on each side were quite similar to one another, suggesting that there were no appreciable differences in glance patterns as a function of age.

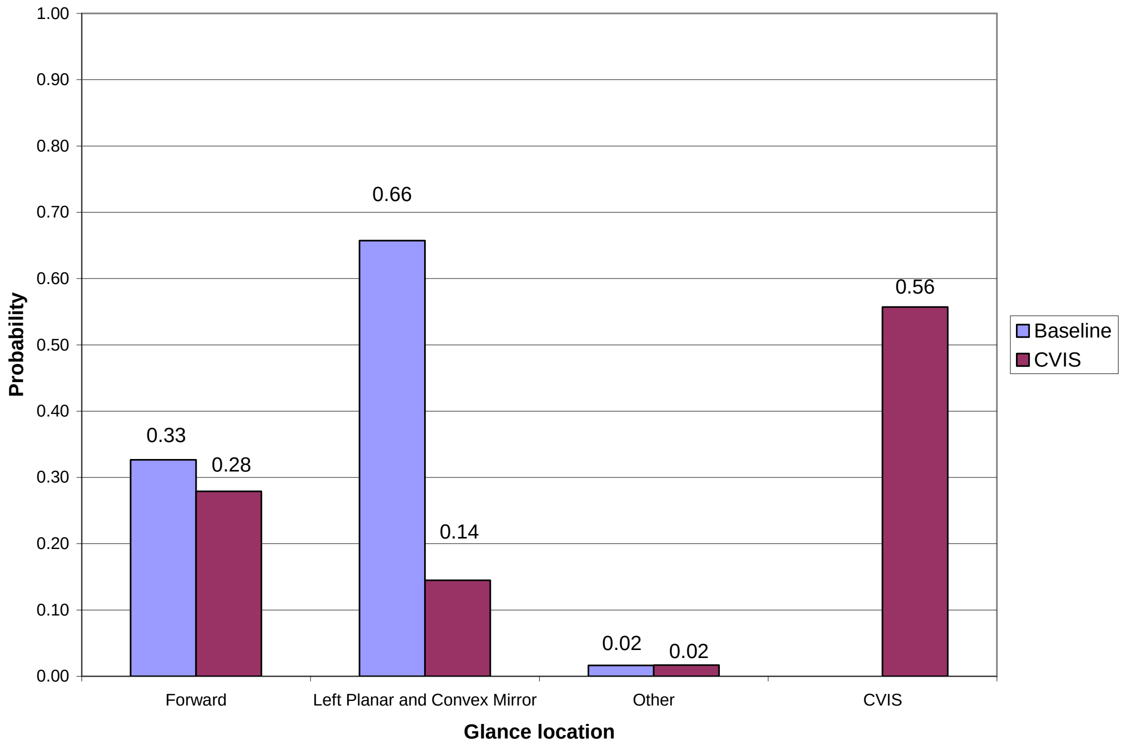

Figure 105. Glance probabilities for the left-side clearance/overlap subtask.

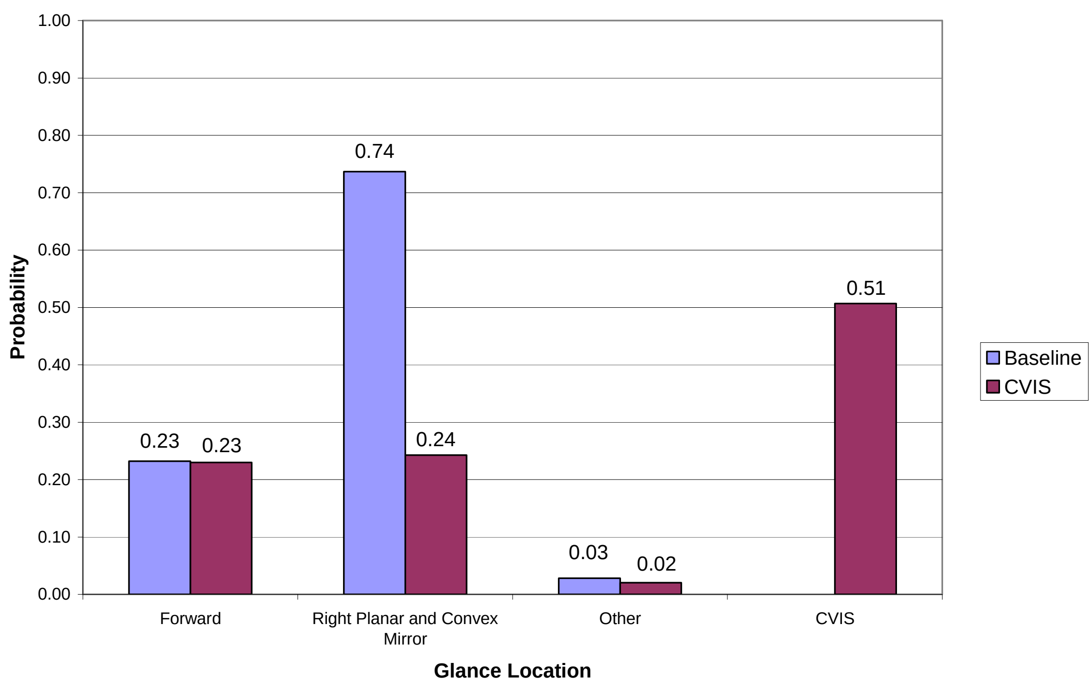

Figure 106. Glance probabilities for the right-side clearance/overlap subtask.

Passing/Merging Subtask Performance and Glance Analyses

In the passing subtask, tractor-trailer drivers pulled forward of the automobile and then merged in front of it. Both left-side and right-side merges were accomplished. (Note that in a left-side merge the driver moved to the left in front of the automobile, and in a right-side merge the driver moved to the right in front of the automobile. There were two replications of passing on each side, for a total of four per subject and condition (baseline or CVIS). Results were analyzed in terms of re-merge clearance (cut-in distance).

The cut-in distance was defined as the longitudinal component of the distance between the back end of the trailer and the front bumper of the automobile at the initiation of the merge. Initiation of merge was determined by a second experimenter in the tractor who viewed the driver and the roadway. When either the steering input or the vehicle trajectory indicated the tractor trailer had begun a merge, the experimenter pressed a key so indicating. Later, the longitudinal component of distance at that time was calculated and used as the cut-in distance. It should be noted that since the speed difference between the two vehicles was relatively low at cut-in, small errors in the timing of merge initiation would be expected to produce only small errors in longitudinal separation.

Cut-in distance values were analyzed using a 2 x 2 x 2 repeated-measures analysis of variance for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (older or younger). The analysis demonstrated that both enhancement and age main effects were significant: enhancement, $F(1,51) = 5.89$, $p = 0.0188$; age, $F(1,6) = 12.69$, $p = 0.0119$. The main effect of side was not significant and there were no significant interactions. The results for enhancement are shown in Figure 107, and the results for age are shown in Figure 108.

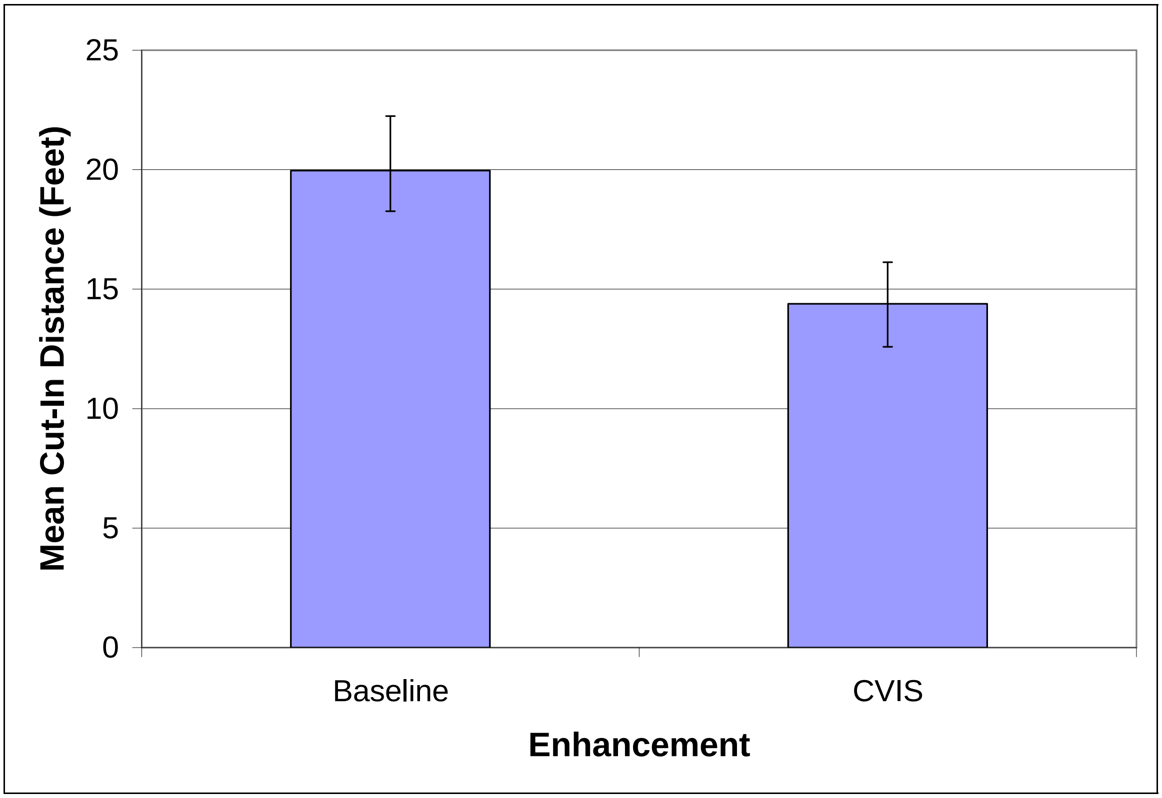

Figure 107. Mean cut-in distance by enhancement (C/VISs or baseline) for the passing/merging subtask.

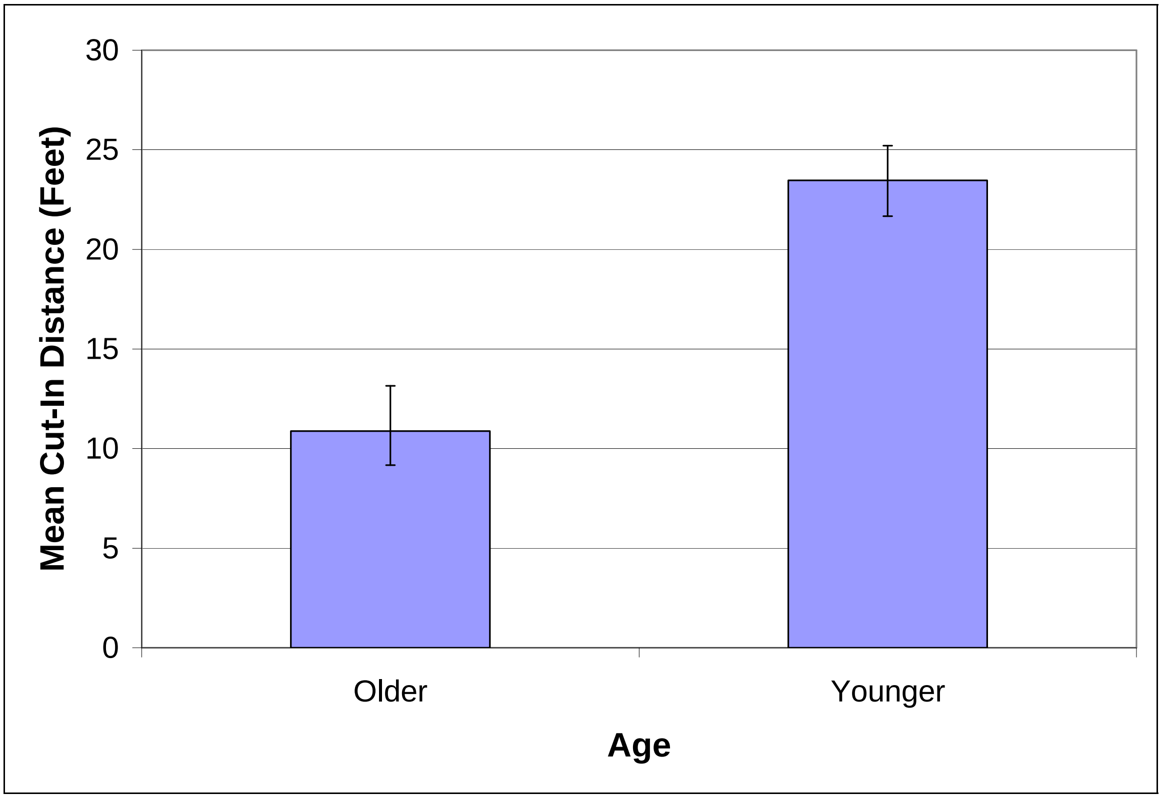

Figure 108. Mean cut-in distance by age for the passing/merging subtask.

As the plot of Figure 107 demonstrates, presence of the wide-angle rear multipurpose look-down enhancement produced shorter cut-in distances, probably reflecting the greater certainty regarding clearance. Figure 108 indicates that younger drivers were more conservative in initiating cut-in than were older drivers.

Glance analyses were carried out for the passing/merging task. The data for the passing/merging task were analyzed using procedures similar to those used for the clearance/overlap task. Glance probabilities were calculated for the interval during which the pass/merge maneuver was performed. Specifically, the interval began when the automobile (confederate) driver moved to the center of the trailer and matched speed to the tractor trailer. It was at this point that the experimenter in the tractor trailer instructed the driver to increase speed and merge in front of the automobile. The interval ended when the tractor-trailer driver began the lateral maneuver to merge in front of the automobile. The results of the glance data analyses are shown in Figure 109 for the left-side pass/merge task and Figure 110 for the right-side pass/merge task. The results indicate, once again, that the two sides were quite similar in terms of glance patterns and that visual resources were taken from the-side mirror views and used for C/VIS.

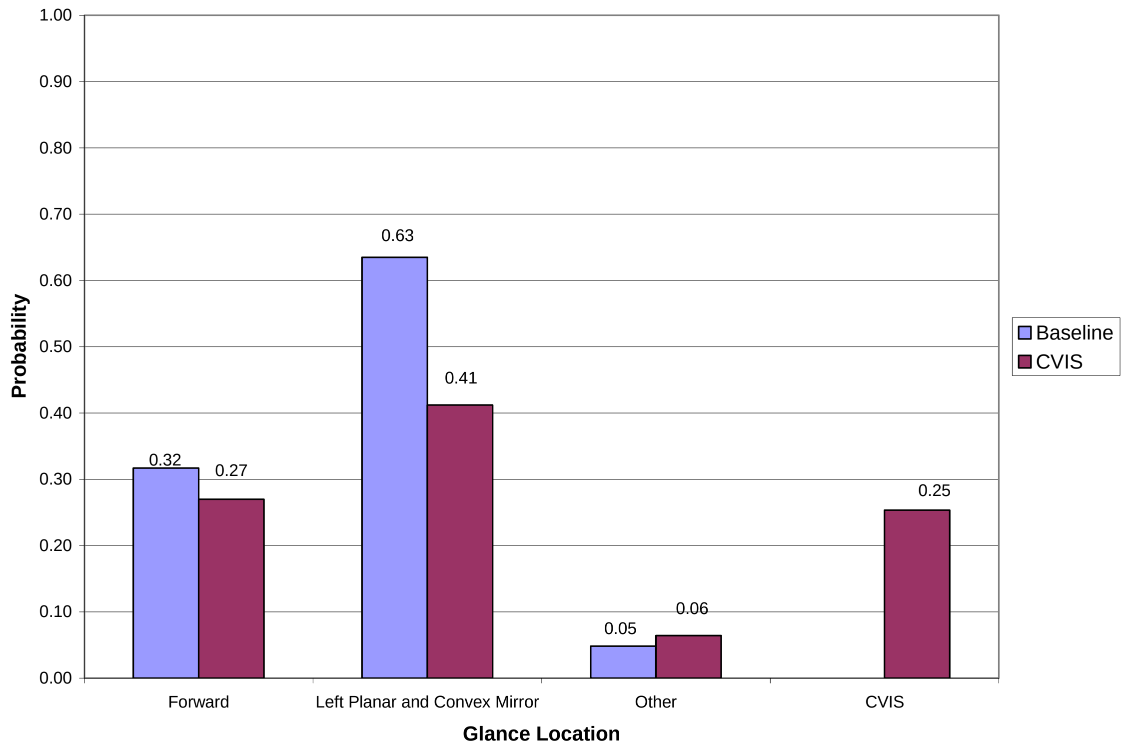

Figure 109. Glance probabilities for the left-side passing/merging maneuver subtask.

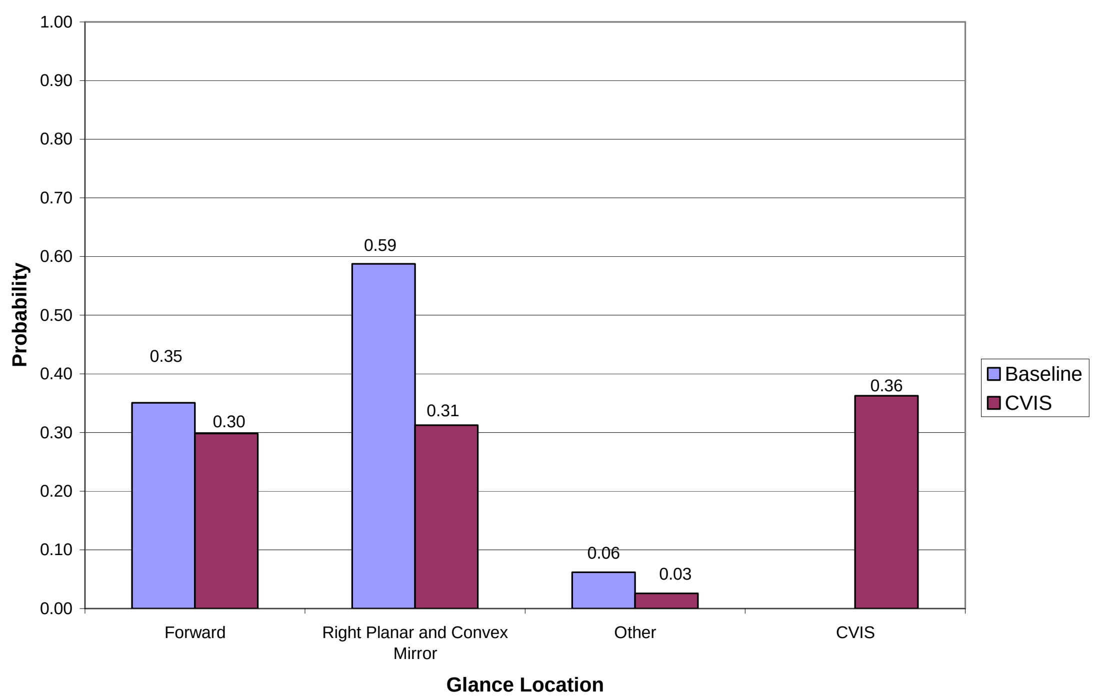

Figure 110. Glance probabilities for the right-side passing/merging maneuver subtask.

Glance patterns were also examined as a function of age group and side for the passing/merging maneuver. The results showed that for the left side, older drivers used the C/VIS more than younger drivers (0.34 versus 0.17). Similarly, for the right side, older drivers used the C/VIS more than younger drivers (0.48 versus 0.34).

Task A (Clearance/Overlap and Passing/Merging) Opinion Data Analyses

For the opinion data, the *comparisons* involved how difficult/easy it was to perform the clearance/overlap task or the passing/merging task. In regard to the clearance/overlap task, the results are shown in Table 30. The data were first analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was a significant enhancement main effect, $F(1,6) = 72$, $p = 0.0001$. The age main effect and enhancement by age interaction were both found not to be significant. The main effect of enhancement was also analyzed by a Wilcoxon Signed Ranks test, an appropriate nonparametric test. The results demonstrated significance for this effect $W = -36$, $N = 8$, $p = 0.01$. Note that the mean and median values of the ratings for baseline and C/VIS are provided in Table 30. The results are also plotted in Figure 111. The enhancement results indicate that the drivers felt that the trailer wide-angle rear multipurpose look-down enhancement made the task much easier.

Table 30. Individual ratings for the scale: How difficult/easy was it to estimate clearance/overlap when the other vehicle was alongside near the back of the trailer?

Subject	Baseline	CVIS
1	3	5
2	7	9
3	5	9
4	3	7
5	4	7
6	5	7
7	5	8
8	3	7
Mean Rating	4.38	7.38
Median	4.50	7.00

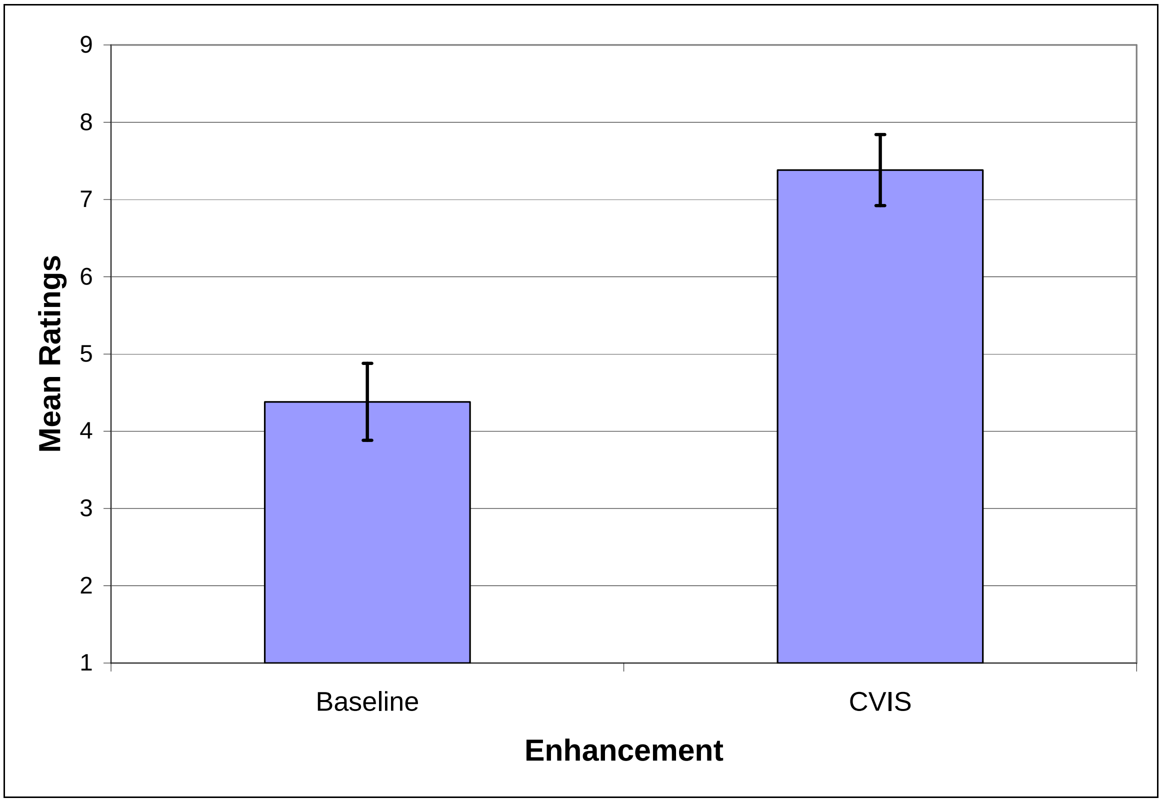

Figure 111. Mean ratings for the clearance/overlap subtask by enhancement.

For the passing/merging task, the opinion data are shown in Table 31. The data were first analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. Only the main effect of enhancement demonstrated significance, $F(1,6) = 18.69$, $p = 0.0050$. The mean and median values for baseline and the C/VISs are included in Table 31 and the results are plotted in Figure 112. The corresponding Wilcoxon Signed Ranks Test for enhancement similarly demonstrated significance, $W = -28$, $N = 7$, $p = 0.02$. The interaction of enhancement and age was not significant. Once again, it is clear that drivers felt that the CVIS made the passing/merging task easier.

Table 31. Individual ratings for the scale: How difficult/easy was it to estimate distance to the other vehicle when merging to the right or left?

Subject	Baseline	CVIS
1	4	5
2	7	9
3	7	9
4	3	7
5	5	7
6	7	7
7	5	8
8	3	7
Mean Rating	5.13	7.38
Median	5.00	7.00

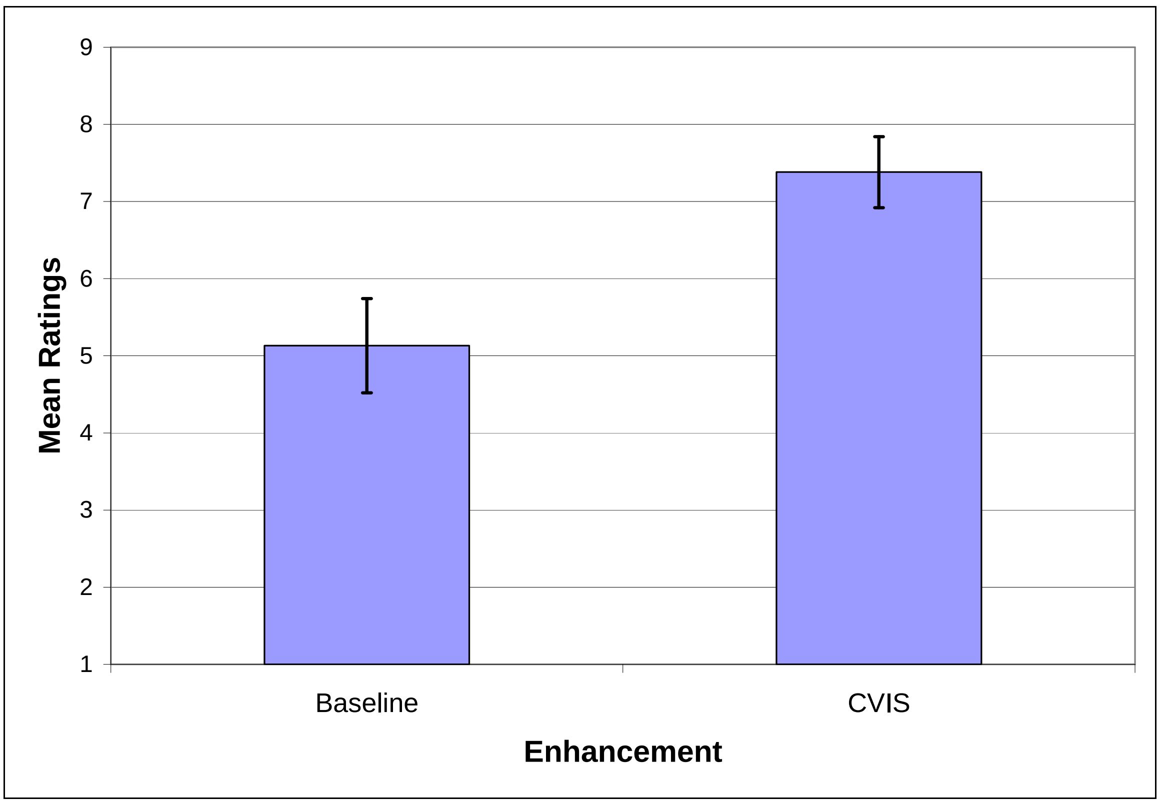

Figure 112. Mean ratings for the passing/merging subtask by enhancement.

Four additional ratings for the C/VIS enhancement were obtained for the combination of clearance/overlap tasks and the passing/merging tasks. The scales were associated with Usefulness, Learning Time, Receptiveness, and Blind Spot Reduction (as described in the appendix showing the rating scales). These scales were administered after completion of all on-road tasks with the enhancement. No baseline comparisons were made. The results are presented in Table 32. As the table shows, the drivers generally provided very high ratings on all of the scales for the enhancements. The most prevalent rating was 9, the highest possible.

Table 32. Ratings on various scales for the trailer wide-angle rear multipurpose look-down enhancement, taken after completing both the clearance/overlap and passing subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
1	6	5	7	7
2	9	9	9	9
3	9	5	9	9
4	7	5	9	9
5	8	6	9	9
6	8	7	9	9
7	9	8	9	9
8	8	6	9	7
Mean Rating	8.00	6.38	8.75	8.50
Median Rating	8.00	6.00	9.00	9.00

The data for each scale reported in Table 32 were analyzed for age effects using one-way analyses of variance with age as the independent variable. None of the scales exhibited a significant age effect on the ratings.

TASK B (BACKING SUBTASKS) RESULTS

Backing (to Parked Car) Subtask Performance and Glance Analyses

The task completion times for the backing to a parked car subtask are shown in Table 33. A two-way repeated-measures analysis of variance on task completion time with enhancement and the nested factor age as independent variables revealed that neither main effect was significant. The enhancement by age interaction was also not significant.

Table 33. Task completion times (seconds) for the parking subtask.

Subject	Baseline	CVIS
1	269	164
2	172	136
3	127	108
4	86	109
5	86	100
6	80	65
7	88	90
8	102	116
Mean Completion Time	126.25	111.00
Standard Error	23.11	10.48

The final position distances for this parking subtask as a function of the presence/absence of the trailer wide-angle rear multipurpose look-down enhancement are shown below in Table 34. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. However, for the enhancement main effect, it was determined that $F(1,6) = 5.02$, $p = 0.066$, suggesting the possibility of significance for a larger sample size. The enhancement by age interaction was also not significant.

Table 34. Final position distances (inches) from the parked car, regardless of whether or not hit, for the parking task as a function of presence/absence of the trailer wide-angle rear multipurpose look-down enhancement.

Subject	Baseline	CVIS
1	149	41
2	74	4.5
3	93	46
4	123	132
5	43	55.5
6	22	15
7	87.5	70
8	119	56
Mean Distance	88.81	52.50
Standard Error	14.94	13.71

Table 35 shows the distance the parked car was moved if it was struck by the trailer during the parking subtask. It should be noted that two older drivers bumped into the parked car while using the trailer wide-angle rear multipurpose look-down enhancement. A Cochran-Q non-parametric test did not demonstrate significant differences.

Table 35. Distance (inches) the parked car was moved if struck during the parking subtask as a function of presence/absence of the trailer wide-angle rear multipurpose look-down enhancement.

Subject	Baseline	CVIS
1	0	0
2	0	2
3	0	0
4	0	0
5	0	0
6	0	19
7	0	0
8	0	0

The final position distances from the 5 ft (1.52m) goal for the parking subtask as a function of the presence/absence of the trailer wide-angle rear multipurpose look-down enhancement are shown below in Table 36. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 36. Absolute error (inches) from the 5 ft (1.52m) goal for the parking subtask as a function of presence/absence of the trailer wide-angle rear multipurpose look-down enhancement.

Subject	Baseline	CVIS
1	89	19
2	14	55.5
3	33	14
4	63	72
5	17	4.5
6	38	45
7	27.5	10
8	59	4
Mean Distance	42.56	28.00
Standard Error	9.12	9.17

The data were then analyzed with a Wilcoxon Signed Ranks non-parametric test. There was no significant enhancement main effect.

Eyeglance data were analyzed for the last 30 s of the backing maneuver. The probabilities are plotted in Figure 113 for presence/absence of the wide-angle rear multipurpose look down enhancement. The results indicate that when the C/VIS was present, the drivers used it, taking visual resources from the left and right outside rear-view mirrors roughly equally. Examination of the glance plots by age group indicated that younger and older drivers used very similar glance patterns.

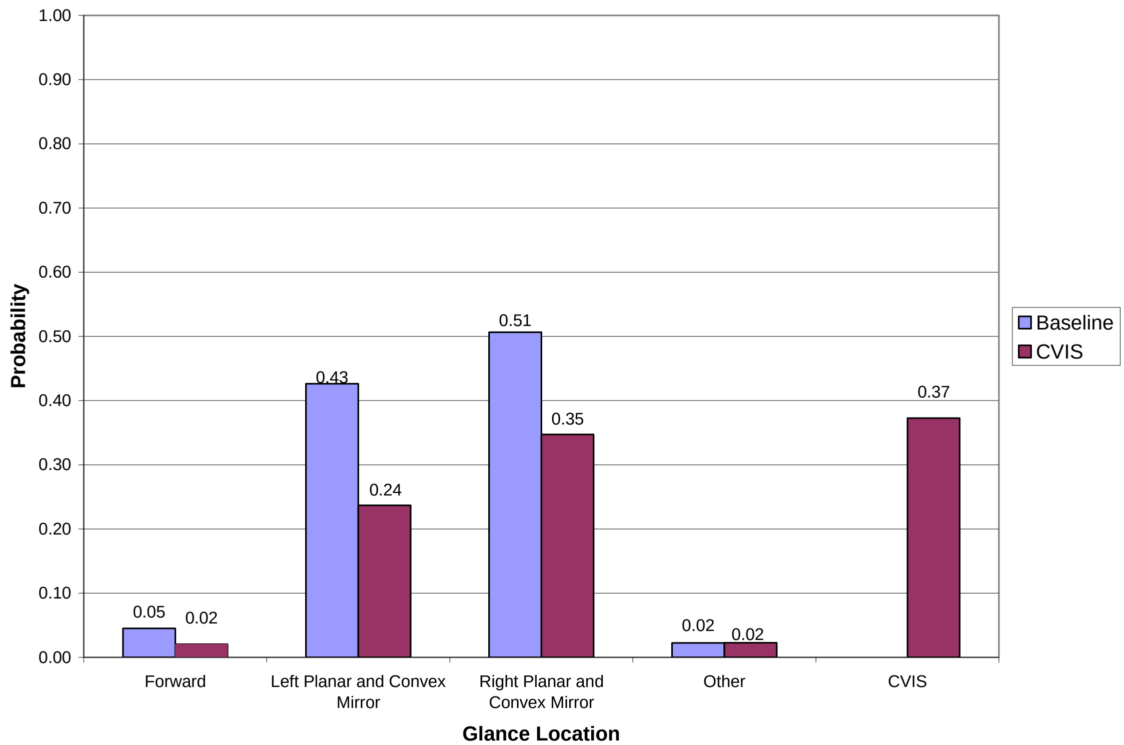

Figure 113. Glance location probabilities for the parking subtask.

Loading Dock Subtask Performance and Glance Analyses

The task completion times for the loading dock backing subtask are shown in Table 37. A two-way repeated-measures analysis of variance on task completion time with enhancement and the nested factor age as independent variables revealed that neither main effect was significant. The enhancement by age interaction was also not significant.

Table 37. Task completion times (seconds) for the loading dock backing subtask.

Subject	Baseline	CVIS
1	125	122
2	70	91
3	93	89
4	94	75
5	63	67
6	56	44
7	97	102
8	102	83
Mean Completion Time	87.50	84.13
Standard Error	8.10	8.25

The closest distances from the trailer to the loading dock are shown below in Table 38. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was no significant enhancement or age main effect. The enhancement by age interaction was also not significant. Because of the substantial differences in means and in standard errors (Table 38), a nonparametric Wilcoxon signed ranks test was also performed. This test similarly did not demonstrate significance for enhancement.

Table 38. Final position distances (inches) from the trailer to the loading dock.

Subject	Baseline	CVIS
1	113	8
2	19	6
3	0	8
4	35.5	38
5	21	4.5
6	67.5	10
7	9	13
8	-17	8
Mean Distance	31.00	11.94
Standard Error	14.68	3.83

It should be noted that one older driver backed into the loading dock during the baseline condition, moving it 17 inches.

The closest distances from the trailer to the "one-foot-from-loading-dock" goal are shown below in Table 39. The results were analyzed with a two-way repeated measures ANOVA with enhancement and the nested factor age as the independent variables. There was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 39. Absolute error (inches) from the 1 ft (0.305 m) goal for loading dock backing subtask.

Subject	Baseline	CVIS
1	101	4
2	7	6
3	12	4
4	23.5	26
5	9	7.5
6	55.5	2
7	3	1
8	29	4
Mean Distance	30.00	6.81
Standard Error	11.77	2.83

It should be noted that there are large differences in the means and in the standard errors even though, statistically, the enhancement effect was not significant, $F(1,6) = 3.02$, $p = 0.133$. It is possible that the large difference in variance may have affected the outcome of the test. The data were then analyzed with a Wilcoxon Signed Ranks non-parametric test. enhancement was shown to be a significant main effect, $W(8) = 28$, $p = 0.0375$, thus demonstrating a reliable effect. The effect is plotted in Figure 114.

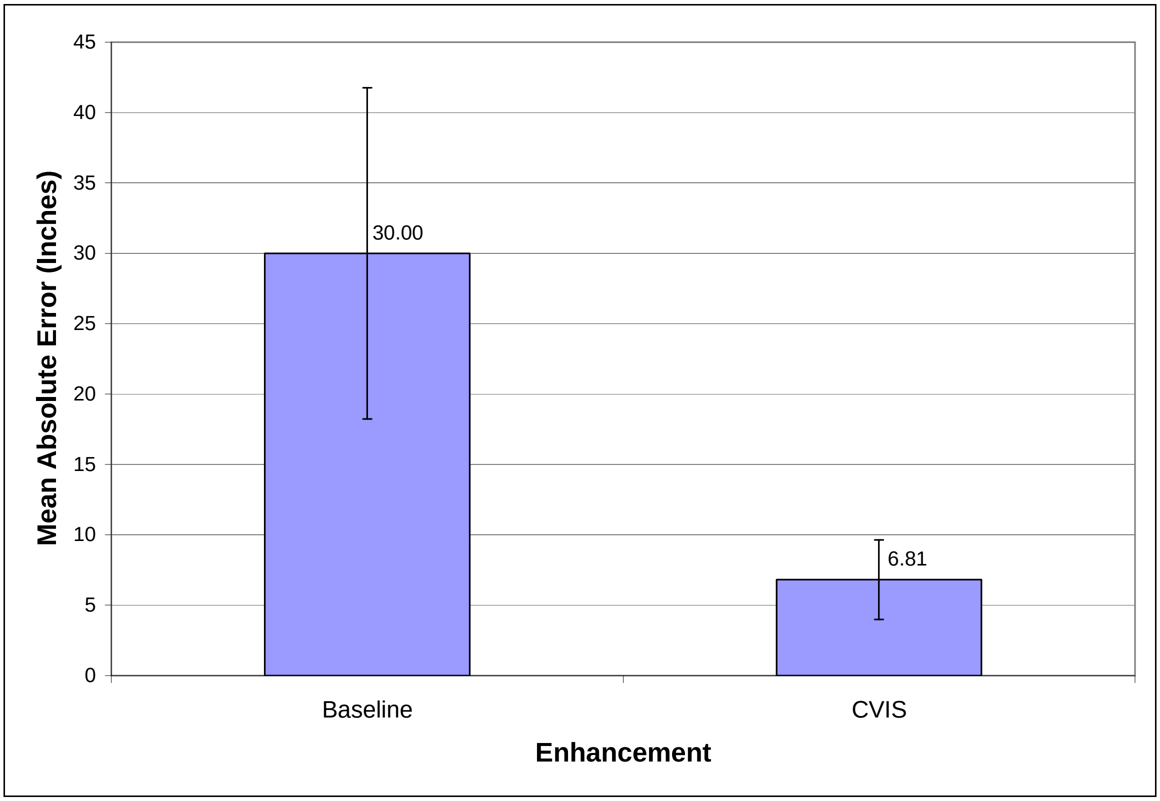

Figure 114. Mean absolute error (inches) from the 1 ft (0.305 m) goal for loading dock backing subtask as a function of enhancement.

Glance location probabilities for the last 30 s of the loading dock backing task are shown in Figure 115 for both baseline and the trailer wide-angle rear multipurpose look down enhancement. The results indicate that drivers relied heavily on their left outside rear-view mirrors but, when the C/VIS was present, it was also used, taking resources from the left outside mirrors, the right outside mirrors and "other" views. There were no appreciable differences in glance probabilities for younger and older drivers.

It should be noted that the loading dock was 12 ft (3.66 m) wide. Consequently, it could be seen in the left outside mirrors most of the time. Because of this view, it is not surprising that the glance probability plot shows that the left outside mirrors were heavily used.

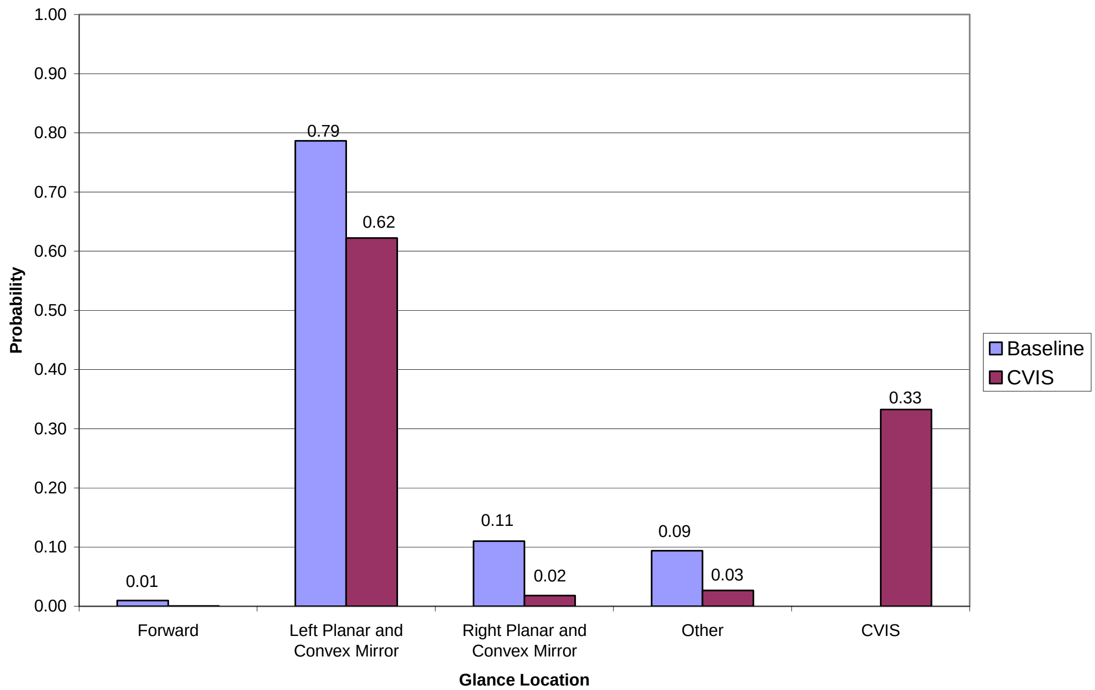

Figure 115. Glance probability locations for the loading dock subtask.

S-curve Backing Subtask Performance and Glance Analyses

In regard to the S-curve backing task, Table 40 shows the subject by subject task completion times in seconds. A two-way repeated-measures analysis of variance on task completion time for enhancement and the nested factor age was performed. There was no significant difference in task completion time with and without the trailer wide-angle rear multipurpose look-down enhancement. There was no significant age effect or significant enhancement by age interaction.

Table 40. S-curve subtask completion times in seconds.

Subject	Baseline	CVIS
1	196	165
2	209	145
3	88	114
4	91	100
5	90	101
6	96	78
7	98	95
8	197	231
Mean Completion Time	133.13	128.63
Standard Error	19.85	17.71

The number of direction (forward/backward) reversals by each driver was also analyzed. Table 41 shows the results. A Wilcoxon Signed Ranks test on the data in the table indicated that there were no statistical differences with and without the C/VIS. To investigate age effects, the data were arranged categorically such that drivers either reversed or they did not. A one-way chi-square test revealed that older drivers reversed significantly more often than younger drivers, $X^2(1) = 6.8182$, $p = 0.0090$. Older drivers reversed a total of 28 times, while younger drivers did not reverse at all. These results are shown in Figure 116.

Table 41. Number of direction reversals in the S-curve subtask.

Subject	Baseline	CVIS
1	0	0
2	6	8
3	0	0
4	2	0
5	0	0
6	0	0
7	0	0
8	6	6
Total Number of Reversals	14	14

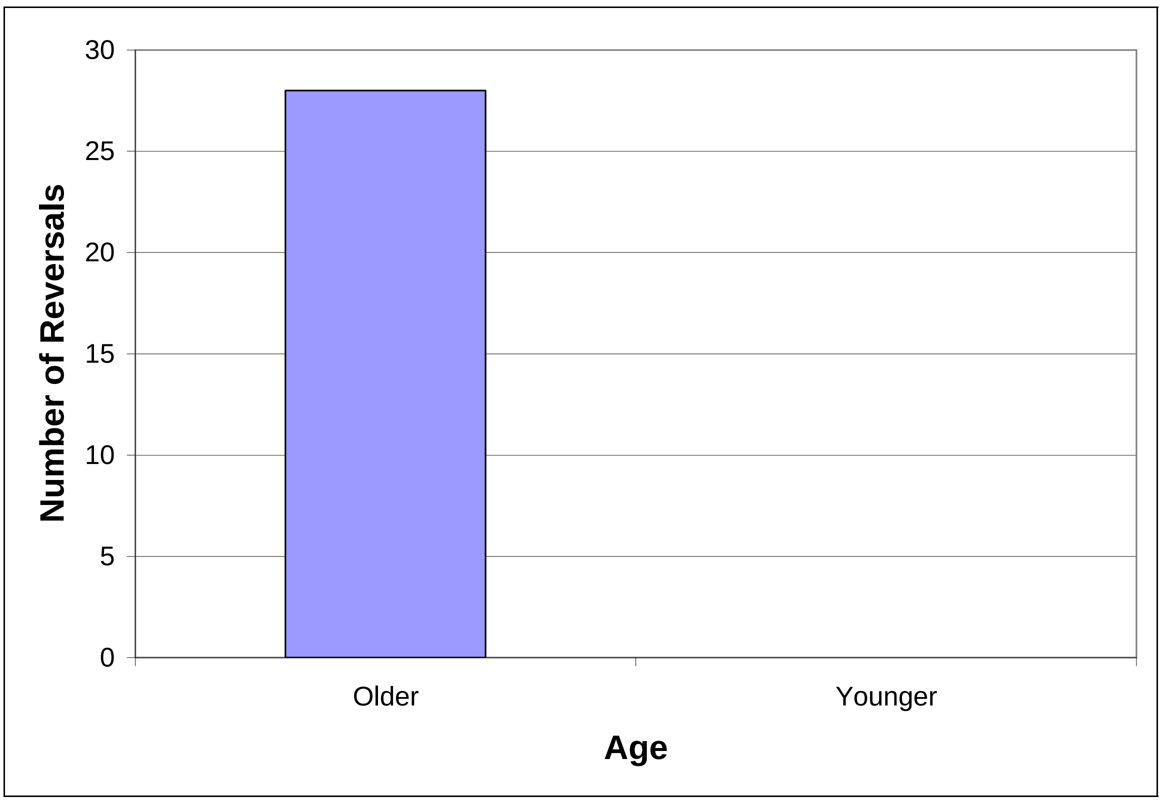

Figure 116. Number of direction reversals by age group during the S-curve backing subtask.

The number of barrels struck in the S-curve subtask was investigated. Table 42 shows the total number of barrels struck by each driver. A Wilcoxon Signed Ranks test indicated that differences with and without the C/VIS were not significant. A one-way chi-square test indicated that age was not significant.

Table 42. Number of barrels struck in the S-curve backing subtask.

Subject	Baseline	CVIS
1	2	1
2	1	2
3	0	2
4	2	2
5	0	0
6	0	3
7	0	0
8	1	1
Total Number of Barrels Struck	6	11

Glance probabilities for the S-curve backing subtask are shown in Figure 117 both with and without the trailer wide-angle rear multipurpose look-down enhancement. The values in the plot are for the time interval from the time that the rear of the trailer entered the course until the rear of the trailer exited the course. The results show that the C/VIS was used very little, and that when it was used it drew resources from the left and right outside rear-view mirrors approximately equally. Differences between younger and older drivers in terms of glance probabilities were found not to be appreciable.

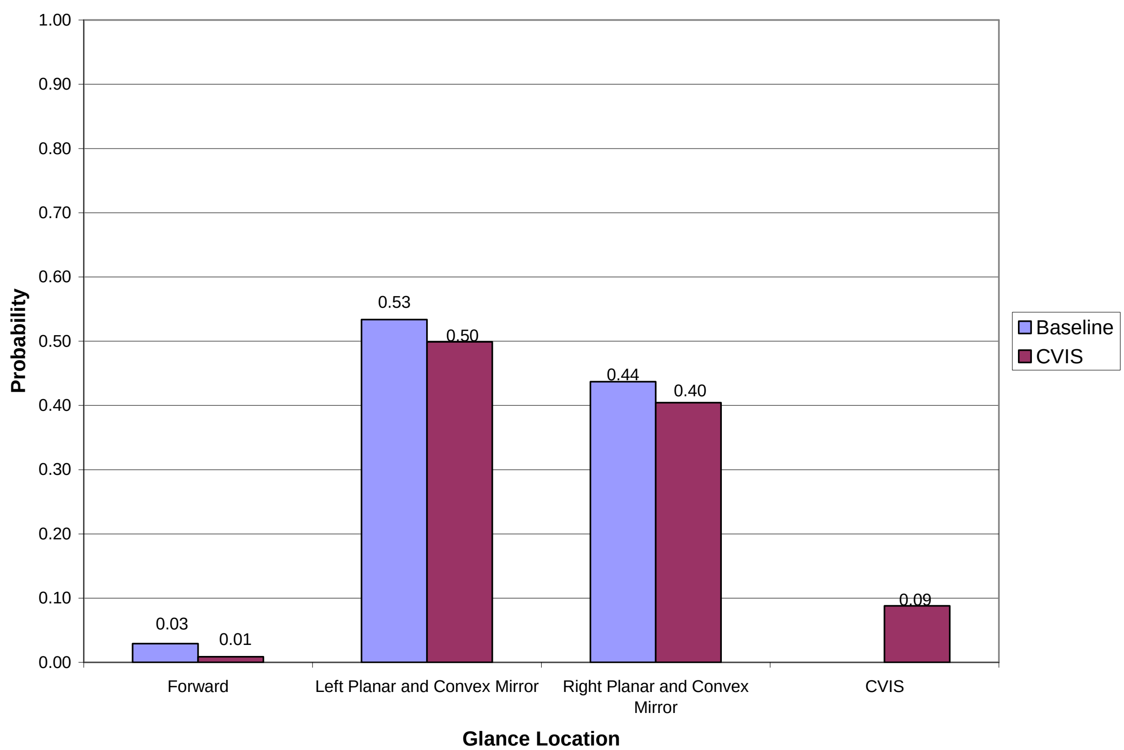

Figure 117. Glance location probabilities for the S-curve subtask.

Task B (Backing Subtasks) Opinion Data Analyses

Opinion data comparing ease/difficulty of performing the various backing subtasks was compared with and without the trailer wide-angle rear multipurpose look-down enhancement. The opinion ratings for the parking task are presented in Table 43. The substantial increase in the ratings for the C/VIS condition resulted in significance for both the two-way repeated-measures analysis of variance ($F(1,6) = 26.09$, $p = 0.0022$) and the Wilcoxon Signed Ranks test ($W = -28$, $N = 7$, $p = 0.02$). Figure 118 shows these differences. Although age was not a significant main effect, there was a significant enhancement by age interaction ($F(1,6) = 6.52$, $p = 0.0433$). Older subjects gave a mean rating of 7.25 for the C/VIS and 3.5 during the baseline, while younger subjects gave a mean rating of 6.75 for the C/VIS and 5.5 for the baseline. Tukey multiple comparison tests revealed a significant difference between the baseline and C/VIS ratings made by older drivers, $q(6) = -5.42$, $p = 0.0066$. In general, the results suggest a substantial preference for the C/VIS condition.

Table 43. Individual ratings for the scale: How difficult/easy was the parking subtask (backing to the parked car)?

Subject	Baseline	CVIS
1	3	4
2	3	9
3	9	9
4	3	7
5	5	7
6	5	8
7	5	7
8	3	5
Mean Rating	4.50	7.00
Median	4.00	7.00

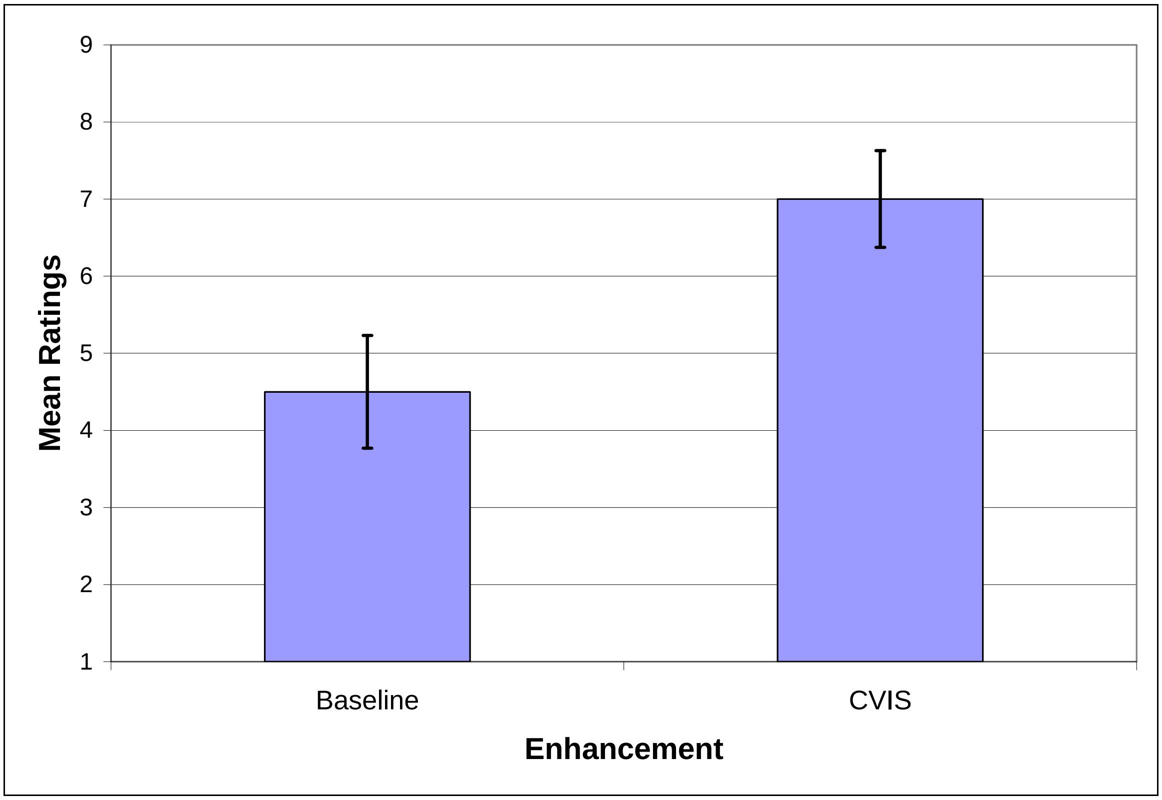

Figure 118. Mean ratings for the parking subtask.

The opinion data comparing the ease/difficulty of performing the loading dock subtask with and without the C/VIS are shown in Table 44. The C/VIS condition resulted in higher average ratings when compared with baseline. Statistical tests similar to those performed on the parking data showed that there was a significant enhancement main effect, $F(1,6) = 28.15$, $p = 0.0018$. This difference is plotted in Figure 119. The Wilcoxon Signed Ranks test also found enhancement to be significant, $W=-28$, $N = 7$, $p = 0.02$. Age and the age by enhancement interaction were not significant.

Table 44. Individual ratings for the scale: How difficult/easy was the loading dock subtask?

Subject	Baseline	CVIS
1	4	5
2	5	9
3	9	9
4	3	7
5	5	7
6	5	7
7	5	9
8	3	7
Mean Rating	4.88	7.50
Median	5.00	7.00

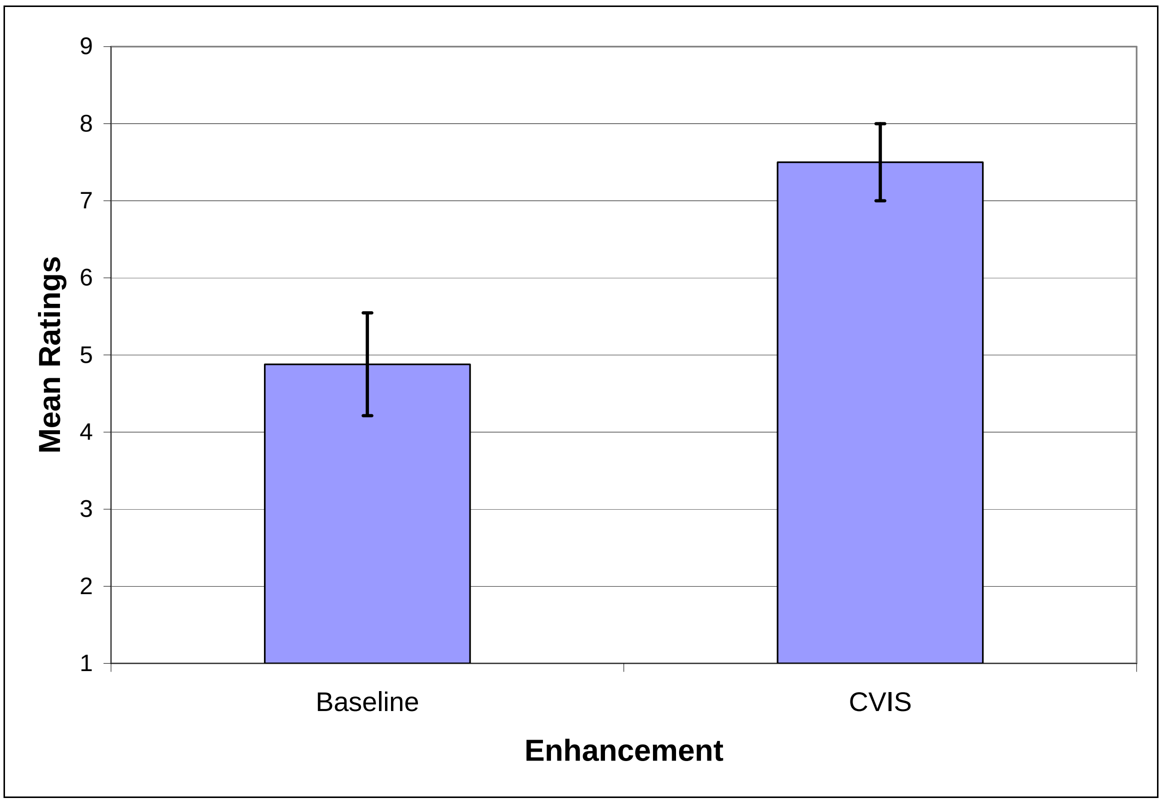

Figure 119. Mean ratings for the loading dock subtask as a function of enhancement.

For the S-curve task, the results are shown by subject in Table 45. The table shows that drivers judged the ease/difficulty to be about the same with and without the C/VIS. As expected, a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables showed that the opinion data ratings were not significantly different between C/VIS and baseline. Additionally, there was no significant age effect or enhancement by age interaction. The Wilcoxon Signed Ranks nonparametric test also showed enhancement to not be significant.

Table 45. Individual ratings for the scale: How difficult/easy was the Peterbilt truck S-curve subtask?

Subject	Baseline	CVIS
1	1	3
2	3	5
3	9	3
4	3	3
5	5	5
6	7	5
7	7	7
8	2	3
Mean Rating	4.63	4.25
Median	4.00	4.00

Once the parking, loading dock, and S-curve subtasks had been completed, drivers were asked to complete additional ratings for the C/VIS enhancement. Results are shown in Table 46. The table shows that drivers were generally favorable to the enhancement, ranking it well above a neutral value of 5. One-way analyses of variance revealed that there were no age effects for any of the scales.

Table 46. Ratings on various scales for the C/VIS enhancement, taken after completing the parking, loading dock, and S-curve subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
1	7	5	8	8
2	9	9	9	9
3	9	5	9	9
4	7	5	7	9
5	8	6	9	9
6	9	8	9	9
7	8	7	9	8
8	7	5	7	7
Mean Rating	8.00	6.25	8.38	8.50
Median Rating	8.00	5.50	9.00	9.00

DISCUSSION

The results of all of the tests suggest that the trailer wide-angle rear multipurpose look-down enhancement is an effective addition to the drivers' workspace and that drivers could use this enhancement. In all of the tests (except the S-curve backing maneuver), performance was improved. In addition, eye glance behavior shows that drivers used the C/VIS when it was available. Finally, the opinion data suggest that the drivers did indeed find the C/VIS useful and that they were receptive to it.

CHAPTER 11: RESULTS FOR THE BACKING/BOBTAILING TRACTOR REAR-VIEW ENHANCEMENT (GROUP 1)

The Volvo tractor was used for these tests. As explained earlier, this enhancement could be used for both on-road subtasks (Task A) and for backing subtasks (Task B). Consequently, both kinds of tests were performed and analyzed.

TASK A (ON ROAD) RESULTS

Clearance/Overlap Subtask Performance and Glance Analyses

For the clearance/overlap subtask, drivers performed very similarly with and without the backing/bobtailing rear-view enhancement; that is, with 96.88 percent correctness for baseline and 93.75 percent correctness when the C/VIS was present. As expected, a Cochran Q test did not demonstrate significance, Q = 0.3443; df =1, $p = 0.5574$. To test for an age main effect, a one-way chi-square test was used. It indicated that age was not significant.

As in previous cases, drivers also provided an estimate of the amount of clearance or the amount of overlap in feet. These data were used to determine the relative level of accuracy in estimation. In regard to estimates with an incorrect statement of clearance or overlap, the estimate of distance was added to the correct value, rather than subtracted from it. Thereafter, the absolute value of the error was determined. A 2 x 2 x 2 repeated-measures analysis of variance on the absolute error data for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (younger or older) revealed that only the main effect of enhancement was significant, $F(1,51) = 7.04$, $p = 0.0106$. There were no significant interactions. Figure 120 shows the results for the main effect of enhancement. The results indicate that drivers were much better at judging distance when the C/VIS was present.

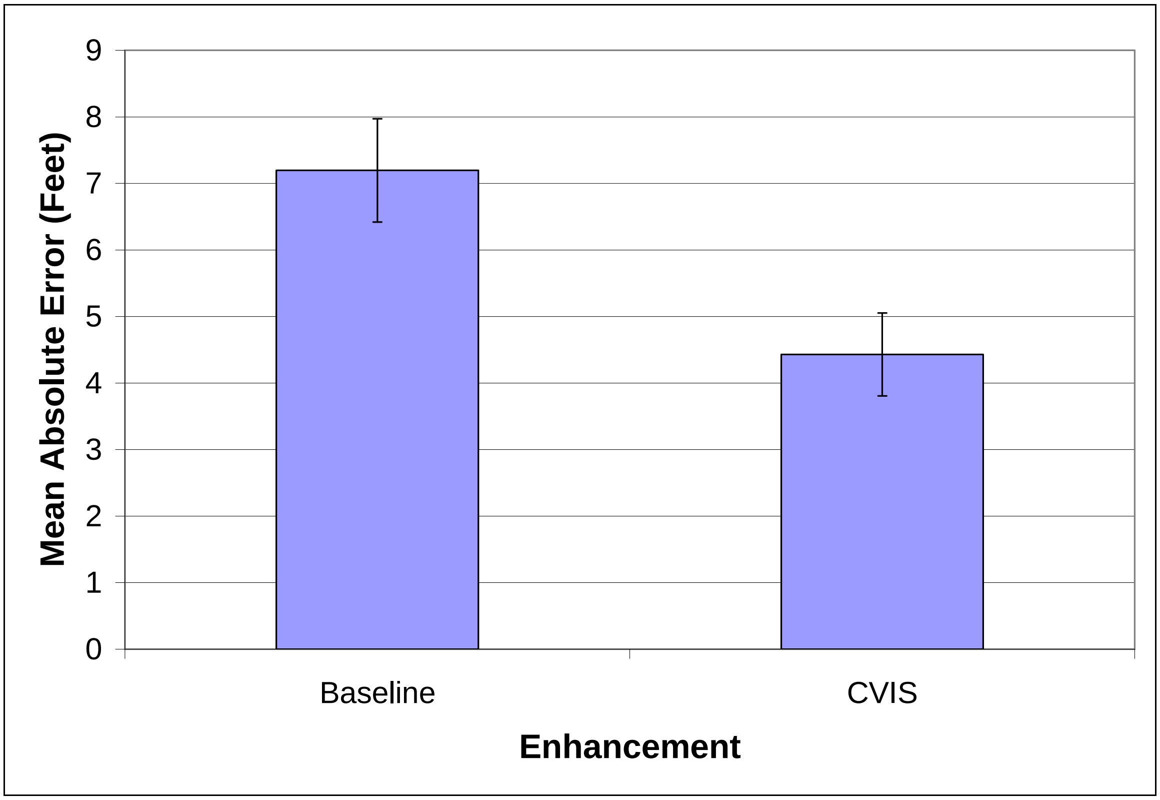

Figure 120. Effect of backing/bobtailing tractor rear-view enhancement on mean error in clearance/overlap distance estimates.

Glance location probabilities were calculated for the time interval starting with completion of clearance/overlap instruction by the experimenter and ending when the driver provided the estimate of distance. Note that the driver was first queried regarding clearance/overlap and then in regard to distance (in feet). The results are plotted separately for the left and right sides of the vehicle, respectively, in Figures 121 and 122.

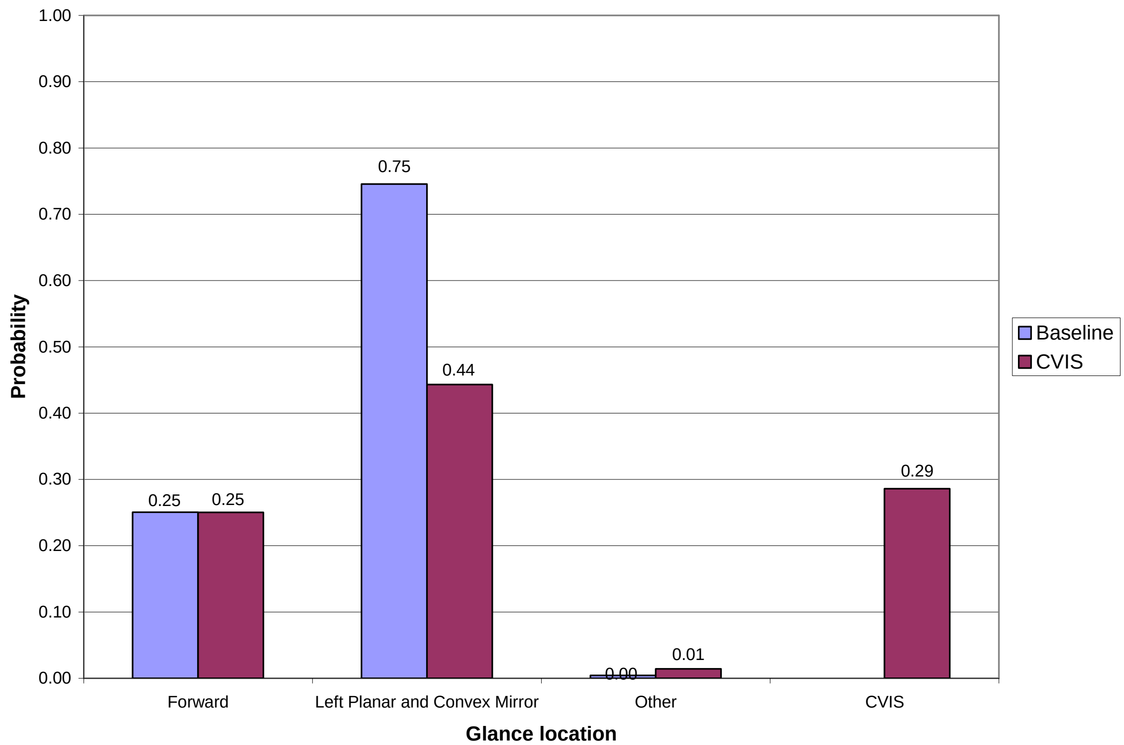

Figure 121. Glance location probabilities for the left clearance/overlap subtask.

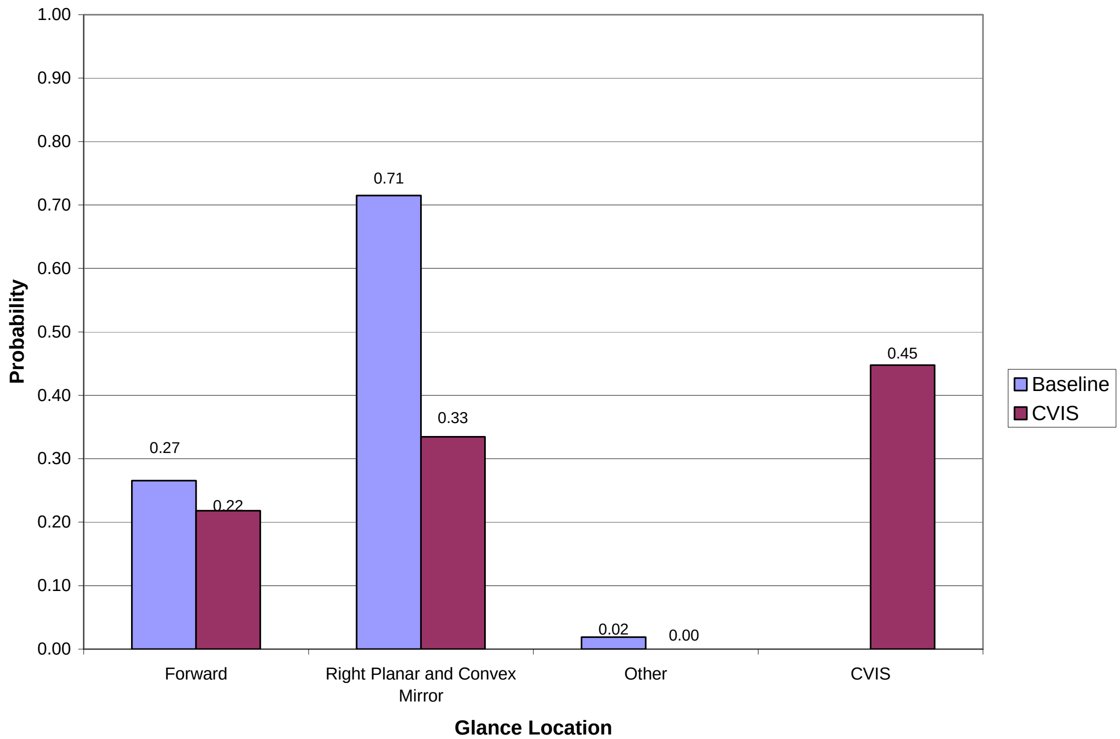

Figure 122. Glance location probabilities for the right-side clearance/overlap subtask.

The plots demonstrate a similar pattern. Drivers used the C/VIS while taking resources primarily from the outside mirrors on the side where the clearance/overlap and distance were being estimated. However, for the right-side subtask, the C/VIS was used a bit more.

Glance patterns were also examined as a function of age. No appreciable differences between the younger and older drivers were found.

Passing/Merging Subtask Performance and Glance Analyses

In the passing/merging subtask, the tractor drivers pulled forward of the confederate automobile and then merged in front of it. Both left-side and right-side merges were performed. There were two replications on each side, for a total of four per subject and condition (C/VISs or baseline). Results were analyzed in terms of re-merge clearance (cut-in distance).

Cut-in distance values were analyzed using a 2 x 2 x 2 repeated-measures analysis of variance for side (left or right), enhancement (baseline or C/VIS), and the nested factor age (older or younger). The analysis demonstrated only a side significant main effect, $F(1,51) = 4.08$, $p = 0.0486$. Enhancement and age were not significant, and there were no significant interactions. The results for side are shown in Figure 123. The results suggest that drivers were a bit more conservative when passing on the passenger (right) side of the vehicle.

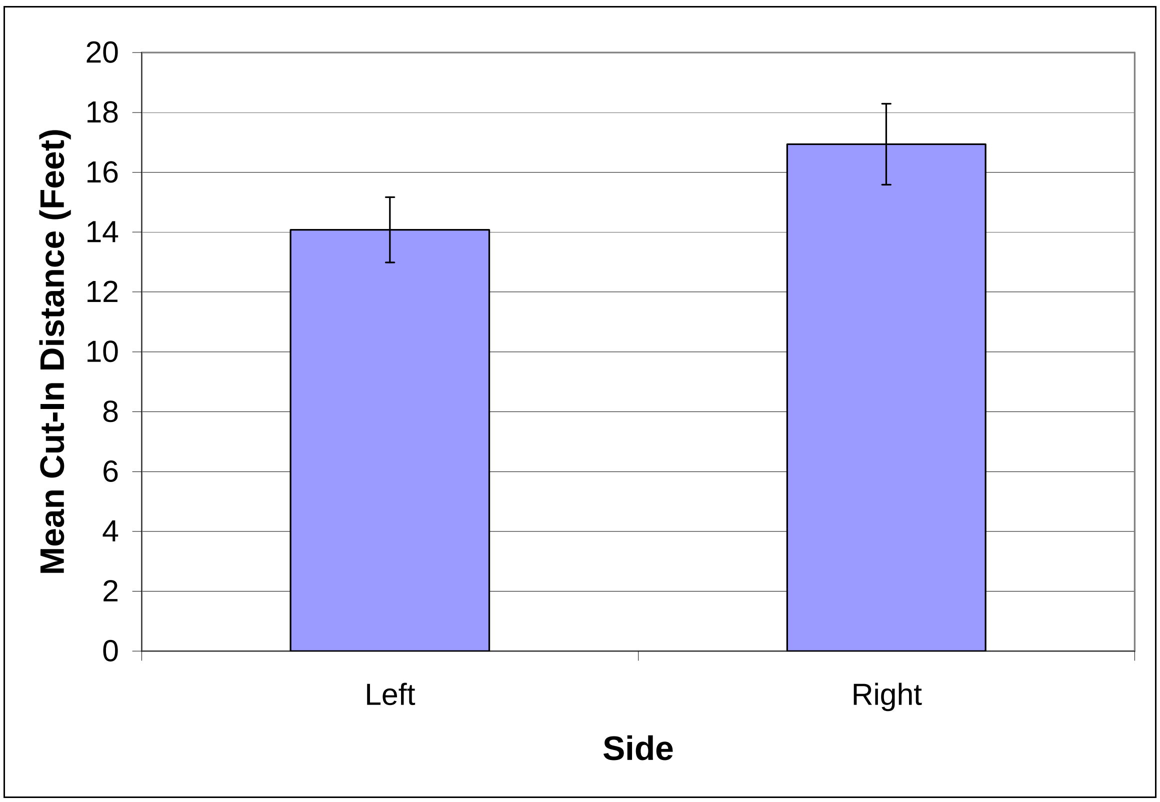

Figure 123. Mean cut-in distance by side (left or right) for the passing/merging subtask.

Glance location probabilities were calculated for the time interval starting 30 s prior to the beginning of the lateral maneuver to the beginning of the lateral maneuver. The results are plotted separately for passes moving to the left and passes moving to the right, respectively, in Figures 124 and 125.

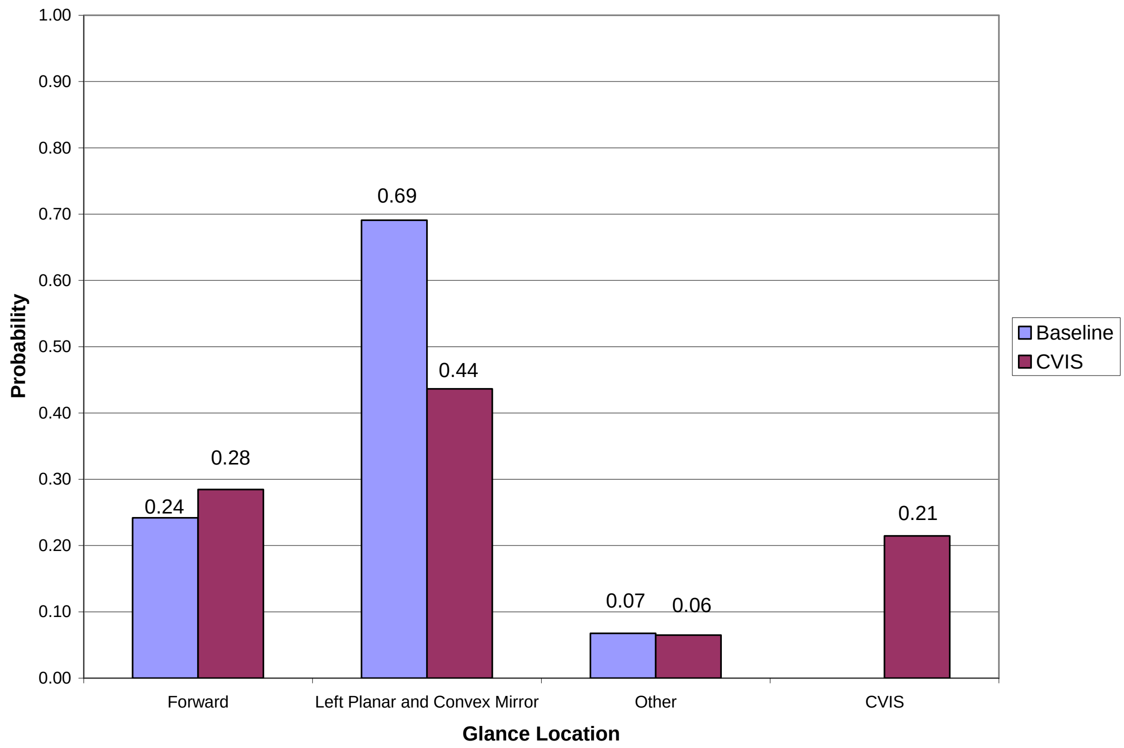

Figure 124. Glance location probabilities for the left-side passing/merging subtask.

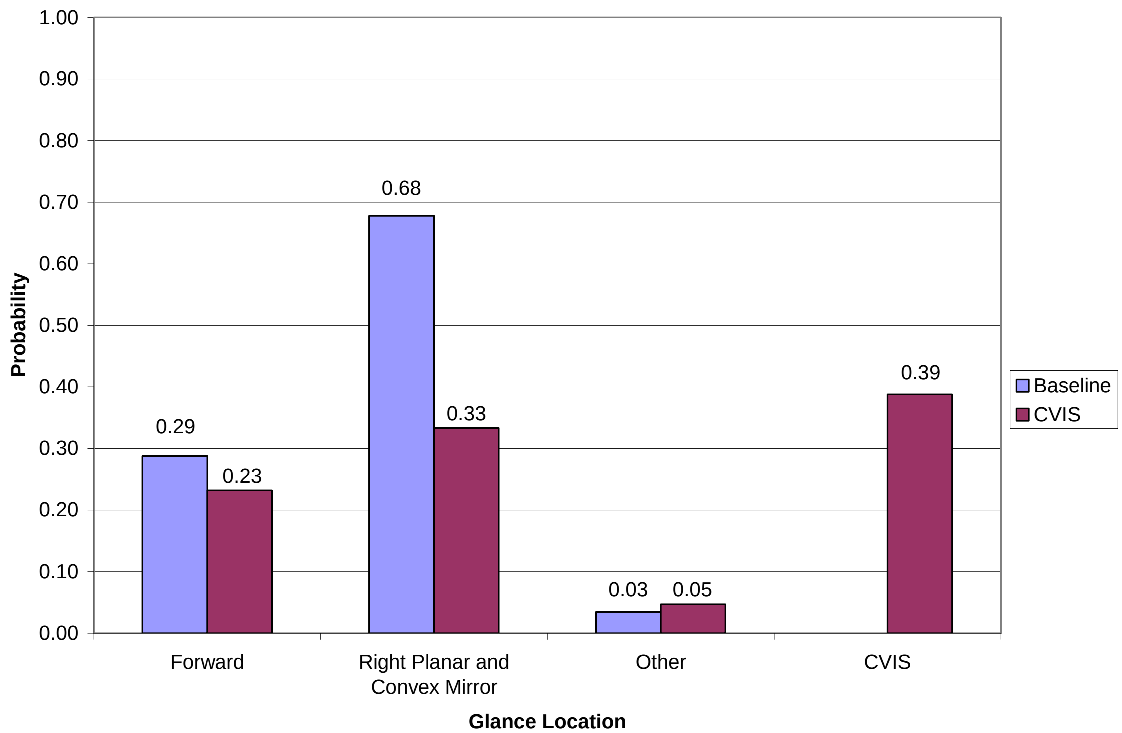

Figure 125. Glance location probabilities for the right-side passing/merging subtask.

As can be seen, the glance patterns for the two sides are quite similar, with resources taken primarily from the mirrors on the side of the pass and used to observe the C/VIS. However, drivers used the C/VIS a bit more for right-side passing than for left-side passing.

Glance patterns were also examined as a function of age group. The patterns were similar, except that older drivers used the C/VIS more than younger drivers.
The C/VIS glance probability for younger drivers was 0.22, while the C/VIS glance probability for older drivers was 0.41, suggesting that older drivers relied more heavily on the C/VIS.

Task A (Clearance/Overlap and Passing/Merging) Opinion Data Analysis

For the opinion data, the *comparisons* involved how difficult/easy it was to perform the clearance/overlap task or the passing/merging task. In regard to the clearance/overlap task, the results are shown in Table 47. Note that the mean and median values of the ratings for baseline and C/VIS are provided in table. The data were analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. Neither main effect was significant. An enhancement by age interaction was found to be marginally significant, $F(1,6) = 5.83$, $p = 0.0523$. The interaction is plotted in Figure 126.

Table 47. Individual ratings for the rating, "How difficult/easy was it to estimate clearance/overlap when the other vehicle was alongside near the back of the tractor?"

Subject	Baseline	CVIS
1	5	7
2	7	7
3	7	9
4	7	3
5	4	7
6	7	7
7	5	9
8	4	6
Mean Rating	5.75	6.88
Median	6.00	7.00

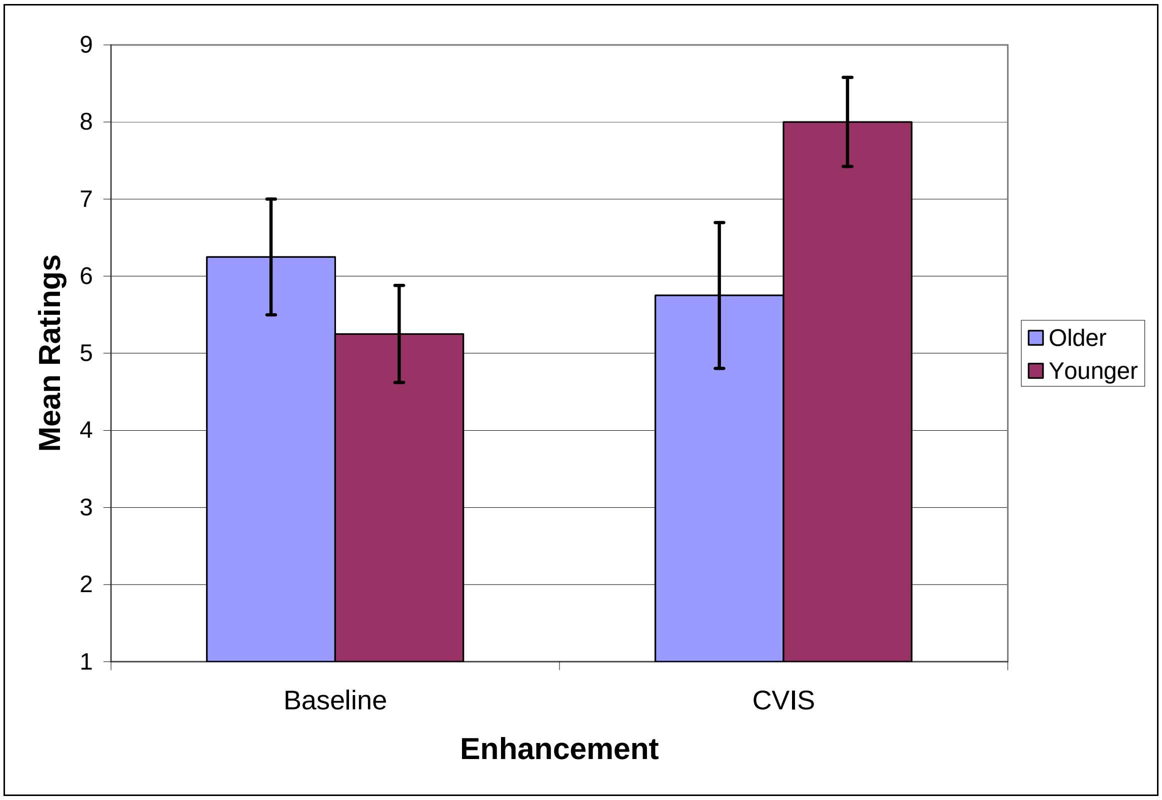

Figure 126. Mean clearance/overlap ratings for the enhancement by age group interaction (*p* = 0.0523).

For the passing/merging task, the opinion data are shown in Table 48. Note that the mean and median values for Baseline and C/VIS are included in the table.

The data were first analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. The main effect of enhancement demonstrated significance, $F(1,6) = 6.94$, $p = 0.0388$ and is plotted in Figure 127. The interaction of enhancement and age was also found to be significant, $F(1,6) = 6.94$, $p = 0.0388$ and is plotted in Figure 128. It should be mentioned that a Wilcoxon Signed Ranks Test for enhancement (main effect) did not demonstrate significance, W = -15, N = 6, $p > 0.05$.

Table 48. Individual ratings for the scale: How difficult/easy was it to estimate distance to the other vehicle when merging to the right or left with the tractor?

Subject	Baseline	CVIS
1	4	7
2	7	5
3	7	9
4	3	3
5	5	7
6	7	7
7	7	9
8	5	7
Mean Rating	5.63	6.75
Median	6.00	7.00

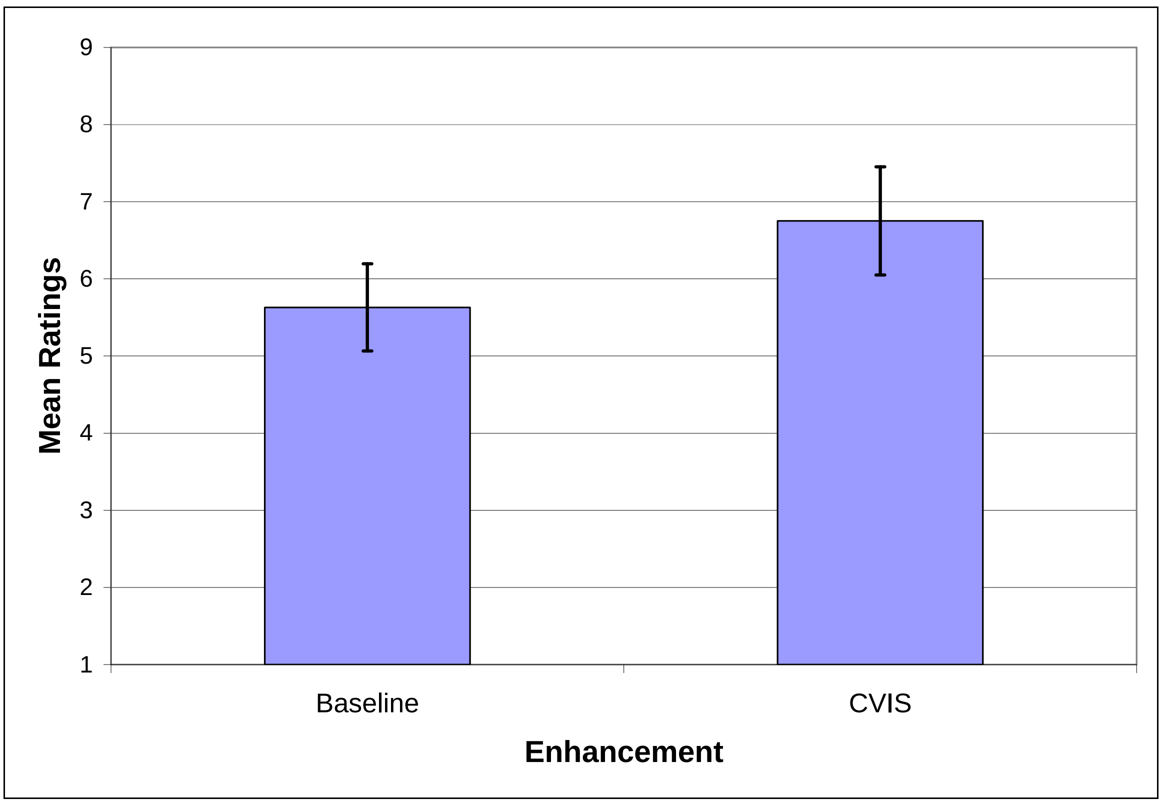

Figure 127. Mean passing/merging subtask ratings by enhancement.

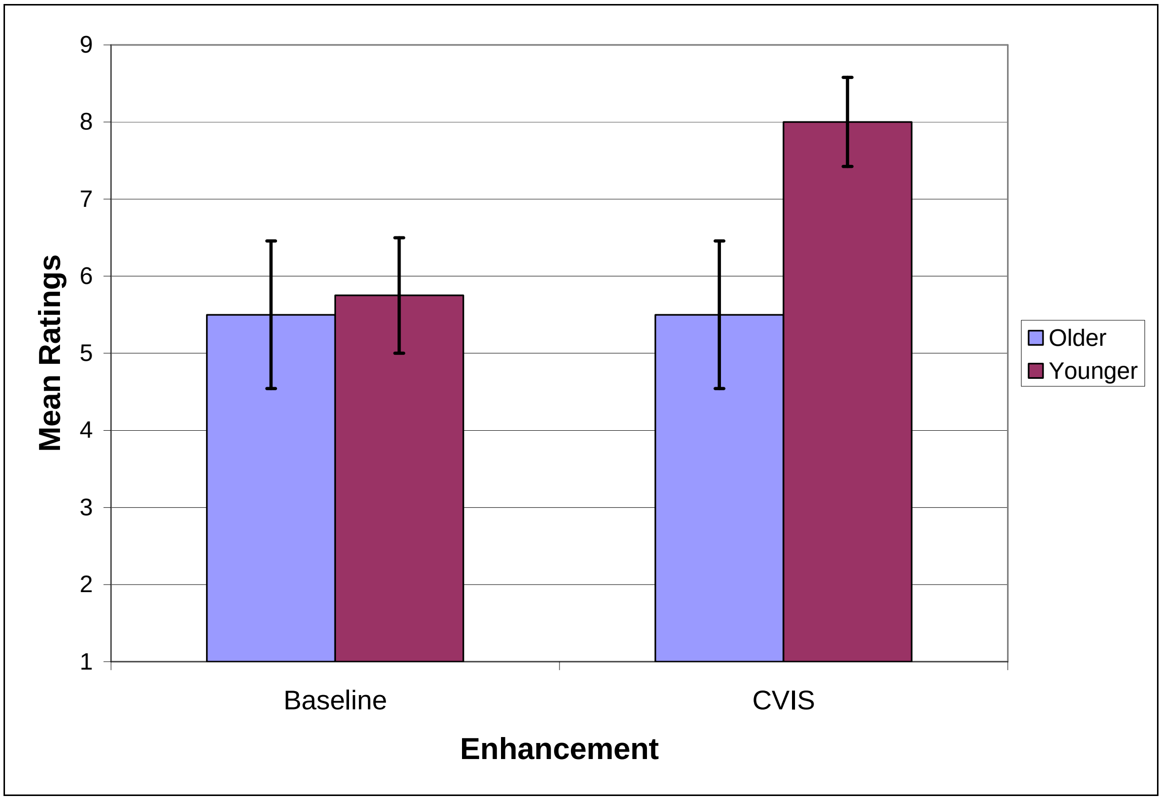

Figure 128. Mean passing/merging subtask ratings for the enhancement by age group interaction.

The clearance/overlap ratings and the passing/merging ratings indicate that the C/VIS conditions received higher ratings than baseline. In addition, the interactions show that it was largely the younger drivers who gave the C/VIS higher ratings.

Four additional ratings for the C/VIS (backing/bobtailing rear-view enhancement) were obtained for the combination of clearance/overlap tasks and the passing/merging tasks. The scales were associated with usefulness, learning time, receptiveness, and blind spot reduction (as described in Appendix B showing the rating scales). These scales were administered after completion of the on-road subtasks with the CVIS enhancement. No baseline comparisons were made. The results are presented in Table 42. As the table shows, the drivers generally provided very high ratings on all of the scales for the enhancements.

The data for each scale reported in Table 49 were analyzed for age effects using one-way analyses of variance with age as the independent variable. None of the scales exhibited a significant age effect on the ratings.

Table 49. Ratings on various scales for the enhancement, taken after completing both the clearance/overlap and passing subtasks with the Volvo tractor.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
1	6	6	8	7
2	9	9	9	7
3	9	5	9	9
4	7	5	7	7
5	8	7	9	9
6	8	7	9	8
7	9	8	9	9
8	7	8	8	4
Mean Rating	7.88	6.88	8.50	7.50
Median Rating	8.00	7.00	9.00	7.50

TASK B (BACKING SUBTASKS) RESULTS

Backing (to a Parked Car) Subtask Performance and Glance Analyses

The task completion times for the Volvo tractor parking subtask (backing to a parked car) are shown below in Table 50. A two-way repeated-measures analysis of variance on task completion time with enhancement and the nested factor age as independent variables revealed that there was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 50. Task completion times (seconds) for the Volvo tractor parking subtask.

Subject	Baseline	CVIS
1	29	37
2	31	53
3	26	34
4	25	26
5	21	36
6	24	27
7	36	35
8	32	25
Mean Completion Time	28.00	34.13
Standard Error	1.73	3.19

The final position distances for the Volvo truck parking task as a function of the presence/absence of the backing/bobtailing tractor rear-view enhancement are shown below in Table 51. The results were analyzed using a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 51. Final position distances (inches) for the Volvo tractor parking subtask as a function of presence/absence of the look-down enhancement.

Subject	Baseline	CVIS
1	83	58
2	55	23
3	65	74
4	88	94
5	113.5	104
6	75	39
7	72	77
8	45	48
Mean Distance	74.56	64.63
Standard Error	7.47	9.79

The final position distances from the 5 ft (1.524 m) goal for the tractor parking task as a function of the presence/absence of the backing/bobtailing enhancement are shown in Table 52. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 52. Mean absolute error (inches) from the 5 ft (1.524 m) goal for the Volvo tractor parking subtask as a function of presence/absence of the enhancement.

Subject	Baseline	CVIS
1	23	2
2	5	37
3	5	14
4	28	34
5	53.5	44
6	15	21
7	12	17
8	15	12
Mean Distance	19.56	22.63
Standard Error	5.60	5.07

Glance probabilities were calculated for the last 30 s of the parking task. They are shown in Figure 129. The results show that drivers used the C/VIS when it was available, taking resources from the right outside mirrors and to a lesser extent from the left outside mirrors.

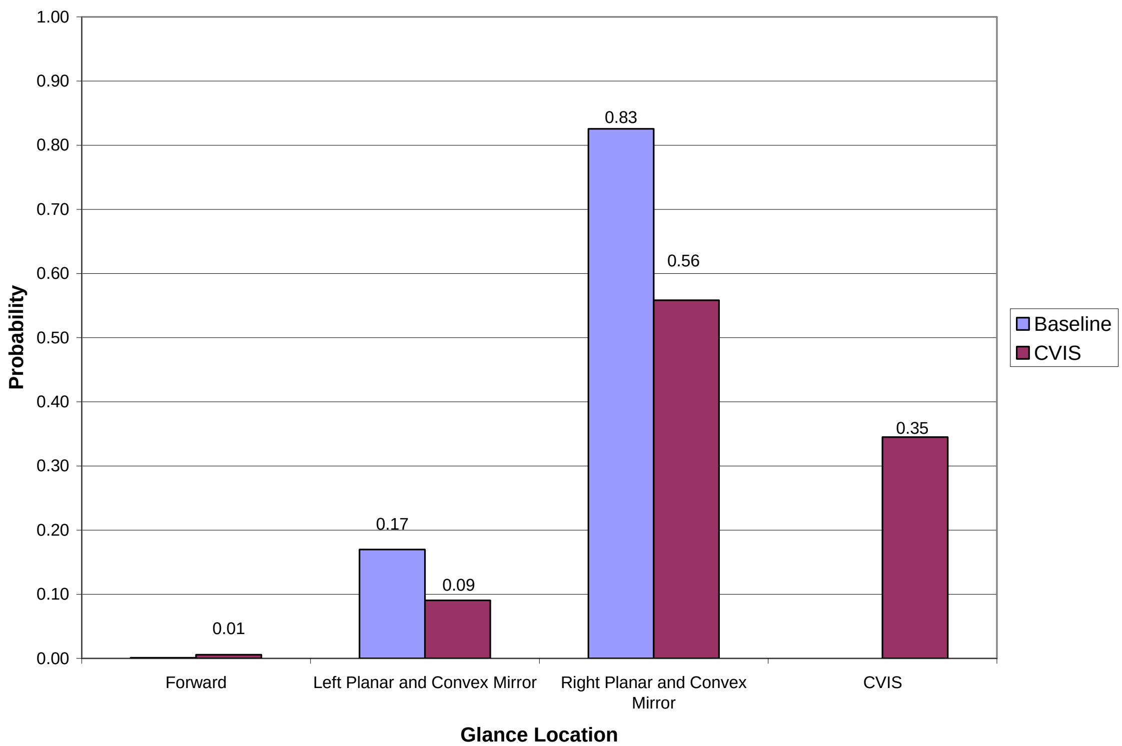

Figure 129. Glance location probabilities for the Volvo tractor during parking subtask.

There were differences in glance patterns for younger and older drivers, as shown in Figures 130 and 131, respectively. Older drivers used the backing/bobtailing enhancement more than younger drivers, when it was available. In addition, older drivers relied more heavily on their mirrors than did younger drivers.

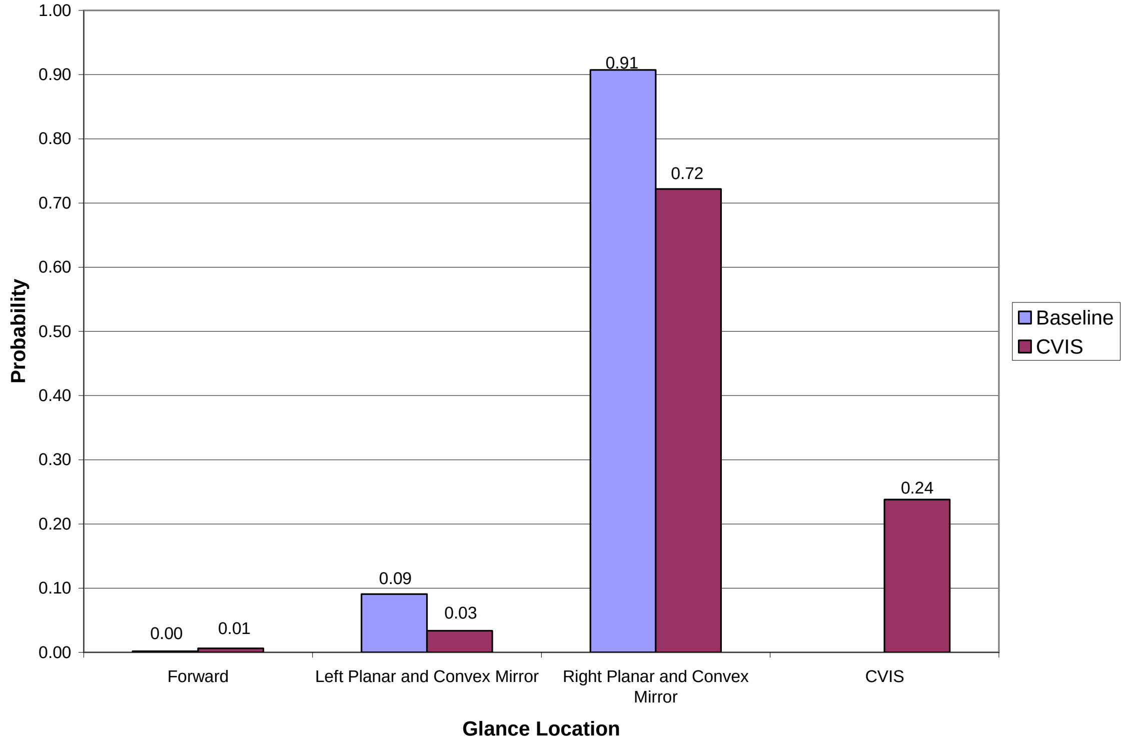

Figure 130. Glance location probabilities for younger drivers of the Volvo tractor during the parking subtask.

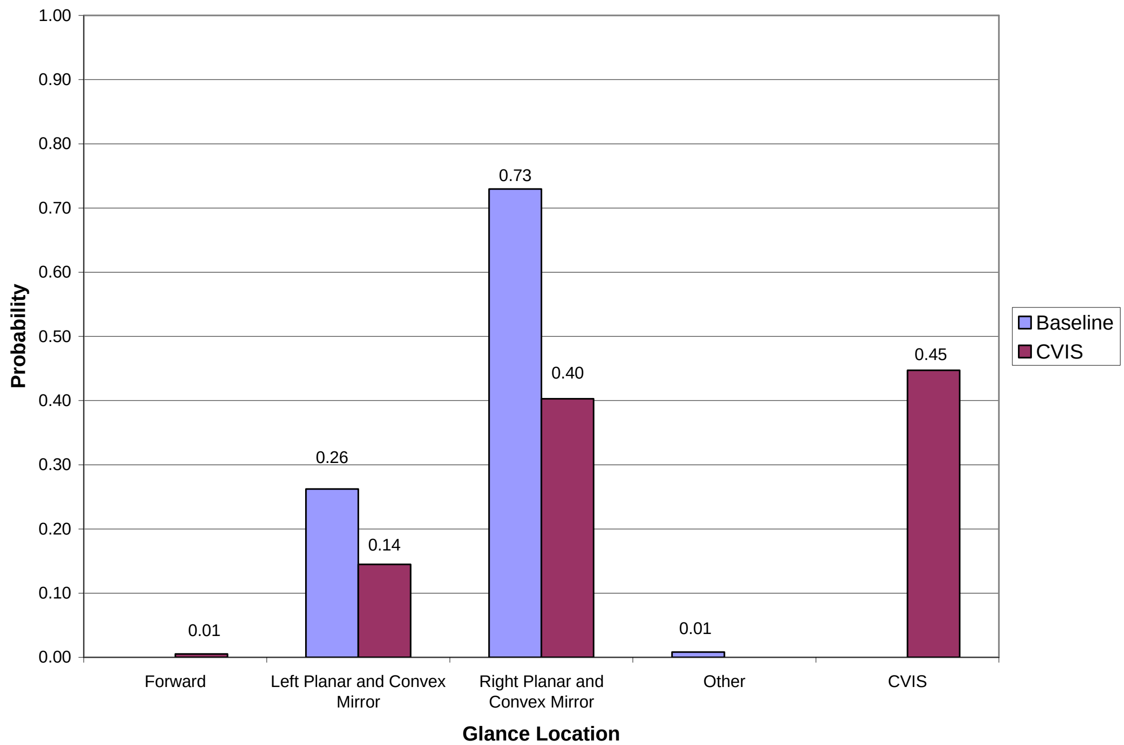

Figure 131. Glance location probabilities for older drivers of the Volvo tractor during the parking subtask.

Cone Barrier Subtask Performance and Glance Analyses

Following the parking task, drivers backed to a cone barrier. This task was used in place of the loading dock backing task because, as explained earlier, the cones were more difficult to see than the loading dock when the tractor was in the uncoupled mode. It should be noted that instructions indicated that the tractor should stop 12 inches away from the cones.

The task completion times for the cone barrier task are shown in Table 53. A two-way repeated-measures analysis of variance on task completion times with enhancement and the nested factor age as independent variables revealed that there was no significant enhancement or age main effect. The enhancement by age interaction was also not significant.

Table 53. Task completion times (seconds) for the cone barrier backing subtask.

Subject	Baseline	CVIS
1	48	61
2	43	40
3	35	39
4	46	44
5	42	41
6	38	44
7	58	67
8	28	35
Mean Completion Time	42.25	46.38
Standard Error	3.19	4.02

The closest distances from the Volvo tractor to the cones are shown in Table 54. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was a significant age main effect $F(1, 6) = 7.95$, $p = 0.0304$. On average, older drivers parked 16.31 in from the cones, while younger drivers parked 39.5 in (as shown in Figure 132). There was no significant enhancement effect. The enhancement by age interaction was also not significant.

Table 54. Final position distances (inches) for the Volvo tractor in the cone barrier subtask.

Subject	Baseline	CVIS
1	48	24
2	-4	6
3	27	30
4	21	24.5
5	52	19
6	32	12.5
7	61	55
8	25	13.5
Mean Distance	32.75	23.06
Standard Error	7.30	5.31

It should be noted that one older driver bumped into the cones during the baseline condition, moving it back four inches.

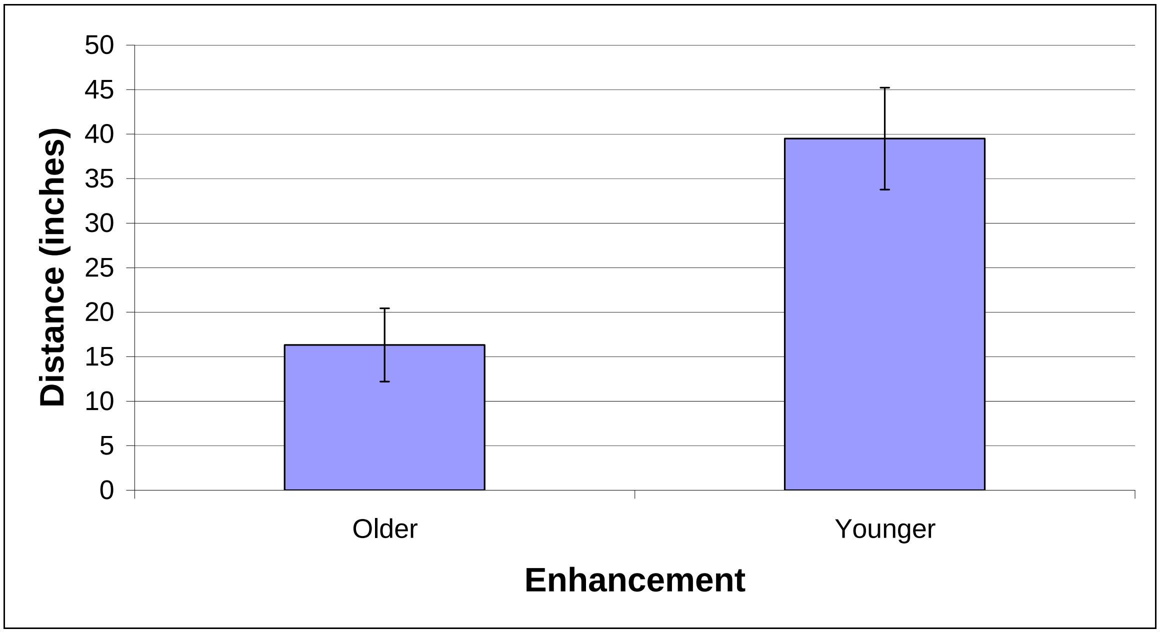

Figure 132. Mean distance (inches) from the tractor to the cones, showing the age main effect.

The absolute error distances to the 12-inches-from-cones goal are shown in Table 55. The results were analyzed with a two-way repeated-measures analysis of variance with enhancement and the nested factor age as the independent variables. There was a significant enhancement main effect $F(1, 6) = 6.58$, $p = 0.0426$, which is plotted in Figure 133. There was also a significant age main effect ($F(1, 6) = 7.95$, $p = 0.0304$), which is plotted in Figure 134. The enhancement by age interaction was not significant.

Table 55. Absolute error (inches) from the 12 in goal for the Volvo truck cone barrier subtask.

Subject	Baseline	CVIS
1	36	12
2	16	6
3	15	18
4	9	12.5
5	40	7
6	20	0.5
7	49	43
8	13	1.5
Mean Distance	24.75	12.56
Standard Error	5.22	4.81

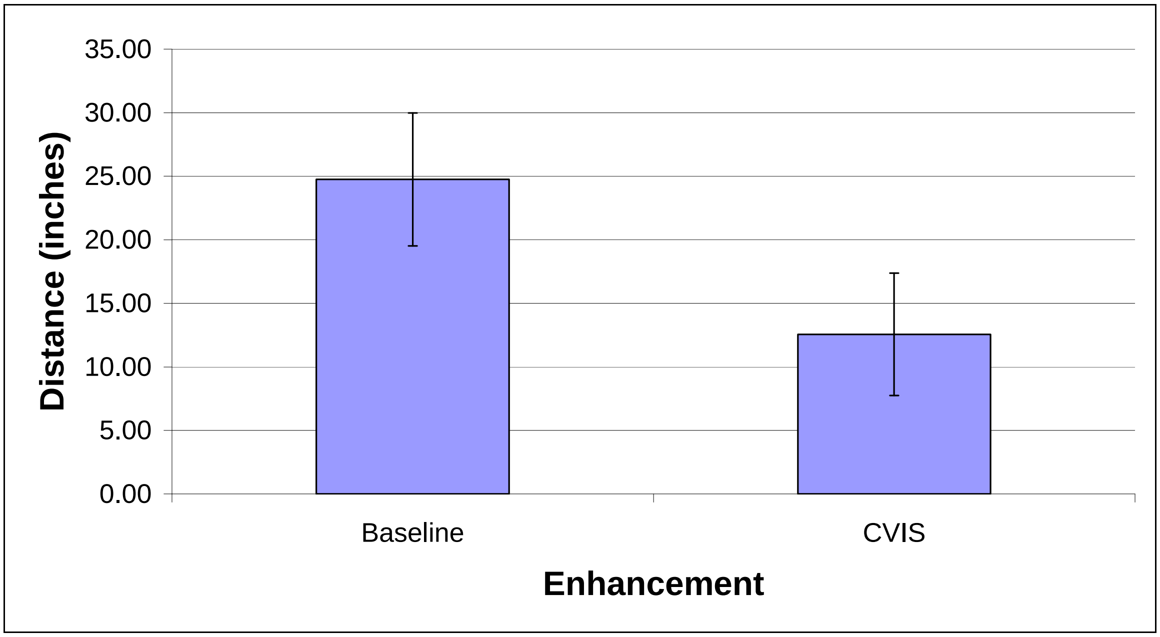

Figure 133. Mean absolute error (inches) from the instructed 12 inches from cone barrier for baseline and enhancement in the cone barrier backing subtask.

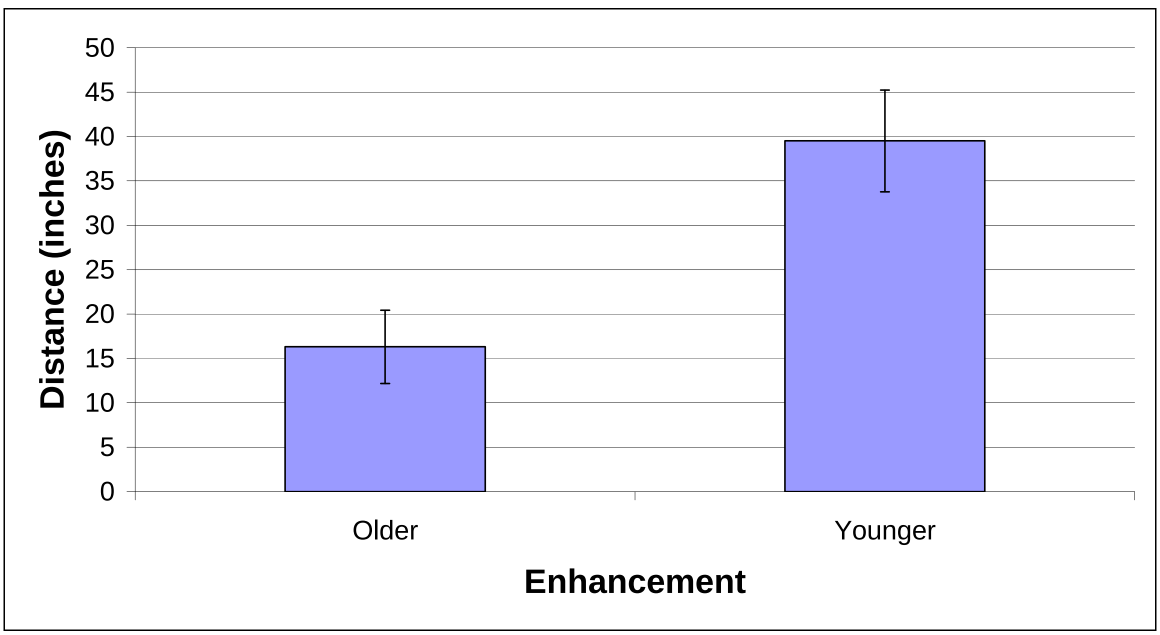

Figure 134. Mean absolute error (inches) from the instructed 12 inches from cone barrier as a function of age group in the cone barrier backing subtask.

The results of these analyses indicate that the backing/bobtailing enhancement facilitated the cone barrier subtask and that older drivers did better than younger drivers.

Glance location probability analyses were carried out for the cone barrier test, using the interval from 30 s prior to completion up to completion. The results are shown in Figure 135. When the C/VIS was available, drivers used it, while taking resources almost completely from the left outside mirrors. There was only a slight difference between younger and older drivers, with younger drivers having a C/VIS probability of 0.19 and older drivers having a C/VIS probability of 0.31.

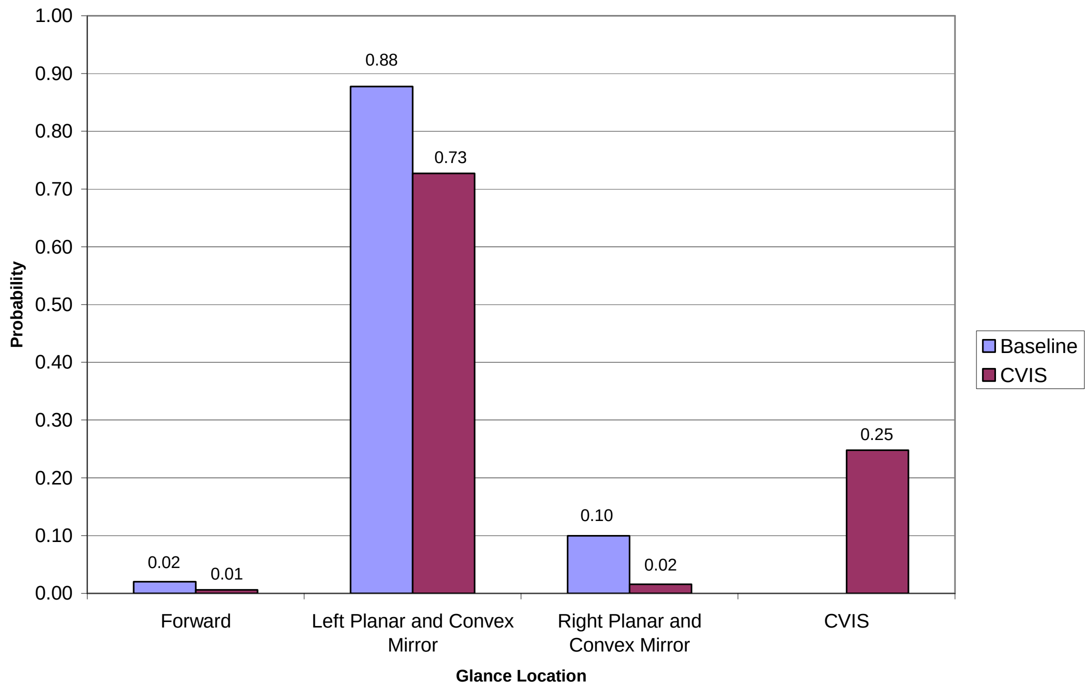

Figure 135. Glance location probabilities for the Ccone barrier subtask as a function of enhancement.

S-curve Backing Subtask Performance and Glance Analyses

In regard to the S-curve backing subtask, Table 56 shows the maneuver completion times. A two-way repeated-measures analysis of variance on task completion times for enhancement and the nested factor age was performed. There were no significant differences in task completion times with and without the backing/bobtailing rear enhancement. In addition, the age effect and the enhancement by age interaction were not significant.

Table 56. Tractor S-curve backing subtask completion times in seconds.

Subject	Baseline	CVIS
1	61	76
2	34	76
3	33	30
4	38	64
5	46	45
6	48	48
7	44	50
8	46	43
Mean Completion Time	43.75	54.00
Standard Error	3.19	5.82

Table 57 shows the number of direction reversals for each driver for the S-curve subtask. A Wilcoxon Signed Ranks test on the data in the table indicated that differences as a function of enhancement were not significant. To investigate age effects, the data were arranged categorically such that drivers either reversed or they did not. A one-way chi-square test revealed that there was no statistically significant difference between older and younger drivers.

Table 57. Number of direction reversals in the S-curve subtask.

Subject	Baseline	CVIS
1	0	0
2	0	1
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
Total Number of Reversals	0	1

The number of barrels struck in the tractor S-curve backing subtask was investigated. Table 58 shows the total number of barrels struck by each driver. A Wilcoxon Signed Ranks test indicated that differences with and without the C/VIS were not significant. A one-way chi-square test indicated that age was not significant.

Table 58. Number of barrels struck in the Volvo S-curve subtask.

Subject	Baseline	CVIS
1	0	0
2	0	1
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
Total Number of Barrels Struck	0	1

Glance location probabilities were examined for the S-curve backing subtask. The results are shown in Figure 136. The plot indicates that drivers used both their right and left outside rear-view mirrors in this subtask. When the C/VIS was available, they used it, taking resources more heavily from the left outside mirrors than the right outside mirrors. The probabilities were also examined as a function of driver age group. Results are shown in Figures 137 and 138 for younger and older drivers, respectively. The plots show that younger drivers favored the left outside mirrors more, while older drivers used a somewhat more balanced approach to the mirrors on each side of the vehicle. Additionally, younger drivers used the C/VIS a bit more than the older drivers, when the C/VIS was available.

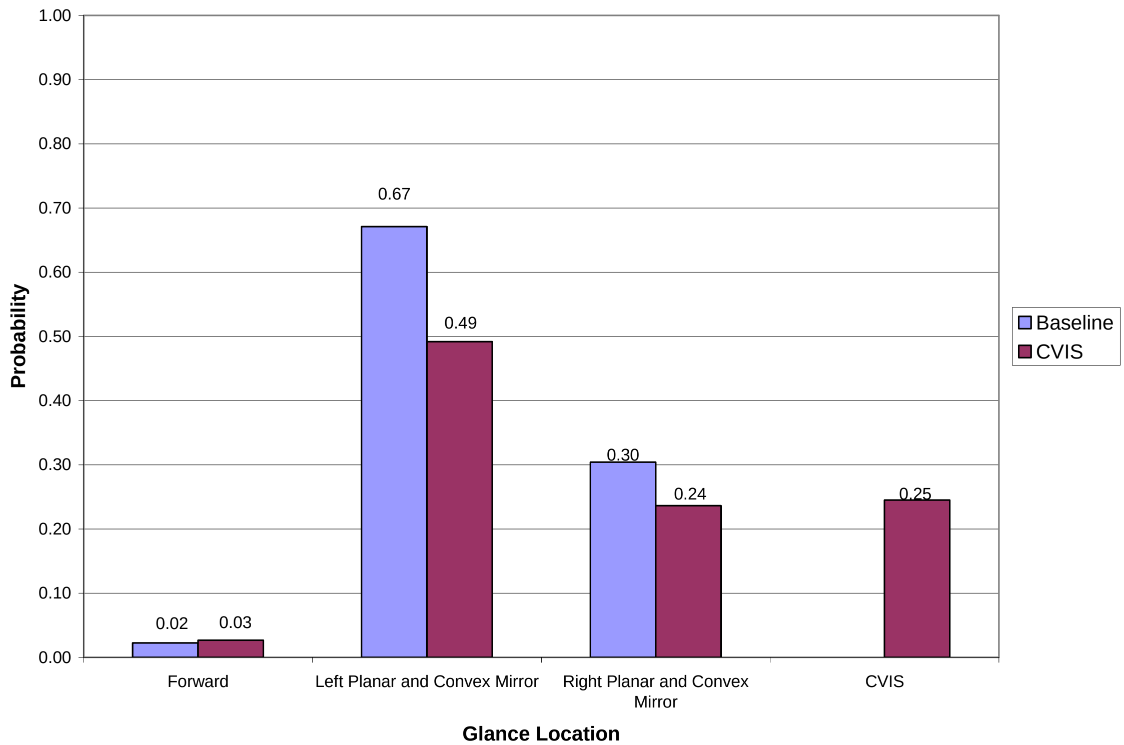

Figure 136. Glance location probabilities for the S-curve backing subtask as a function of enhancement.

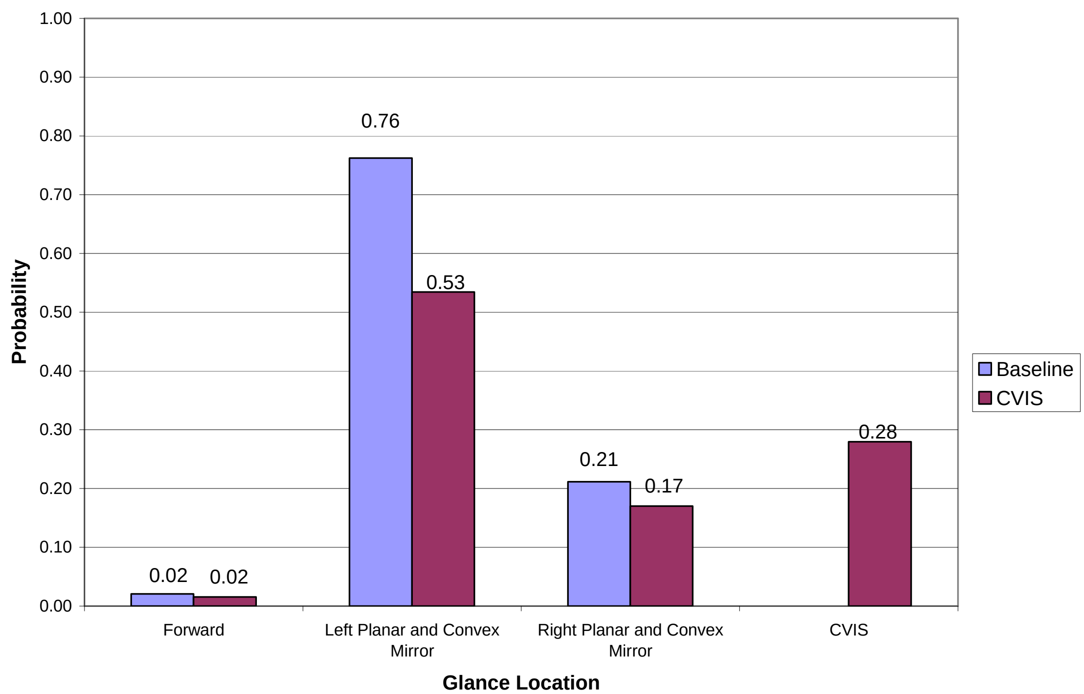

Figure 137. Glance location probabilities for the S-curve backing subtask as a function of enhancement for younger drivers.

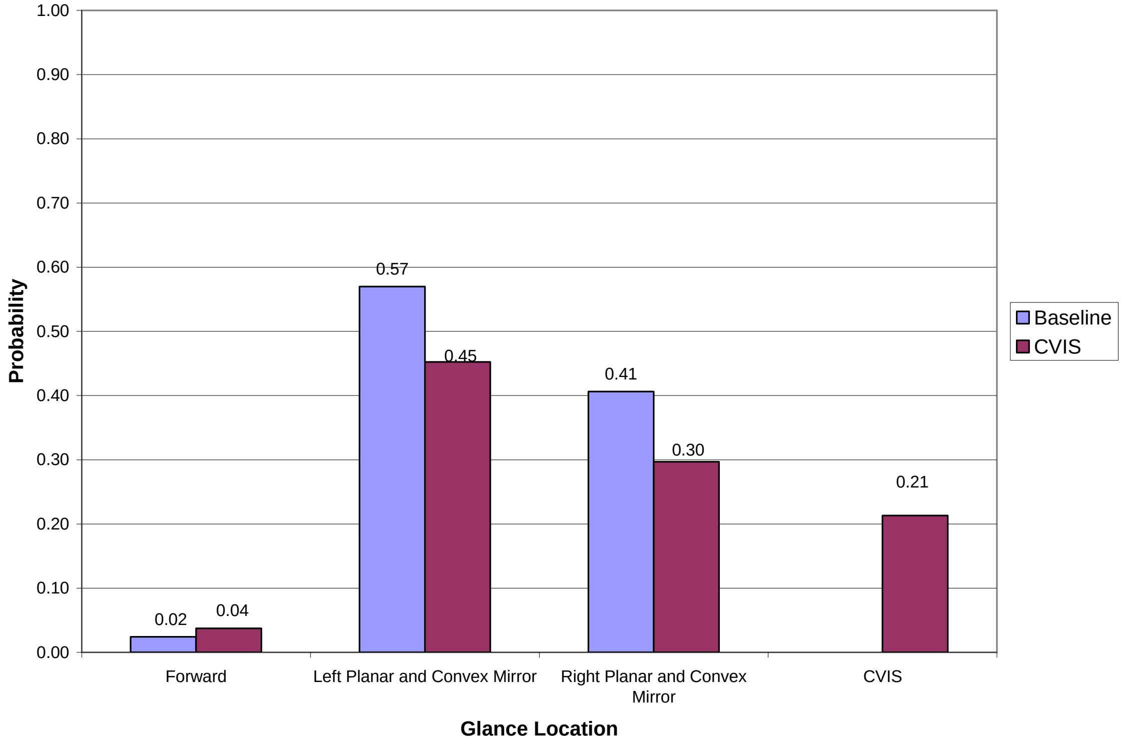

Figure 138. Glance location probabilities for the S-curve backing subtask as a function of enhancement for older drivers.

Task B (Backing Subtasks) Opinion Data Analyses

Opinion data comparing ease/difficulty of performing the various backing maneuvers was compared for baseline and C/VIS. For backing to the parked car (parking), the opinion ratings comparing baseline and C/VIS are presented in Table 59. enhancement was found to be significant using the two-way repeated-measures analysis of variance, ($F(1,6) = 6.97$, $p = 0.0386$, but not significant using the Wilcoxon Signed Ranks test ($W = -15$, $N = 5$, $p > 0.05$). Both age and the age by enhancement interaction were not significant main effects. The enhancement results are plotted in Figure 139. Clearly, drivers provided higher (that is, better) ratings when the backing/bobtailing C/VIS was present.

Table 59. Individual ratings for the scale: How difficult/easy was the Volvo truck parking subtask?

Subject	Baseline	CVIS
1	3	7
2	7	9
3	9	9
4	7	7
5	8	8
6	7	8
7	5	8
8	5	7
Mean Rating	6.38	7.88
Median	7.00	8.00

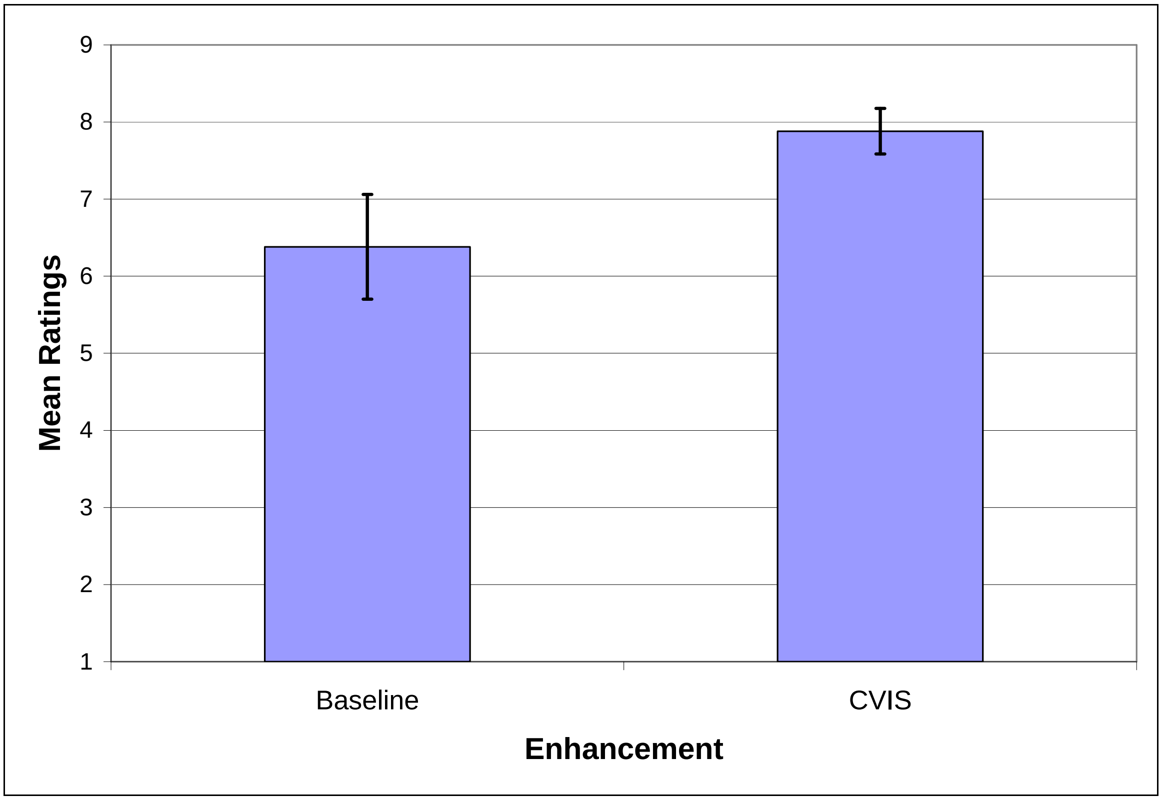

Figure 139. Driver ratings for tractor parking subtask as a function of enhancement.

The opinion data comparing the ease/difficulty of performing the cone barrier subtask with and without the C/VIS using the Volvo truck are shown in Table 60. Statistical tests similar to those performed on the parking data did not find a significant enhancement or age main effect. The age by enhancement interaction was not significant.

Table 60. Individual ratings for the scale: How difficult/easy was the cone barrier subtask with the Volvo truck?

Subject	Baseline	CVIS
1	4	7
2	7	9
3	9	9
4	7	7
5	8	8
6	8	8
7	6	8
8	6	7
Mean Rating	6.88	7.88
Median	7.00	8.00

For the tractor S-curve backing subtask, the results are shown by subject in Table 61. The table shows that drivers judged the ease/difficulty to be about the same with and without the C/VIS. A two-way repeated-measures Analysis of Variance with enhancement and the nested factor age as the independent variables showed, of course, that the opinion data ratings were not significantly different between C/VIS and baseline. Additionally, there was no significant age effect or enhancement by age interaction. The Wilcoxon Signed Ranks nonparametric test similarly showed enhancement to not be significant.

Table 61. Individual ratings for the scale: How difficult/easy was the S-curve backing subtask?

Subject	Baseline	CVIS
1	3	7
2	9	5
3	9	9
4	7	7
5	8	8
6	8	8
7	7	9
8	7	7
Mean Rating	7.25	7.50
Median	7.50	7.50

Once the parking, cone, and S-curve subtasks had been completed, drivers were asked to complete additional ratings for the C/VIS enhancement. Results are shown in Table 62. The table shows that drivers were generally favorable to the enhancement, ranking it well above a neutral value of 5. One-way analyses of variance revealed that there were no age effects for any of the scales.

Table 62. Ratings on various scales for the C/VIS enhancement, taken after completing the parking, loading dock, and S-curve subtasks with the Volvo truck.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
1	7	6	8	7
2	9	3	9	7
3	9	5	9	9
4	7	5	7	7
5	7	7	9	7
6	8	8	9	8
7	9	8	9	9
8	8	7	8	9
Mean Rating	8.00	6.13	8.50	7.88
Median Rating	8.00	6.50	9.00	7.50

DISCUSSION

The results of all of the tests suggest that the backing/bobtailing tractor rear-view enhancement is an effective addition to the driver's workspace and that drivers could use this enhancement. While there were some tests in which there was no improvement in performance with the C/VIS, there were others that did show improvement. In addition, eyeglance behavior shows that drivers used the C/VIS when it is available. Finally, the opinion data suggest that the drivers did indeed find the C/VIS useful and that they were receptive to it. It appears that the C/VIS may have made the driver's job a little easier.

CHAPTER 12: RESULTS FOR THE CONVEX MIRROR SURROGATES AND FOR THE COMBINATION OF CONVEX AND FLAT (WEST COAST) MIRROR SURROGATES (GROUP 3)

These tests were performed using the Peterbilt tractor with 48 ft (14.6 m) trailer. All surrogates were tested in the same experiment and used the same baseline. For that reason, they are presented here in the same chapter. This approach reduced the amount of repetition that would be necessary if results for the two forms of surrogates were reported separately. In addition, it is possible to compare the surrogates directly.

Recall that the west coast mirror surrogates were only tested in combination with the convex mirror surrogates. The reasoning here was that west coast mirrors would only be replaced with surrogates if convex mirrors were also going to be replaced with surrogates. Since west coast mirrors are used for distance judgments, it would be unlikely that they would be replaced first and by themselves. Video does not generally provide stereoscopic viewing and, therefore, might compromise distance judgments if used to replace mirrors.

In this presentation of results, as in the experimental description, the surrogates are referred to as Cconvex and Ccombined. Convex refers to the convex mirror surrogates by themselves, while Ccombined refers to the combination of convex mirror surrogates and west coast mirror surrogates. Note that surrogates on both sides of the vehicle were examined. In addition, both on-road subtasks (Task A) and backing subtasks (Task B) were examined, since drivers generally use their mirrors for both types of tasks.

TASK A (ON ROAD) RESULTS

Clearance/Overlap Subtask Performance and Glance Analyses

In the clearance/overlap subtasks, results showed that the convex surrogate had the same accuracy as the baseline mirrors, whereas the combined surrogates reduced accuracy slightly, as shown in Figure 140. However, a Cochran Q test indicated that the differences shown in the graph of Figure 140 were not significant. A one-way chi-square test was run on the nested factor of age and was found not to be significant. Because there was no appropriate test for interactions between age and percent correct, two additional one-way chi-square tests were run: one for older drivers and one for younger drivers. The results did not demonstrate a significant effect of surrogate on either older or younger drivers.

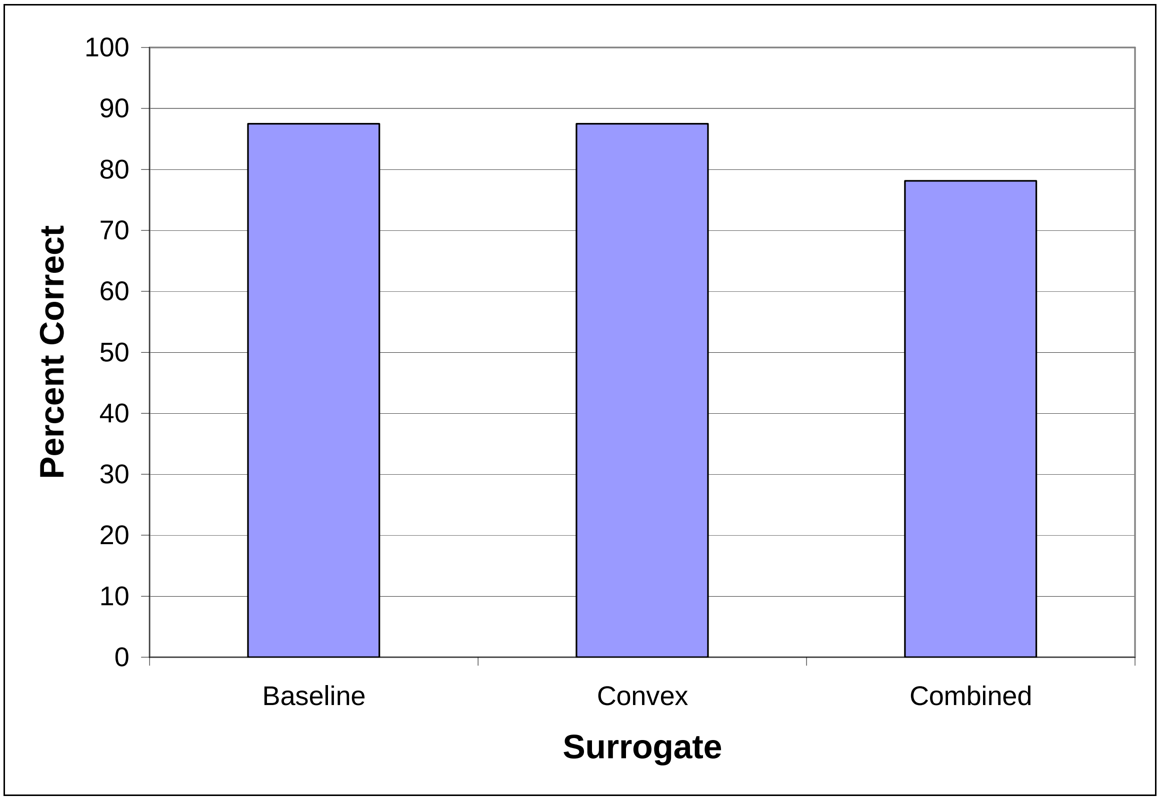

Figure 140. Effect of surrogate type on the clearance/overlap determination subtask (differences are not significant).

Drivers also provided an estimate of the amount of clearance or the amount of overlap in feet. These data were used to determine the relative level of accuracy in estimation. A 2 x 3 x 2 repeated-measures analysis of variance on the absolute error data for side (left or right), surrogate (baseline, convex, or combined), and the nested factor age (younger or older) revealed a significant side main effect $F(1,80)=5.78$, $p=0.0185$. The results are shown in Figure 141. The surrogate main effect was found to be not significant, but was not far from it, $F(2,80)=2.94$, $p=0.0584$. Figure 142 shows the surrogate main effect that did not quite reach significance. The age main effect and all interactions were not found to be significant.

The data depicted in Figure 142 were subjected to a Tukey HSD post hoc test and were found not to demonstrate significant differences, $t = 2.25$, $p = 0.065$, but again were close.

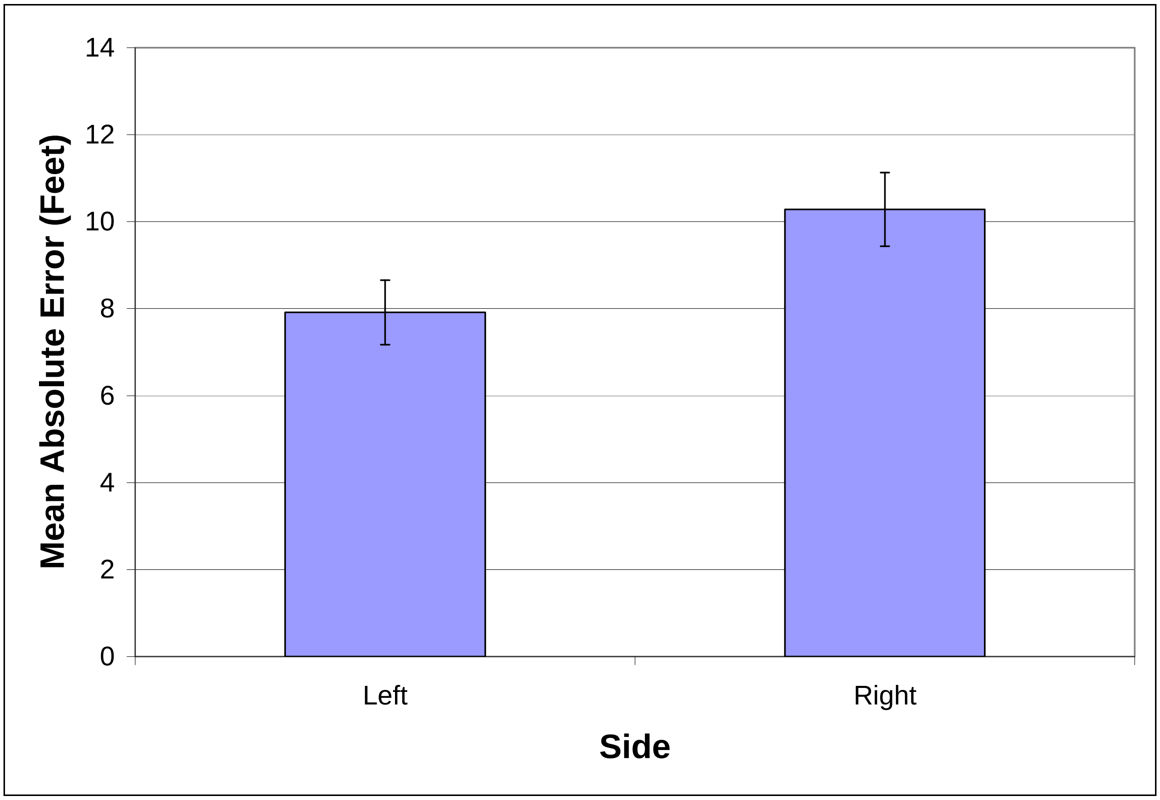

Figure 141. Mean absolute error by side in the clearance/overlap subtask.

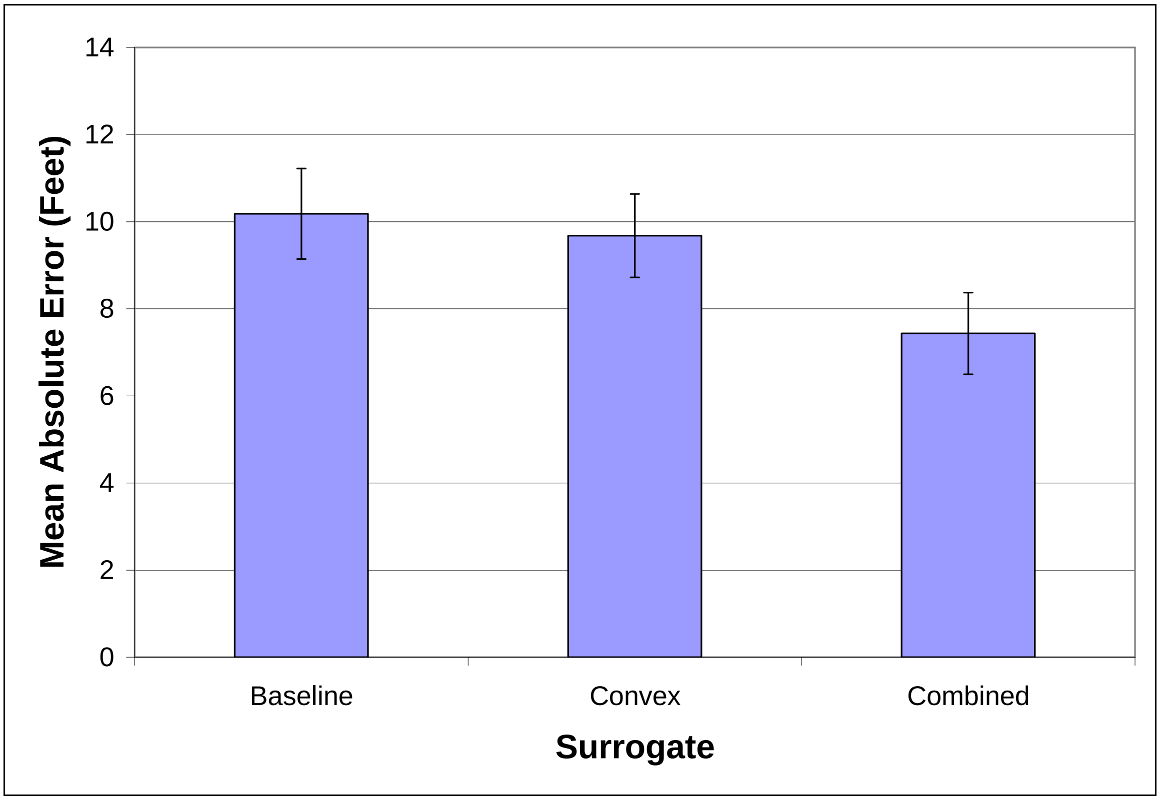

Figure 142. Mean absolute error in distance estimation as a function of surrogate type in the clearance/overlap subtask (p = 0.0584).

Glance probability diagrams were then developed for the clearance/overlap task. Recall that the interval of measurement was from the time that the experimenter gave the query regarding clearance or overlap to the time that the driver provided an estimate of distance of clearance or overlap. The results are presented as a function of side of the vehicle. Figure 143 shows a plot for the left-side clearance/overlap subtask trials, while Figure 144 shows a plot for the right-side clearance/overlap subtask trials.

It is important to note in these and all following glance analysis plots (in this chapter) that the mirrors that the surrogates replaced were covered, so that they could not be used. In other words, drivers could not use the corresponding mirror when the surrogate was provided, a situation quite different from that for enhancements (Groups 1 and 2). Also, it should be mentioned that it *was* possible in the data reduction to determine whether the driver was looking in the direction of the mirrors or in the direction of the surrogates. Consequently, the glance probability diagrams provide that information.

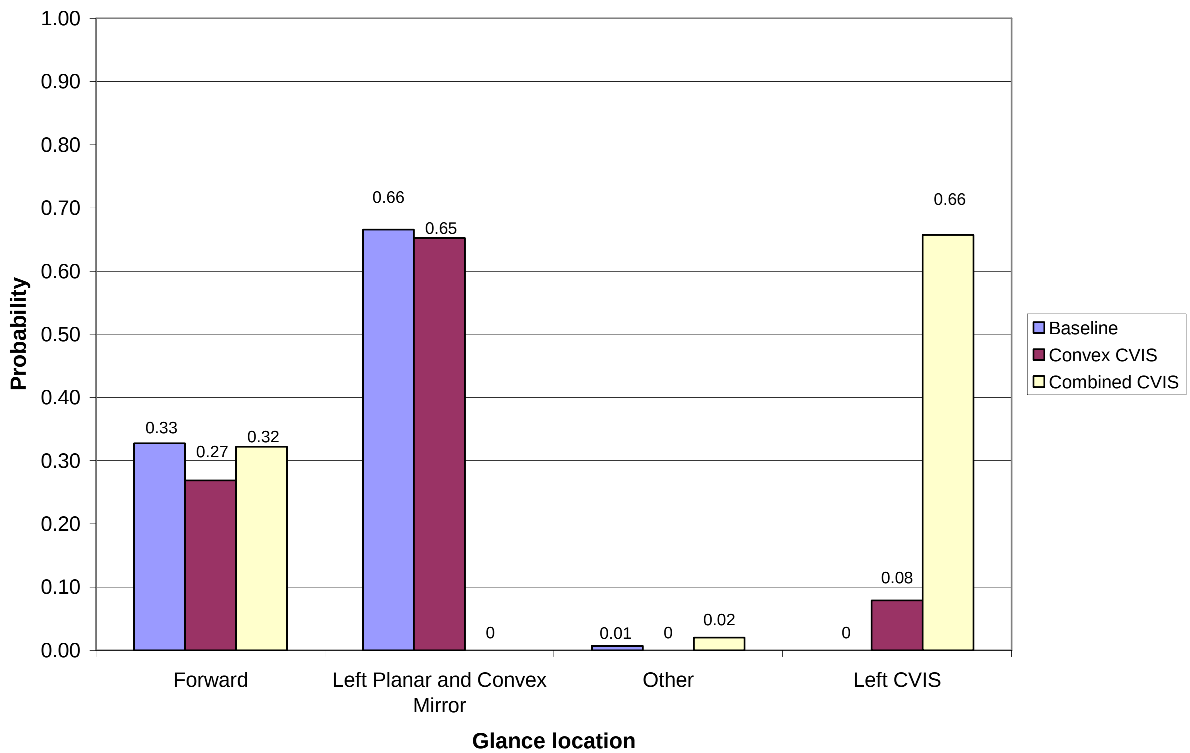

Figure 143. Glance location probabilities for the left-side clearance/overlap subtask as a function of surrogate type.

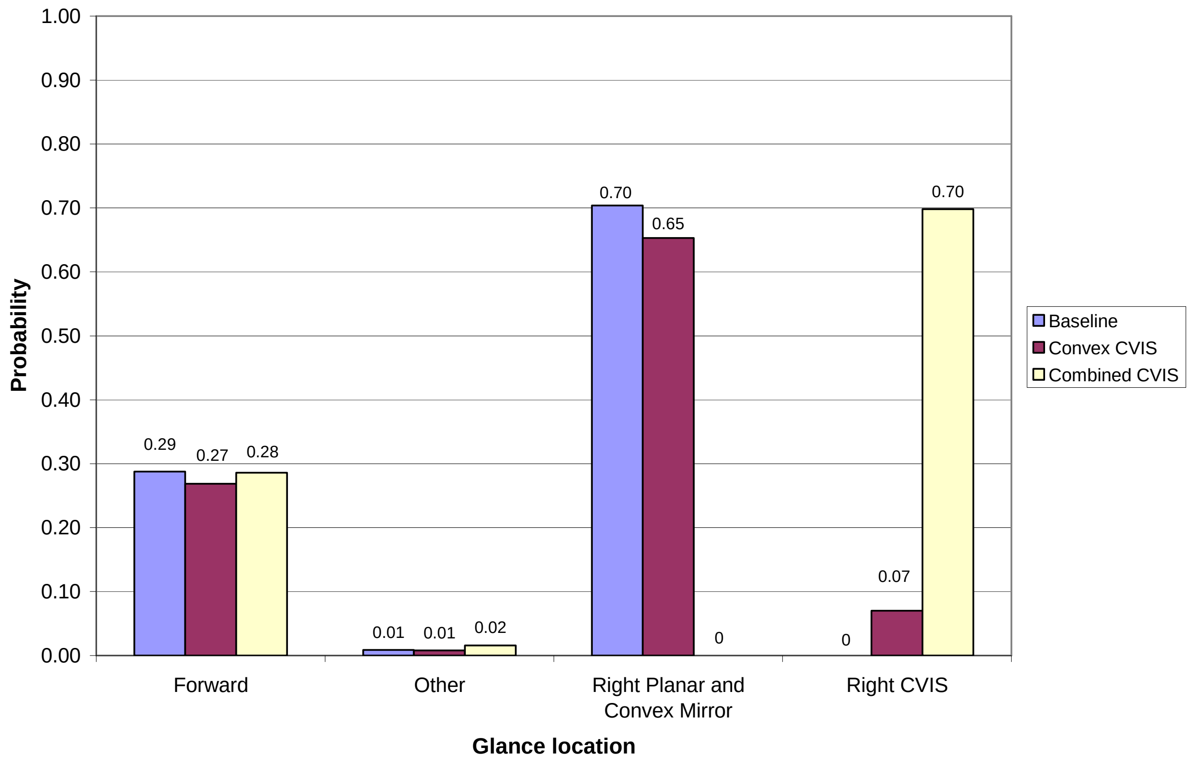

Figure 144. Glance location probabilities for the right-side clearance/overlap subtask as a function of surrogate type.

The glance diagrams show that there is very little difference in the patterns on the two sides of the vehicle. They also show that whenever the flat mirrors were available, the drivers relied heavily on them. However, in the case of the combined C/VISs, drivers had no choice and used the surrogates the same amount as the mirrors were used in the baseline situation.

Glance probabilities were also examined as a function of age group. There was only one detectable difference. In the convex C/VIS case, older subjects used the convex surrogate less (0.02) than younger subjects (0.15).

Passing/Merging Subtask Performance and Glance Analyses

In the passing/merging subtask, cut-in distance values were analyzed using a 2 x 3 x 2 repeated-measures analysis of variance for side (left or right), surrogate (baseline convex, or combined), and the nested factor age (older or younger). The analysis demonstrated a significant surrogate main effect, $F(2,80) = 3.45$, $p = 0.0366$. The results are shown in Figure 145. Note that the baseline condition produced results significantly different from the two C/VIS conditions using the post hoc Tukey HSD test. These results suggest that drivers were more conservative in their cut-in distances when one or both surrogates were present. This behavior could be a result of lack of adequate practice or, in the case of the combined surrogate, the lack of ability to judge distance as well as with mirrors.

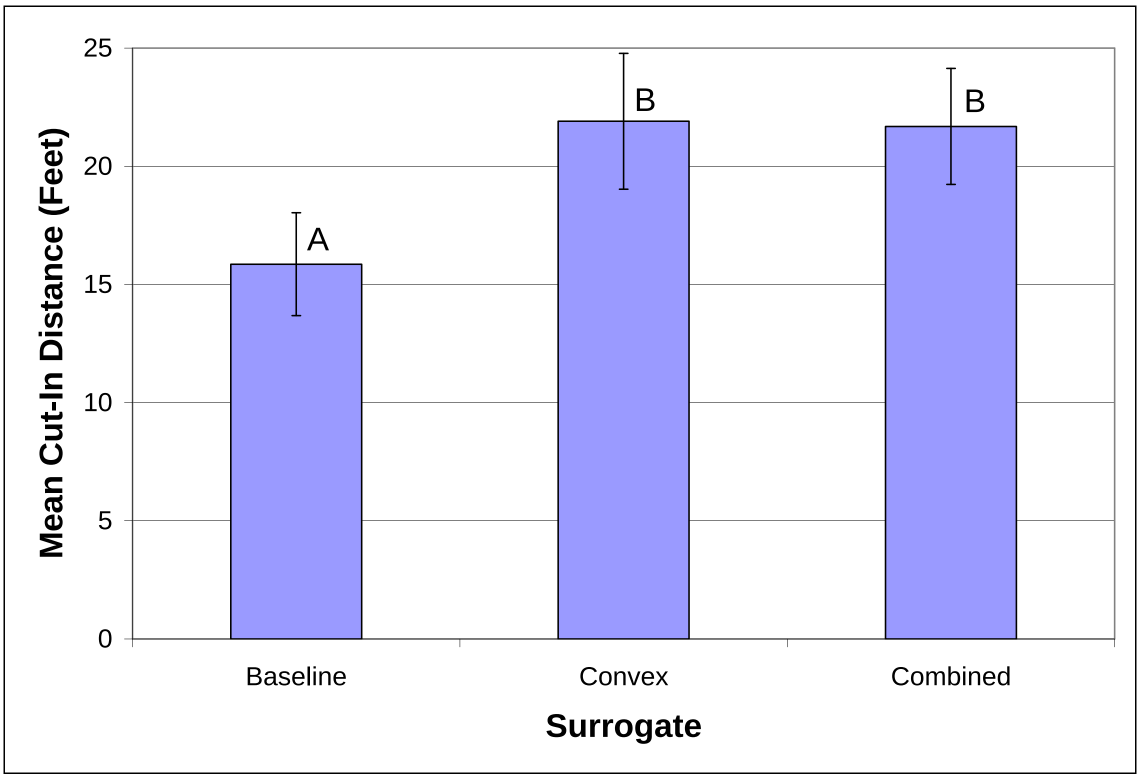

Figure 145. Mean cut-in distance as a function of surrogate for the passing/merging subtask.

The main effects of age and side were not significant and there were no significant interactions. However, the surrogate by side interaction was close with $F(2,80) = 2.92$, $p = 0.0596$. This tentative interaction is plotted in Figure 146.

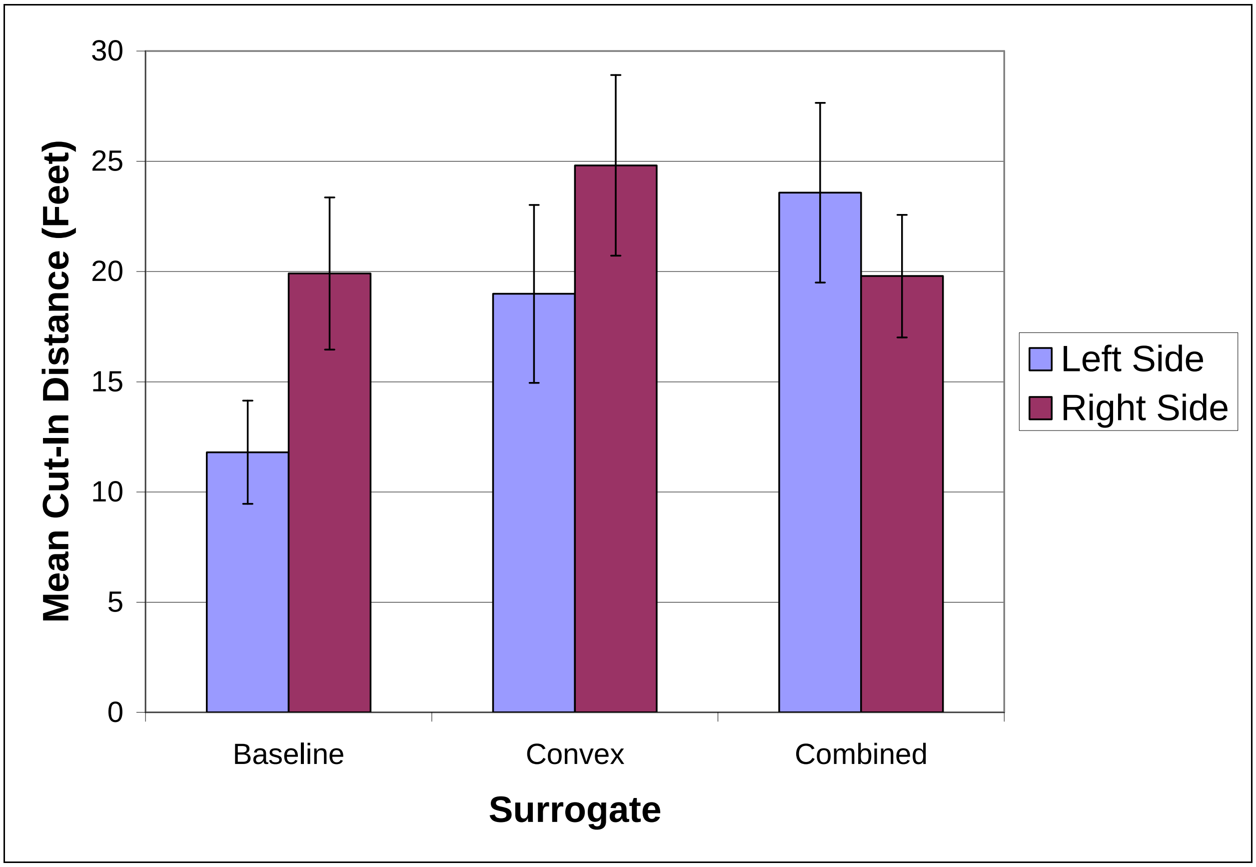

Figure 146. Tentative mean cut-in distance for surrogate by side for the passing/merging subtask (*p* = 0.0596).

Glance probabilities were analyzed for the passing/merging subtask as a function of side. The results for the left side are presented in Figure 147, and the results for the right side are presented in Figure 148. The plots are quite similar to those for the clearance/overlap subtask. Note, however, that the drivers used the convex surrogate a bit more on the right side (0.17) than they did on the left (0.04). This could be the result of the monitor providing a better view than the actual convex mirror on the right side. The right-side convex mirror is substantially angled and is also quite convex.

The glance probabilities were examined as a function of age group. The only substantial difference was in use of the convex surrogate. Younger drivers used this surrogate more than older drivers (0.18 versus 0.04).

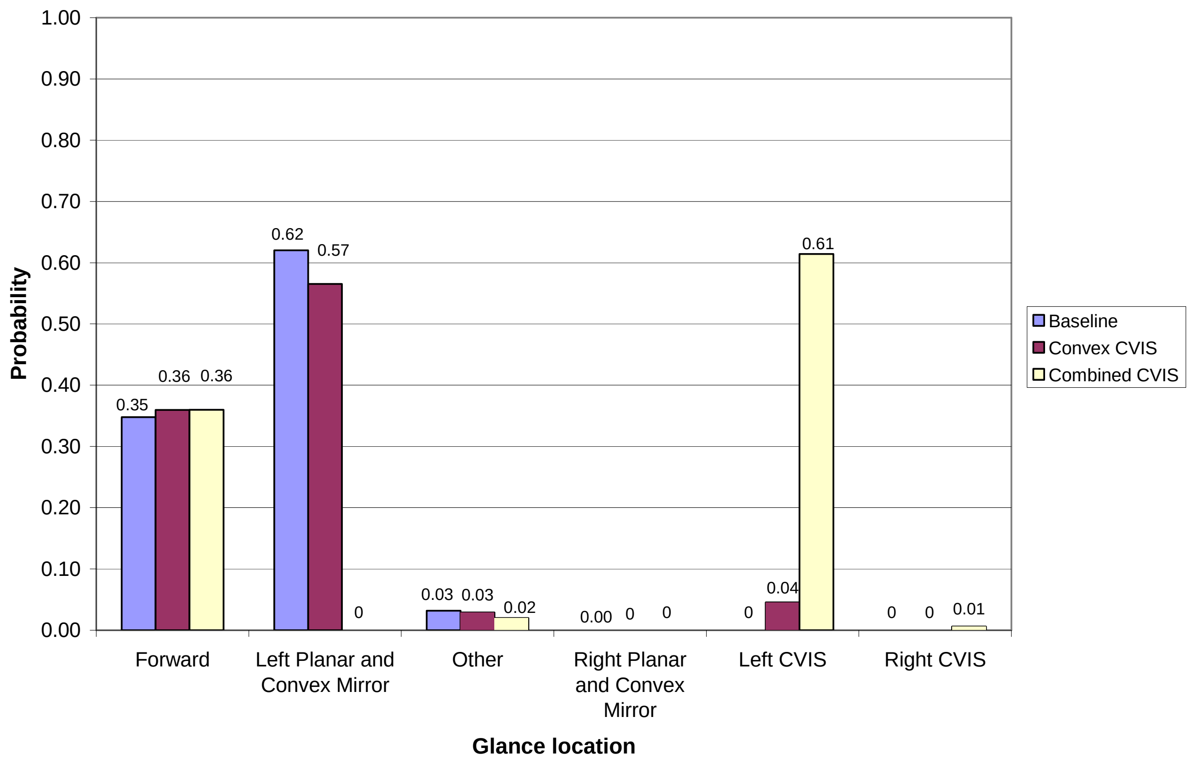

Figure 147. Glance location probabilities for the left-side passing/merging subtask as a function of surrogate type.

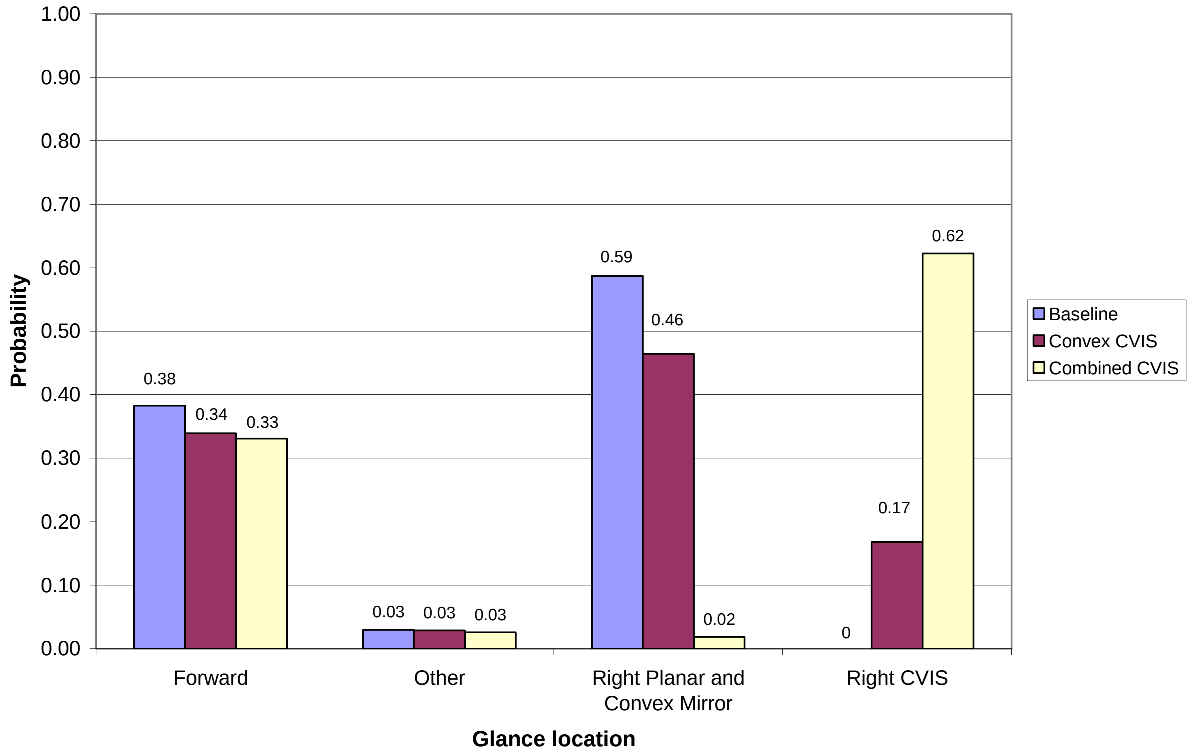

Figure 148. Glance location probabilities for the right-side passing/merging subtask as a function of surrogate type.

Tasks A (Clearance/Overlap and Passing/Merging) Opinion Data Analyses

Opinion data for ease/difficulty of performing the various maneuvers was compared for baseline, convex C/VISs and combined CVISs. The opinion ratings for the clearance/overlap task are presented in Table 63. A two-way repeated-measures analysis of variance was performed. No significant main effects (surrogate or age) or interaction were found. A Friedman test similarly did not show significant differences for surrogate.

Table 63. Opinion ratings for ease/difficulty of performing the clearance/overlap subtask as a function of surrogate.

Subject	Baseline	Convex	Combined
17	4	4	3
18	8	8	8
19	6	7	6
20	5	5	6
21	7	5	4
22	5	3	4
23	7	1	5
24	7	7	3
Mean Rating	6.125	5	4.875
Standard Error	0.479	0.824	0.611

The opinion ratings comparing baseline, convex C/VISs and combined C/VISs for the passing/merging task are presented in Table 64. Once again, no significant main effects or interactions were found. Similarly, a Friedman test for surrogate did not show significant differences.

Table 64. Opinion ratings for the ease/difficulty of performing the passing/merging subtask as a function of surrogate.

Subject	Baseline	Convex	Combined
17	6	6	5
18	8	8	8
19	6	7	7
20	5	5	6
21	9	7	7
22	7	7	4
23	1	3	9
24	9	9	5
Mean Rating	6.375	6.5	6.375
Standard Error	0.925	0.655	0.596

Following completion of Task A, drivers provided additional ratings for the convex C/VIS surrogates. Results are shown in Table 65. One-way analyses of variance on each rating question revealed that learning time between age groups was not significant, but was close $F(1, 6) = 5.17$, $p = 0.0633$. The tentative results are plotted in Figure 149. There was a significant difference in usefulness ratings between age groups, $F(1, 6) = 7.71$, $p = 0.0321$, as shown in Figure 150.

Table 65. Ratings on various scales for the convexsurrogate, taken after completing the clearance/overlap and passing subtasks (Task A).

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
17	6	6	6	6
18	2	3	5	3
19	8	7	7	7
20	6	5	3	7
21	5	7	5	4
22	3	3	7	7
23	7	7	9	7
24	3	7	3	7
Mean Rating	5.00	5.63	5.63	6.00

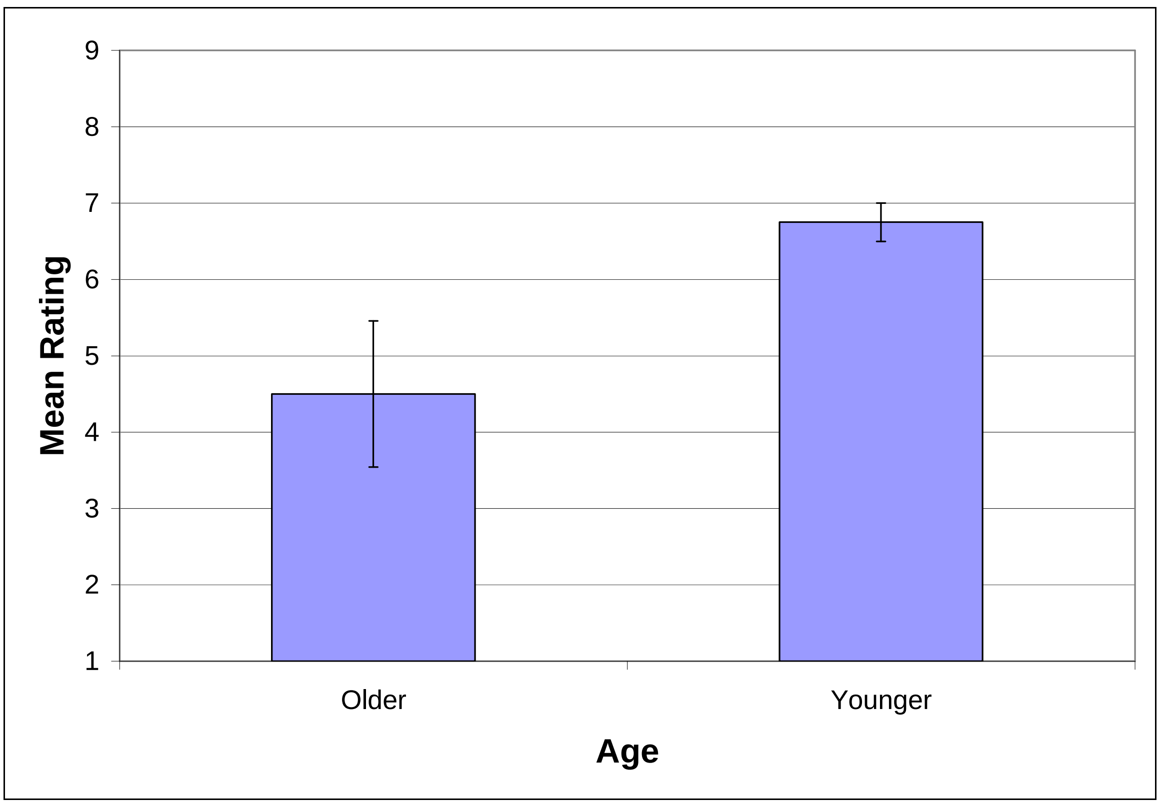

Figure 149. Tentative age difference in learning time ratings for the convex C/VIS (*p* = 0.0633) for Task A.

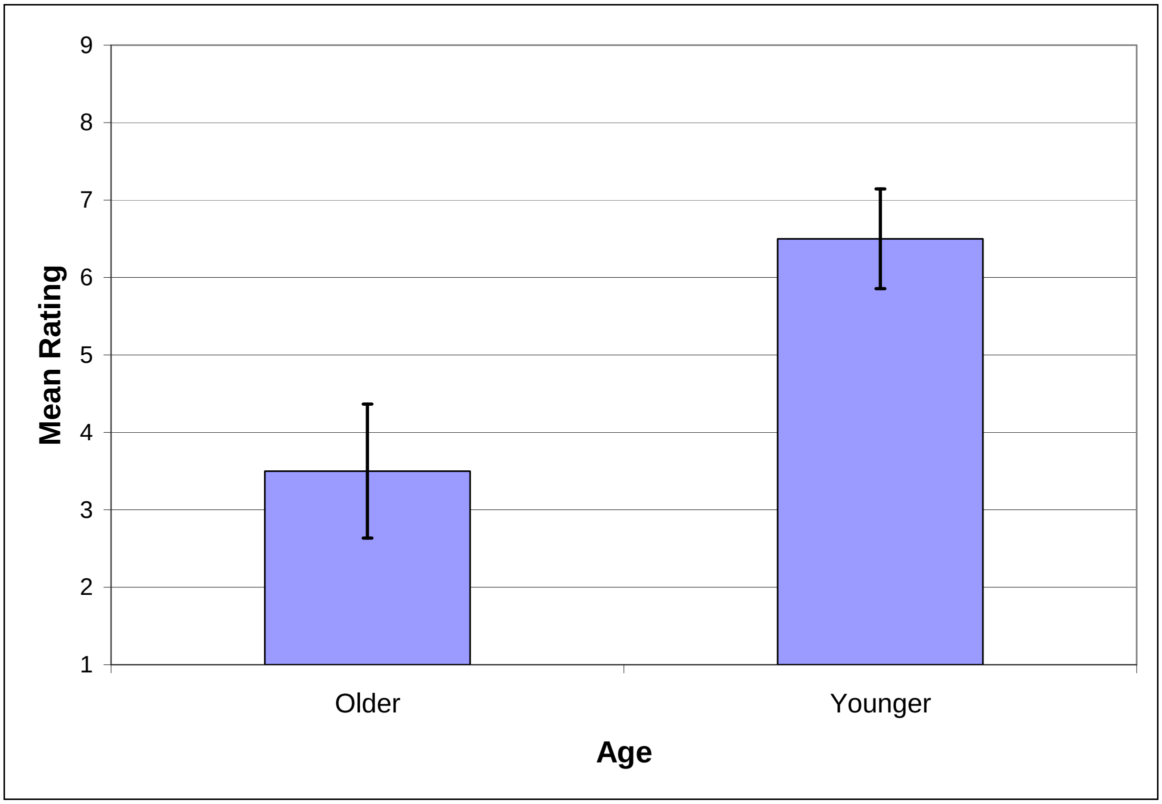

Figure 150. age difference in usefulness ratings for the convex C/VIS, for Task A.

Drivers completed additional ratings for the combined C/VISs. Results are shown in Table 66. One-way analyses of variance on each rating question revealed that there were no significant differences between age groups.

Table 66. Ratings on various scales for the combined C/VIS surrogates, taken after completing the clearance/overlap and passing subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
17	5	5	5	6
18	7	7	7	7
19	6	6	7	8
20	5	5	7	7
21	4	6	4	3
22	6	3	6	7
23	9	7	9	7
24	5	7	3	7
Mean Rating	5.88	5.75	6.00	6.50

TASK B (BACKING SUBTASKS) RESULTS

Backing (to a parked car) Subtask Performance and Glance Analyses

As mentioned previously, in the parking subtask, the instructions to the driver indicated that the final position of the trailer should be "5 feet from the front bumper of the car.". Initially, task completion times between baseline, convex surrogate, and combined surrogate were compared. The results are presented in Table 67 by driver. A two-way repeated-measures analysis of variance on task completion times with surrogate and the nested factor age as independent variables revealed that there was a significant surrogate main effect, $F(2, 12) = 14.61$, $p = 0.0006$. The age main effect and the surrogate by age interaction were not significant.

Results for the main effect of surrogate are plotted in Figure 151. The Tukey HSD post hoc test revealed that the combined C/VIS completion time was significantly longer than the baseline and convex C/VIS times. Note that the combined C/VIS was the only configuration in which the west coast (flat) mirrors were not available for use.

Table 67. Task completion times (seconds) for the parking subtask.

Subjects	Baseline	Convex	Combined
17	102	135	237
18	105	74	136
19	113	119	115
20	163	179	300
21	142	87	115
22	115	71	225
23	91	113	168
24	119	85	253
Mean Completion Time	118.75	107.88	193.63
Standard Error	8.22	12.96	24.66

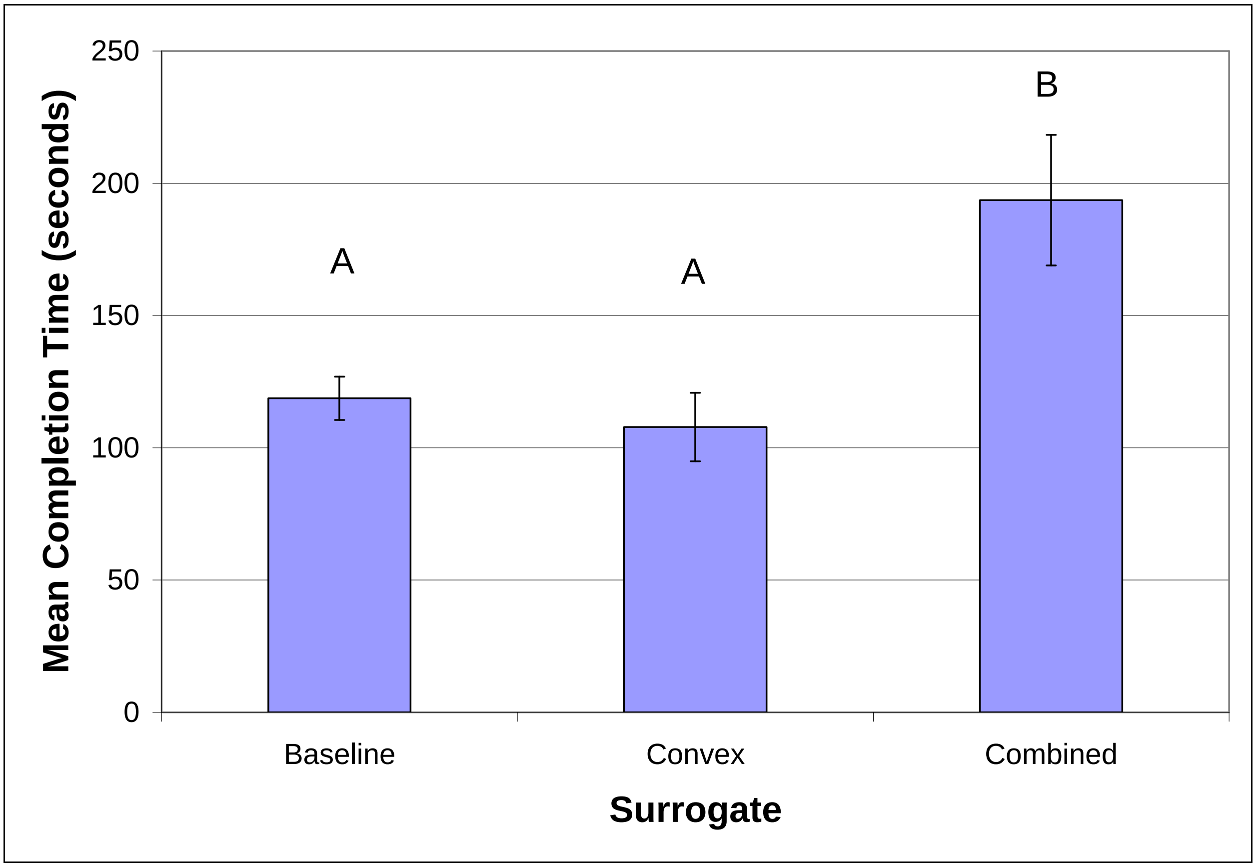

Figure 151. Mean task completion time as a function of surrogate for the parking subtask.

In regard to final position in the parking task, the distance from the end of the trailer to the front bumper of the automobile was measured and recorded. Table 68 shows the measurements as a function of surrogate. The results were analyzed using a two-way repeated-measures analysis of variance with surrogate and the nested factor age as the independent variables. A significant surrogate main effect was found $F(2, 12) = 4.85$, $p = 0.0286$. The results are plotted in Figure 152. There was no significant age main effect or surrogate by age interaction.

The main effect of surrogate was further analyzed using a Tukey HSD test. The results (Figure 152) indicate that the final positions differed significantly for the convex surrogate and the combined surrogate. This suggests that either drivers were more inaccurate in using the west coast surrogate or they were more conservative (since their final positions were farther away from the parked car with the west coast surrogate).

Table 68. Final position distances (inches) for the parking subtask as a function of surrogate.

Subjects	Baseline	Convex	Combined
17	120	103	93
18	154	121	92
19	55	55	173
20	76	67	78
21	185	86	211
22	116	39	81
23	56	5	169
24	40	18	148
Mean Distance	100.25	61.75	130.63
Standard Error	18.39	14.35	18.01

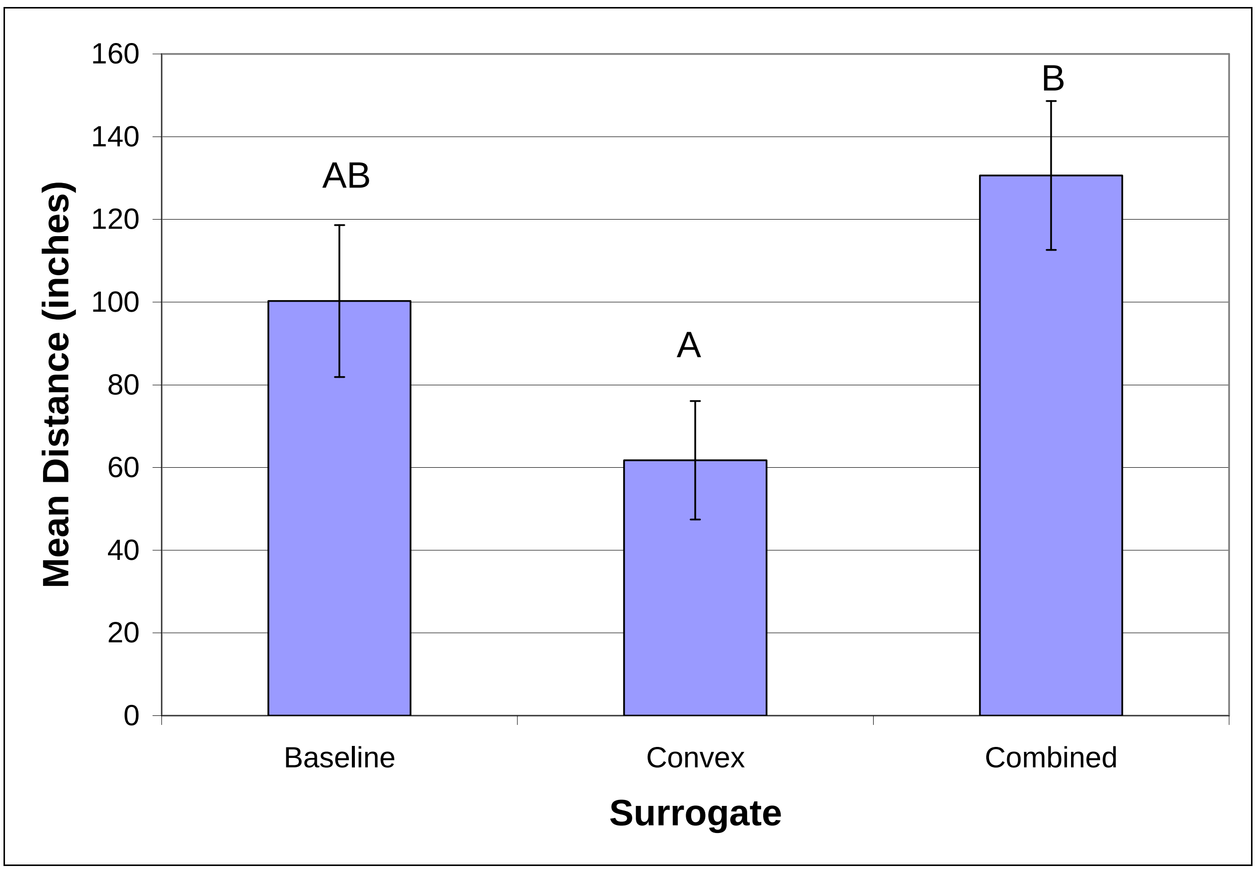

Figure 152. Final position distances (inches) for the parking subtask as a function of presence/absence of the convex and combination C/VIS surrogates.

It should be mentioned that one driver in the convex C/VIS condition struck the structure in front of the bumper of the automobile. This released the brake and caused the automobile to move about 6.5 in (16.5 cm) to the rear. Since the bumper itself was not struck, the measurement of final position was taken from the original position of the automobile.

The final position distances (absolute error) from the 5 ft (1.52 m) goal for the parking subtask as a function of surrogate are shown in Table 69. The results were analyzed using a two-way repeated-measures analysis of variance with surrogate and the nested factor age as the independent variables. There was no significant surrogate or age main effect. The surrogate by age interaction was also not significant.

Table 69. Absolute error (inches) from the 5 ft goal for the parking subtask as a function of surrogate.

Subject	Baseline	Convex	Combined
17	60	43	33
18	94	61	32
19	5	5	113
20	16	7	18
21	125	26	151
22	56	21	21
23	4	55	109
24	20	42	88
Mean Distance	47.50	32.50	70.63
Standard Error	15.72	7.44	18.01

The data were then analyzed with a Friedman (non-parametric) test for a surrogate main effect. The results were not significant.

Glance data for the last 30 s of the backing (to a parked car) subtask were analyzed to obtain glance probabilities for the three conditions: baseline, convex C/VIS, and combined C/VIS. The results are shown in Figure 153. The plot shows that when mirrors were available they were much more heavily relied upon, especially for the right-side mirrors. However, when drivers were required to use the combined C/VISs on the left and right, they used the right combined C/VISs much more than the left. This is probably a result of the initial approach being from the left, which put the car in view for the right mirrors and right C/VISs.

Glance patterns were also examined separately for younger and older drivers. They were found to be quite similar, except in the combined C/VIS condition. Younger drivers relied heavily on the right combined C/VIS (0.81), while older drivers relied almost exclusively on the right combined C/VIS (0.99).

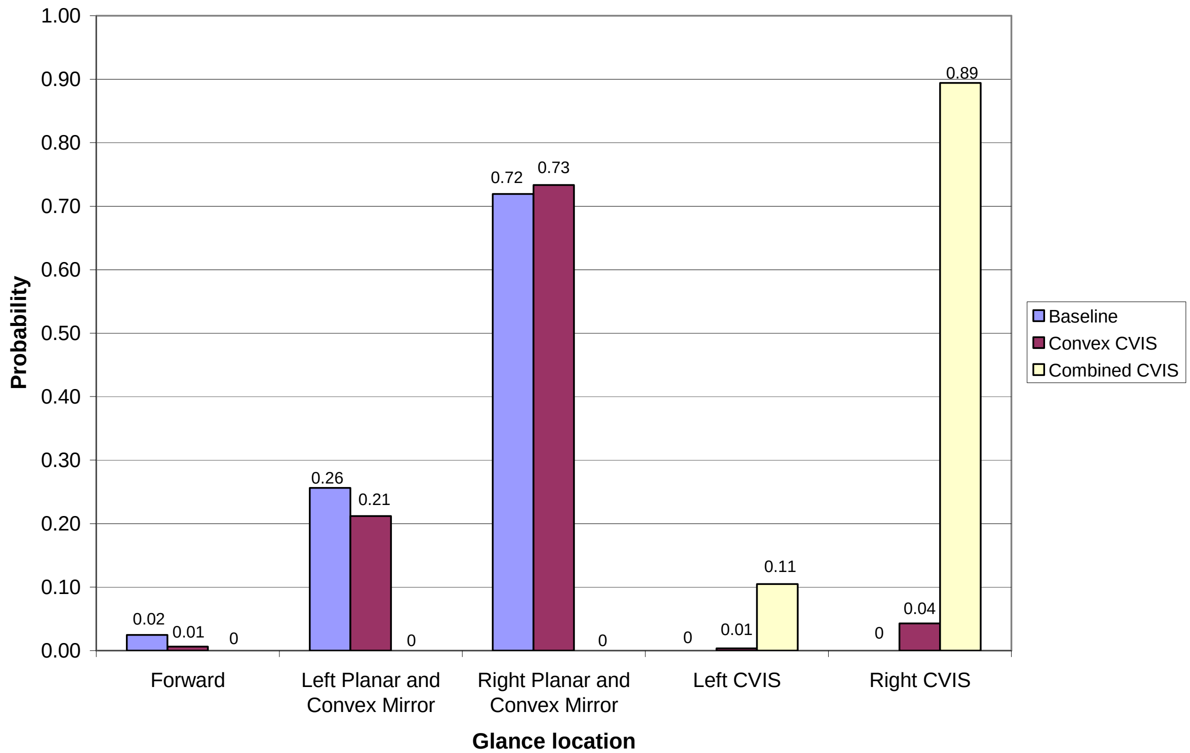

Figure 153. Glance location probabilities as a function of surrogate for the backing (to a parked car) subtask.

Loading Dock Subtask Performance and Glance Analyses

The task completion times for the loading dock backing subtask are shown in Table 70. A two-way repeated-measures analysis of variance on task completion time with surrogate and the nested factor age as independent variables revealed that there was a significant surrogate main effect, $F(2, 12) = 8.32$, $p = 0.0054$. There was no significant age main effect or surrogate by age interaction. The surrogate main effect is plotted in Figure 154. The Tukey post hoc test demonstrated a significant difference between the combined C/VIS and the other two conditions; that is, baseline and convex C/VIS. This result provides reasonably clear evidence that removal of the flat mirror creates problems in backing tasks.

Table 70. Task completion times (seconds) for the loading dock backing subtask as a function of surrogate.

Subjects	Baseline	Convex	Combined
17	104	93	128
18	55	47	119
19	103	79	106
20	94	139	102
21	64	67	85
22	59	46	121
23	60	60	94
24	55	51	147
Mean Completion Time	74.25	72.75	112.75
Standard Error	7.77	11.09	7.07

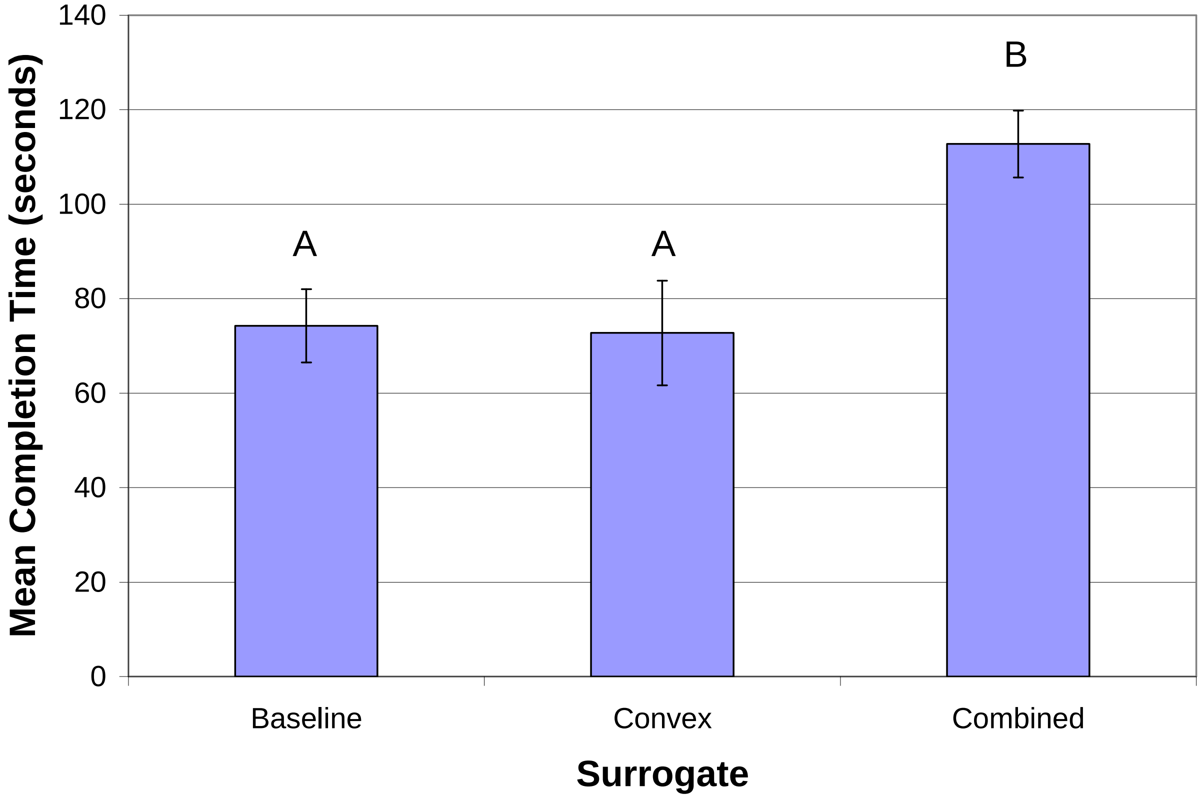

Figure 154. Task completion times for the loading dock backing subtask as a function of surrogate.

The closest distances from the trailer to the loading dock are shown in Table 71. The results were analyzed using a two-way repeated-measures analysis of variance with surrogate and the nested factor age as the independent variables. There was no significant surrogate or age main effect. The surrogate by age interaction was also not significant.

Table 71. Final position distances (inches) for the truck loading dock backing subtask.

Subjects	Baseline	Convex	Combined
17	49	40	11
18	49	64	0.5
19	16	19	38
20	29	114	67
21	41	23	128
22	19	8	36
23	23	44	34
24	37	41	-22
Mean Distance	32.88	44.13	36.56
Standard Error	4.62	11.72	16.19

The absolute errors in trailer distances from the "one foot from loading dock" goal are shown below in Table 72. The results were analyzed using a two-way repeated-measures analysis of variance with surrogate and the nested factor age as the independent variables. There was no significant surrogate or age main effect. The surrogate by age interaction was also not significant.

Table 72. Absolute error (inches) from the one foot goal for the loading dock backing subtask.

Subjects	Baseline	Convex	Combined
17	37	28	1
18	37	52	11.5
19	4	7	26
20	17	102	55
21	29	11	116
22	7	4	24
23	11	32	22
24	25	29	34
Mean Distance	20.88	33.13	36.19
Standard Error	4.62	11.31	12.70

Eyeglance data for the last 30 s of the loading dock subtask were analyzed to obtain glance probabilities for all conditions: baseline, convex C/VISs, and combined C/VISs. The results are shown in Figure 155. The plot shows that when mirrors were available, the left mirrors were heavily used. On the other hand, when the mirrors were not available, the drivers used the left and right C/VISs approximately equally. The results suggest that the flat mirrors in particular were heavily relied on in the loading dock task. In fact, for the convex C/VIS runs, the C/VISs were essentially not used at all.

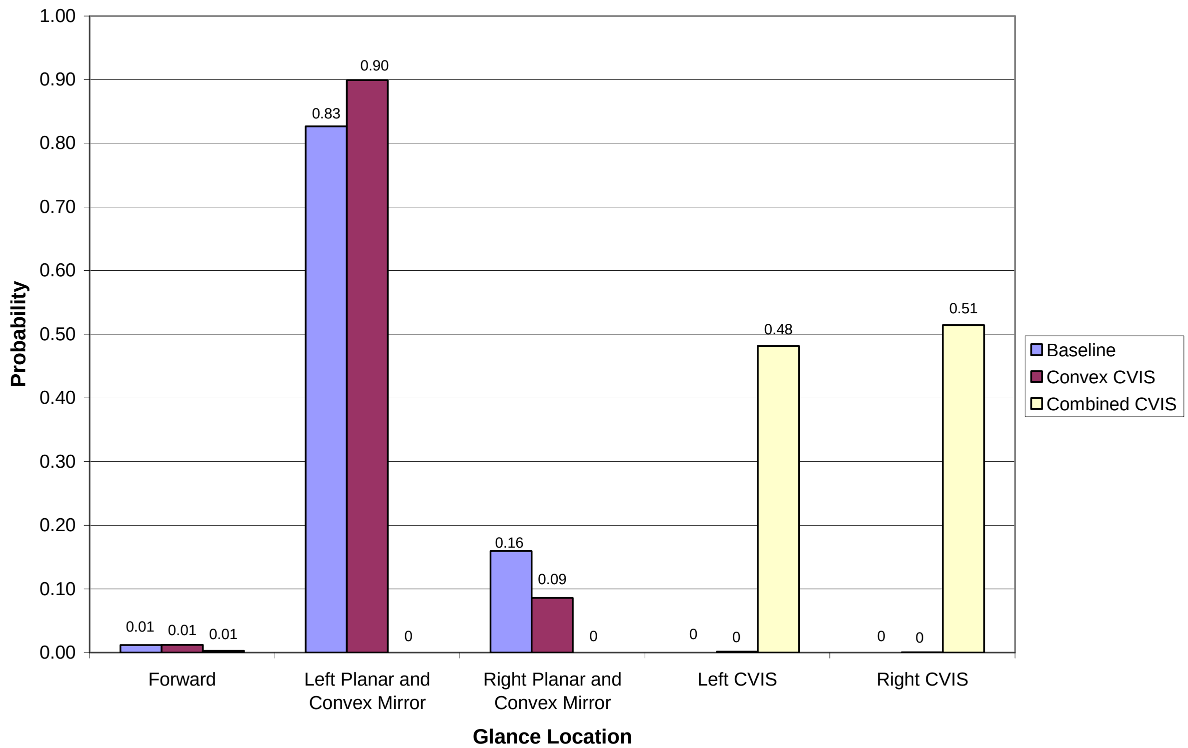

Figure 155. Glance location probabilities for the loading dock subtask as a function of surrogate.

The glance location probabilities were also analyzed by age group. Figures 156 and 157 show the results. The plots show that for the combined C/VIS condition, younger drivers relied heavily on the left C/VISs while older drivers relied heavily on the right C/VISs. Also, in the convex C/VIS condition, older drivers favored the left mirror a bit more than younger drivers.

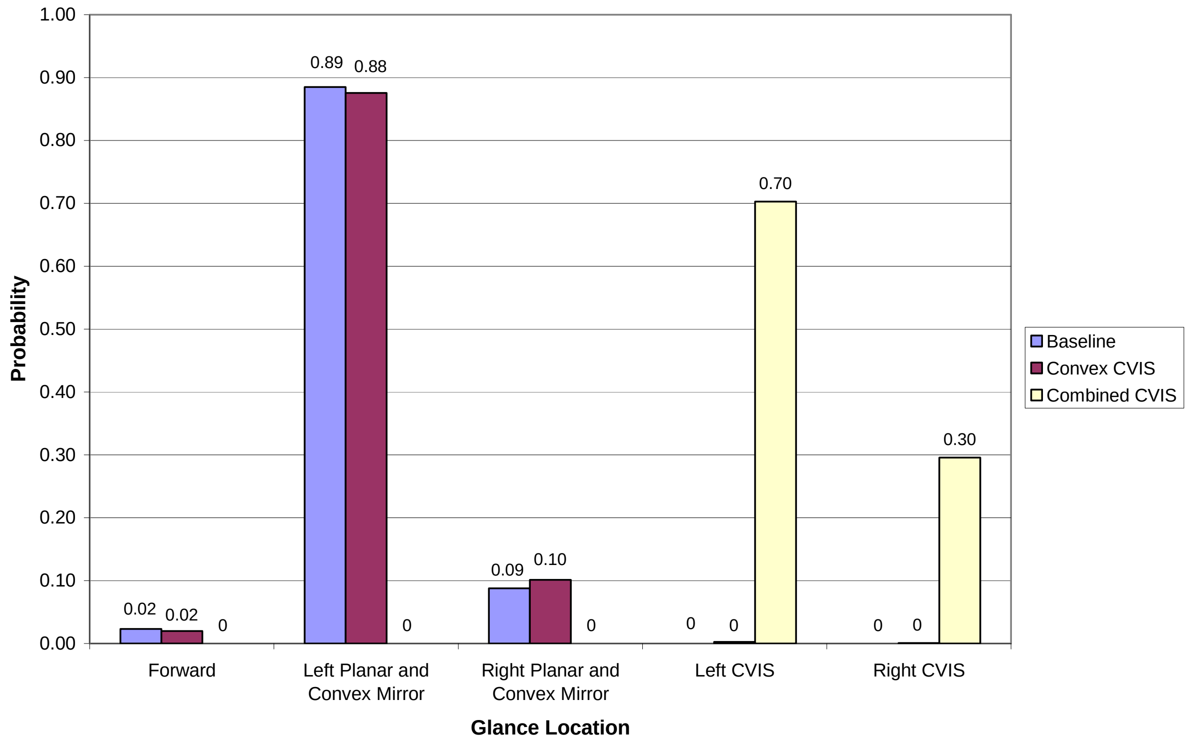

Figure 156. Glance location probabilities for the loading dock subtask as a function of surrogate for the younger drivers.

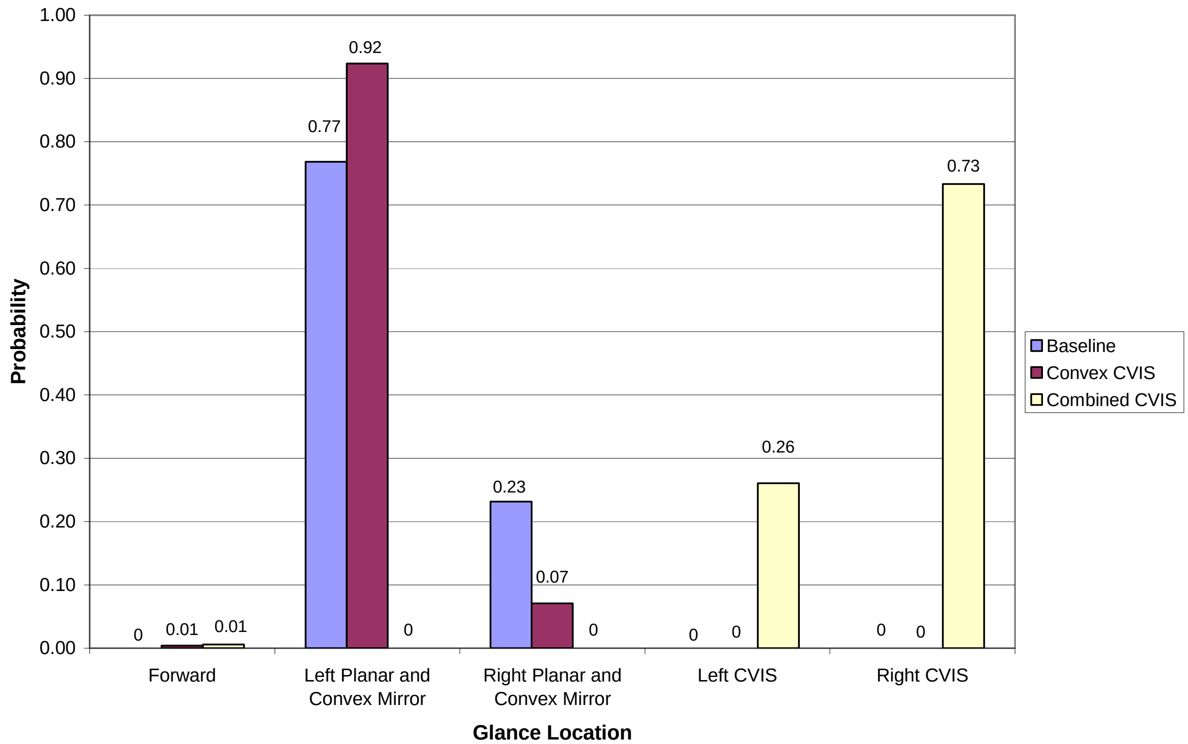

Figure 157. Glance location probabilities for the loading dock subtask as a function of surrogate for the older drivers.

S-curve Backing Subtask Performance and Glance Analyses

The S-curve subtask results were analyzed using several measures that would indicate the "quality" of the S-curve maneuver by the driver. The first analysis was for task completion times. Table 73 shows the task completion times in seconds. A two-way repeated-measures analysis of variance on task completion times for surrogate and the nested factor age revealed that there was a significant surrogate main effect, $F(2, 12) = 4.66$, $p = 0.0318$. There was no significant age main effect and no significant surrogate by age interaction. Post hoc Tukey HSD tests indicated that the combined C/VIS had significantly longer task completion times than either the baseline or the convex C/VIS conditions, as shown in Figure 158.

Table 73. S-curve subtask completion times in seconds as a function of surrogate.

Subjects	Baseline	Convex	Combined
17	118	95	113
18	106	56	105
19	107	122	137
20	278	300	300
21	74	84	105
22	85	63	147
23	68	75	94
24	67	55	253
Mean Completion Time	112.88	106.25	156.75
Standard Error	24.56	28.79	27.22

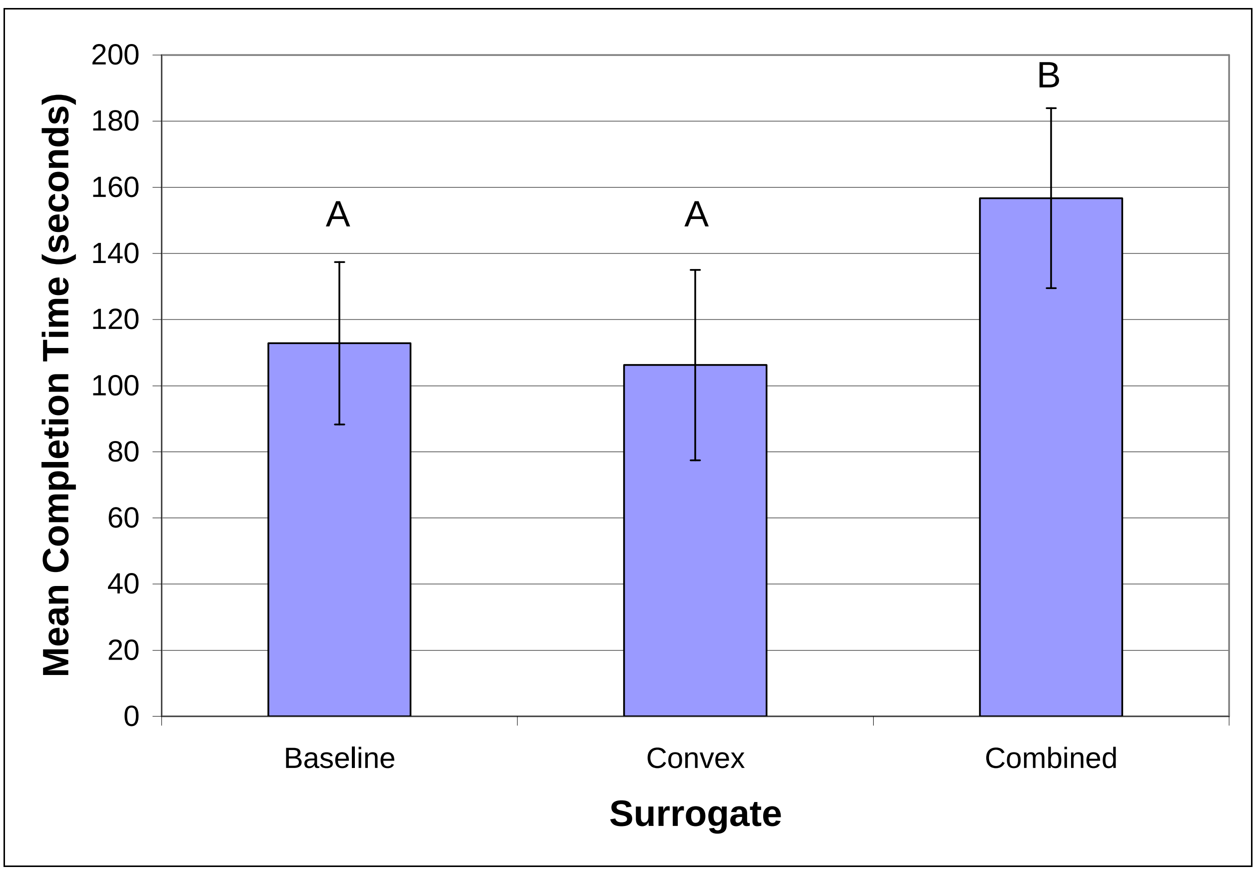

Figure 158. Task completion times for the S-curve backing subtask as a function of surrogate.

The number of direction (forward/backward) reversals by each driver was also analyzed. Table 74 shows the results. A Friedman test on the data in the table indicated that there were no statistically significant differences among the surrogate conditions. To investigate age effects, the data were arranged categorically such that drivers either reversed or they did not. A one-way Kruskal-Wallace test revealed that there were no age-related performance differences among the surrogate conditions.

Table 74. Number of direction reversals in the S-curve subtask as a function of surrogate.

Subjects	Baseline	Convex	Combined
17	2	0	0
18	0	0	0
19	0	0	2
20	6	10	6
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	4
Total Number of Reversals	8	10	12

The number of barrels struck in the S-curve task was also investigated. Table 75 shows the total number of barrels struck by each driver. A Friedman test indicated that differences as a function of surrogate were not significant. A one-way chi-square test indicated that age was not significant.

Table 75. Number of barrels struck in the S-curve subtask as a function of surrogate.

Subjects	Baseline	Convex	Combined
17	0	0	0
18	4	0	0
19	0	1	0
20	5	4	2
21	0	0	0
22	0	0	0
23	0	4	4
24	0	0	0
Total Number of Barrels Struck	9	9	6

Glance data from the time that the back end of the trailer passed a line between the first two barrels to the time that the trailer passed a line between the last two barrels were used to calculate glance probabilities. The results are shown in Figure 159. The results suggest that drivers relied heavily on their mirrors when they were available. When the mirrors were not available (combined C/VIS), the drivers relied more heavily on the right-side C/VISs than on the left-side C/VISs.

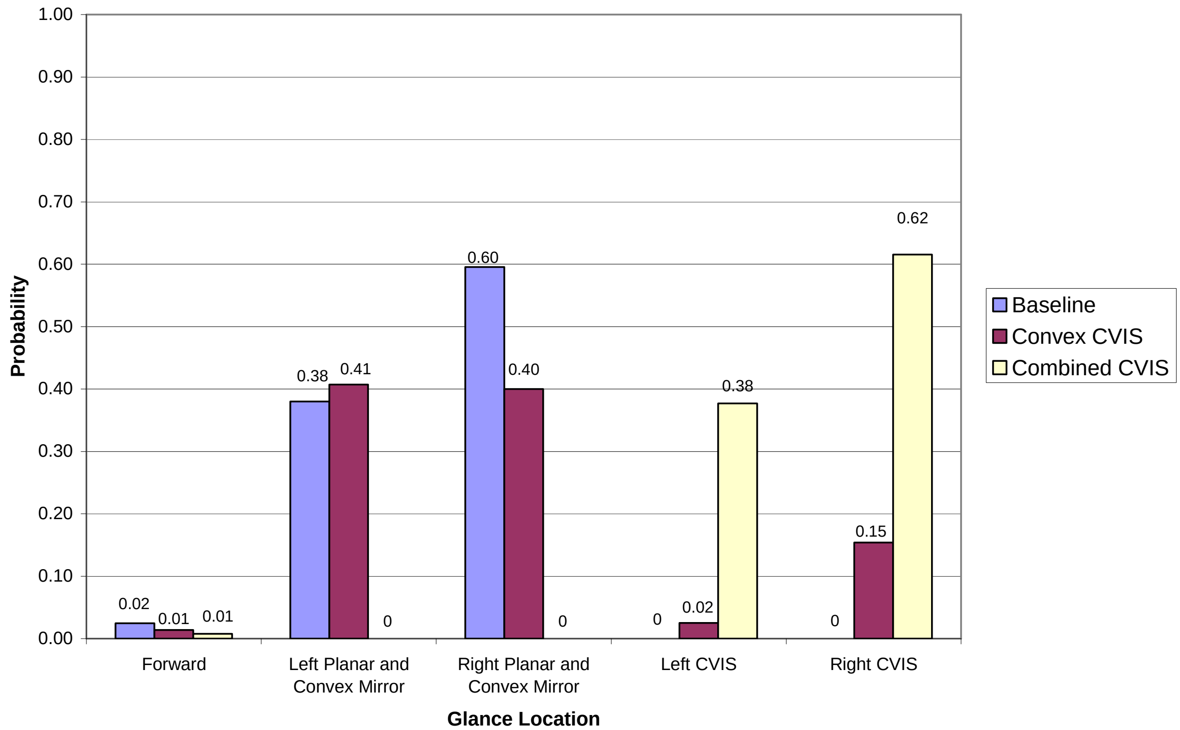

Figure 159. Glance location probabilities for the S-curve subtask as a function of surrogate.

The glance location probabilities were then analyzed by age group. The plots were similar, except that older drivers favored their right C/VISs in the combined C/VIS condition (0.68, right versus 0.31, left) whereas younger drivers were more balanced (0.53, right versus 0.47, left).

Task B (Backing Subtasks) Opinion Data

The opinion ratings regarding ease/difficulty of performing the parking (to a parked car) subtask as a function of surrogate are presented in Table 76. A two-way repeated-measures ANOVA revealed no significant main effects (surrogate or Age) or interaction. A Friedman test for surrogate similarly did not indicate significant differences.

Table 76. Individual ratings for the scale: How difficult/easy was the parking subtask?

Subject	Baseline	Convex	Combined
17	7	7	3
18	7	7	7
19	7	8	7
20	3	5	4
21	3	4	3
22	3	5	3
23	3	3	5
24	9	9	3
Mean Rating	5.25	6	4.375
Median	5.00	6.00	3.50

The opinion data comparing the ease/difficulty of performing the loading dock subtask as a function of surrogate are shown in Table 77. A two-way repeated-measures ANOVA found no significant main effects (surrogate or age) and no significant interaction. The Friedman (nonparametric) test similarly found no significant difference as a function of surrogate.

Table 77. Individual ratings for the scale: How difficult/easy was the loading dock subtask?

Subject	Baseline	Convex	Combined
17	7	7	3
18	5	7	7
19	8	8	7
20	3	5	4
21	7	7	6
22	7	7	5
23	5	7	7
24	9	9	5
Mean Rating	6.375	7.125	5.5
Median	7.00	7.00	5.50

For the S-curve subtask, the ratings results are shown by subject in Table 78. The table shows that drivers judged the ease/difficulty to be about the same with and without the C/VISs. A two-way repeated-measures ANOVA with surrogate and the nested factor age as the independent variables showed that the opinion data ratings were not significantly different among C/VISs and baseline. Additionally, there was no significant age effect or surrogate by age interaction. The

Wilcoxon Signed Ranks nonparametric test also showed ratings as a function of surrogate not to be significant.

Table 78. Individual ratings for the scale: How difficult/easy was the S-curve subtask?

Subject	Baseline	Convex	Combined
17	7	7	3
18	3	7	7
19	8	4	8
20	3	1	2
21	5	5	4
22	5	5	3
23	7	7	3
24	9	9	3
Mean Rating	5.875	5.625	4.125
Median	6.00	6.00	3.00

Drivers completed additional ratings for the convex C/VIS surrogates. Results are shown in Table 79. One-way analyses of variance on each rating question revealed that differences in learning time between age groups were not significant, $F(1, 6) = 5.17$, $p = 0.0633$, but were close. Older drivers gave learning time a lower mean rating than younger drivers, as shown in Figure 160.

Table 79. Ratings on various scales for the convex surrogate, taken after completing the parking, loading dock, and S-curve subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
17	6	7	7	6
18	1	5	3	2
19	8	7	8	7
20	4	3	3	3
21	3	6	3	3
22	5	3	7	5
23	3	7	9	5
24	7	7	5	7
Mean Rating	4.63	5.63	5.63	4.75
Median Rating	4.50	6.50	6.00	5.00

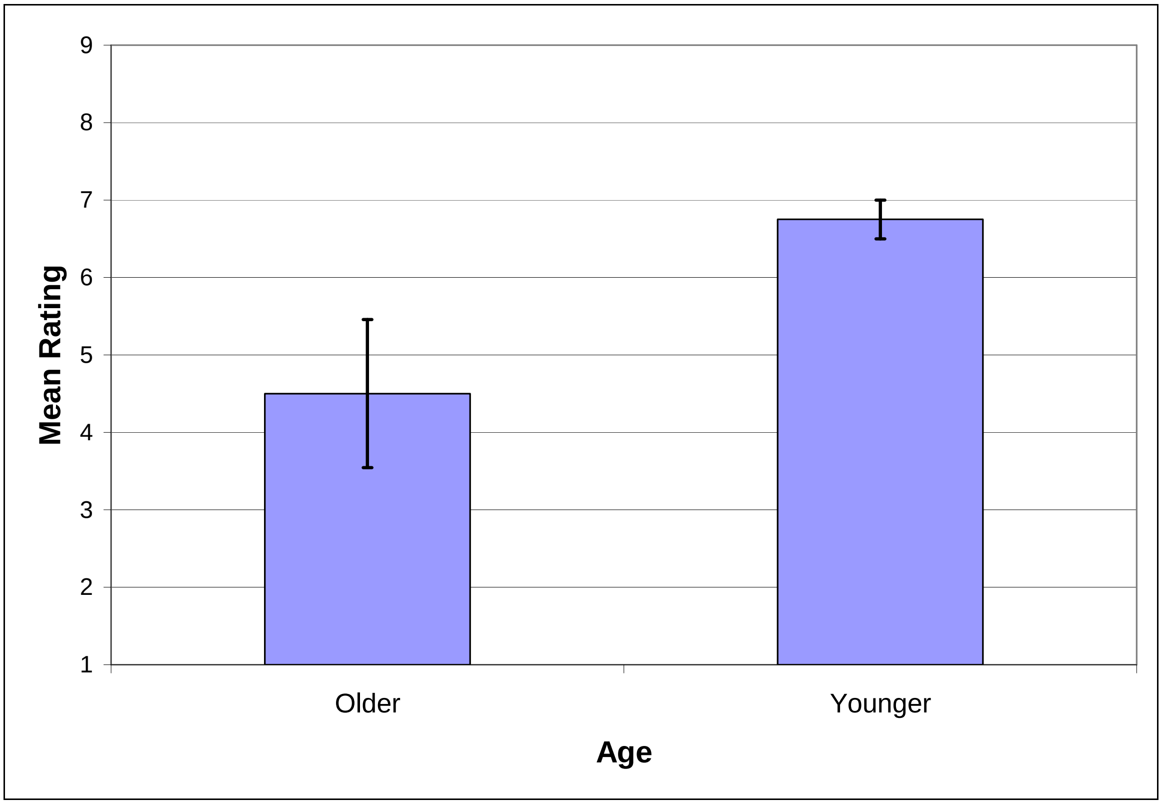

Figure 160. Tentative age effect on learning time ratings for the convex surrogate, taken after completing Task B (*p* = 0.0633).

Drivers also completed additional ratings for the combined surrogates. Results are shown in Table 80. One-way analyses of variance on each rating question revealed that there was a significant difference in usefulness ratings between age groups, $F(1, 6) = 10.57$, $p = 0.0175$. Older drivers gave lower ratings of usefulness than did younger drivers, as shown in Figure 161.

Table 80. Ratings on various scales for the combined C/VISs, taken after completing the parking, loading dock, and S-curve subtasks.

Subject	Usefulness	Learning Time	Receptiveness	Blind Spot Reduction
17	6	6	6	6
18	3	7	3	3
19	8	7	7	7
20	5	5	3	5
21	6	6	4	3
22	5	3	7	5
23	7	5	9	5
24	5	7	5	7
Mean Rating	5.63	5.75	5.50	5.13
Median Rating	5.50	6.00	5.50	5.00

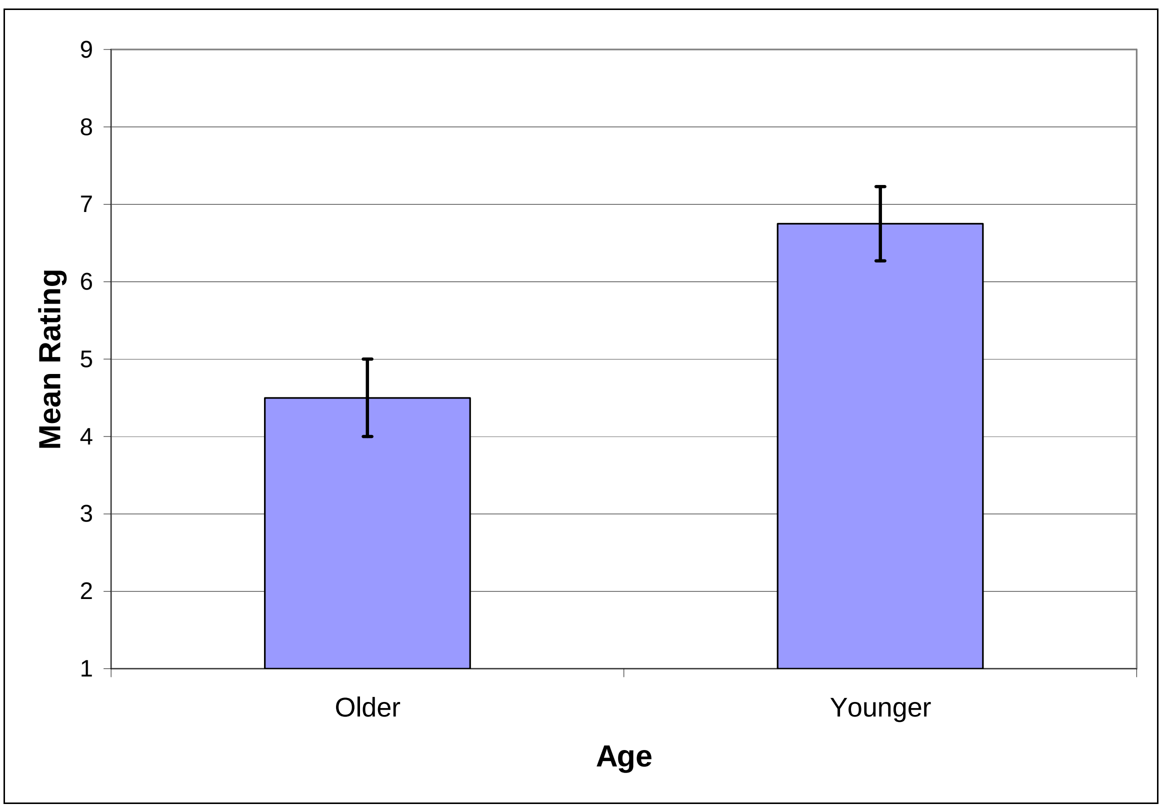

Figure 161. Age effect on usefulness ratings for the combined surrogate taken after completing Task B.

Discussion

The data, graphs, and statistical analyses presented in this chapter indicate that drivers preferred the use of their flat mirrors. When forced to use the flat mirror surrogates, as was the case for the combined C/VISs, their performance was slower and less accurate, and they became more conservative in allowing clearance during passing. Also, while the convex C/VIS condition retained the flat mirrors, drivers used the flat mirrors quite heavily. This, however, is not necessarily a criticism of the convex C/VISs. Ratings taken reflect a similar pattern. Drivers felt that learning time would be longer with the combined C/VIS and that convex and combined C/VISs did not do a lot for usefulness and for blind spot reduction, as expected.

CHAPTER 13. SELECTED PERFORMANCE COMPARISONS BETWEEN ENHANCEMENTS IN GROUPS 1 AND 2.

Comparisons were made between enhancement C/VISs appearing in Groups 1 and 2. Some of the C/VISs had overlapping capabilities, and it was considered important to compare drivers' performance using these capabilities. This type of information could be used in deciding which type of C/VIS to implement. Two sets of comparisons were made. They are presented in this chapter.

PERFORMANCE COMPARISON FOR THE MERGE/RE-MERGE ENHANCEMENTS AND THE TRAILER WIDE-ANGLE REAR MULTIPURPOSE LOOK-DOWN ENHANCEMENT FOR TASK A

The merge/re-merge enhancements were intended to help the driver determine when there was clearance or overlap with a vehicle alongside near the back end of the trailer. This enhancement was intended to take the guesswork out of determining whether clearance existed. Such an enhancement would be considered useful when the tractor-trailer driver would have to change lanes in front of the vehicle in the adjacent lane. Similarly, one function of the trailer wide-angle rear multipurpose look-down enhancement was to provide a view of the adjacent lanes at the back of the trailer for use in determining clearance. Consequently, this look-down enhancement could be used for the same purpose as the merge/re-merge enhancements.

In regard to accuracy of the clearance/overlap query by the experimenter, it was found that both types of C/VISs resulted in 100 percent accuracy, as previously reported in Chapters 8 and 10. This result is plotted in Figure 162 because it is so rare that such a result is obtained. Obviously, there is no statistically significant difference as a function of enhancement (merge/re-merge versus wide-angle rear multipurpose look-down).

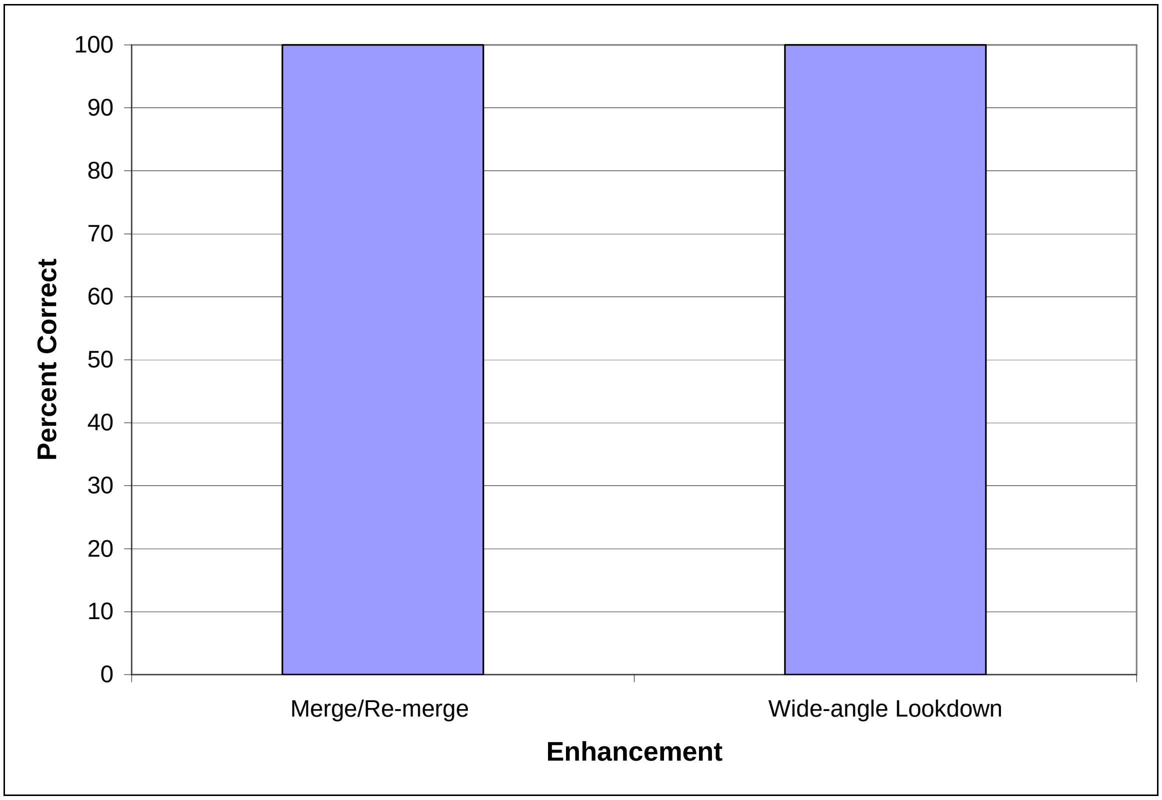

Figure 162. Accuracy of the clearance/overlap driver response as a function the type of C/VIS (differences are not significant).

Drivers also responded with an estimate of distance (amount) of clearance or overlap. These data were examined for differences using a pooled t-test. Results indicated that differences were indeed significant $t(62) = 2.678$, $p = 0.0095$. The results are plotted in Figure 163. They show that the merge/re-merge enhancement allowed more accurate estimates of distance than did the wide-angle rear multipurpose look-down enhancement. This finding could be a result of the use of 55^{o} lenses in the merge/re-merge enhancements, which provide a more "normal" looking visual scene than the wide-angle lens used in the wide-angle rear multipurpose look-down enhancement.

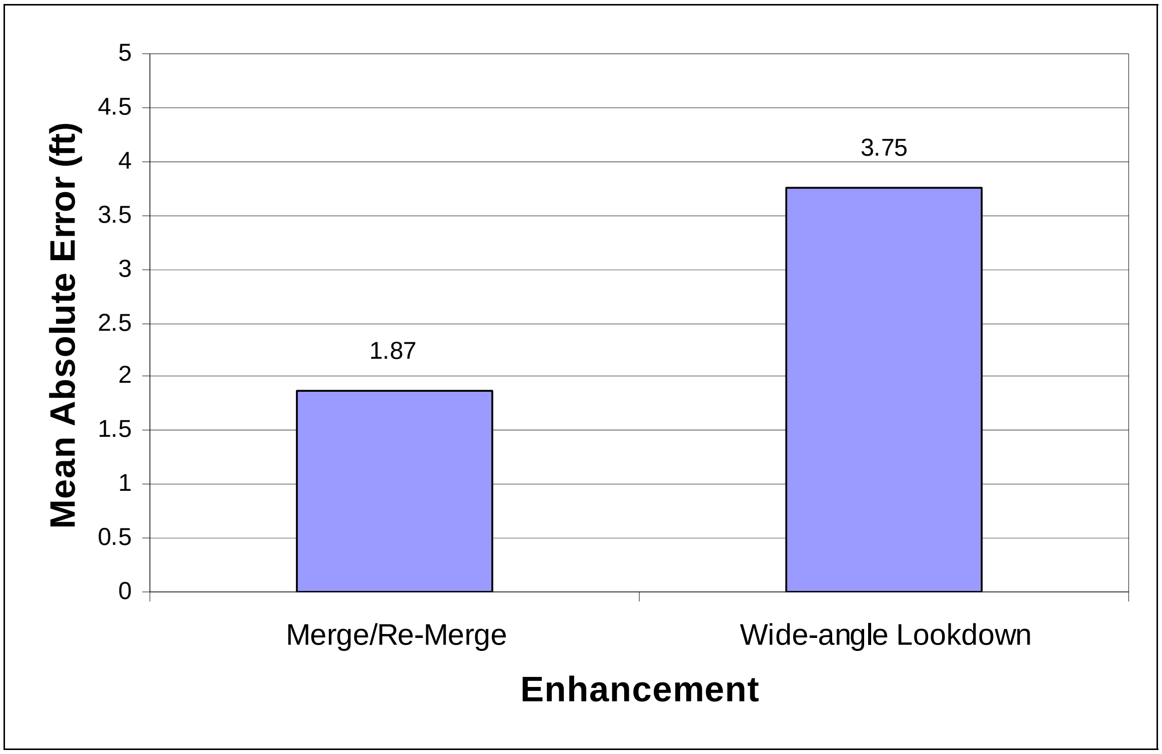

Figure 163. Comparison of distance estimate error magnitude (ft) as a function of type of C/VIS.

A comparison was also made for cut-in distances for the passing/merging on-road subtask. Cut-in distances were analyzed using a pooled t-test, with the result that differences were found not to be significant. The mean cut in distance was 13.5 ft (4.1 m).

PERFORMANCE COMPARISON FOR THE TRAILER REAR LOOK-DOWN AND THE TRAILER WIDE-ANGLE REAR MULTIPURPOSE LOOK-DOWN ENHANCEMENT FOR TASK B.

The trailer look-down enhancement was intended for backing tasks only, while the trailer wide-angle rear multipurpose look-down enhancement was intended for both backing and on-road use. These two C/VISs were compared for two of the Task B tests; that is, backing to a parked car and backing to a loading dock. The subtask of backing through an S-curve was not compared in this analysis because both C/VISs were found to be relatively ineffective for that subtask and subjects used them sparingly. For the subtasks of backing to a parked car and backing to a loading dock, the data from the experiments (see Chapters 9 and 10) were assembled and compared using pooled t-tests.

In regard to task completion times for the backing (to a parked car) task, neither enhancement differed significantly from baseline. In addition, for the two C/VISs, the mean task completion times were nearly identical: 113.5 s for the look-down enhancement (Table 17) and 111.0 s for the wide-angle rear multipurpose look-down (Table 33). A pooled t-test indicated that, as expected, the differences were not significant.

Final position differences were analyzed for the two C/VISs. (Both C/VISs were close to significance when compared to their baseline conditions.) Data for the two C/VISs were taken from Tables 18 and 34. Results of a pooled t-test indicated that differences were not significant**.** The mean final position was 45.6 in (1.16 m) from the parked car.

In regard to final position absolute error, there was significance as a function of baseline for final position absolute errors for both C/VISs (Tables 19 and 36). When backing to the parked car, the between-C/VIS comparison t-test did not result in significance for the mean absolute error in final position. This mean absolute error had a value of 25.1 in (0.64 m).

For the backing (to a parked car) subtask, the number of reversals *did* result in significance for the t-test between the two enhancements, t(14) = 2.147, $p = 0.0498$. The reversals by driver are shown in Table 81. Because the data may not meet the assumptions for parametric analysis, a nonparametric test was also run. A Kruskal-Wallace test also indicated significance, X1) = 4.68, $p = 0.0305$. As the table shows, the trailer wide-angle rear multipurpose look-down enhancement resulted in approximately twice as many direction reversals.

Table 81. Number of direction reversals in the backing (to a parked car) task as a function of enhancement.

	Trailer look-down (Group 2)	Trailer wide-angle rear multipurpose look-down (Group 1)
	2	4
	2	10
	2	4
	4	4
	2	2
	6	6
	0	4
	2	4
Mean	**2.5**	**4.75**
Median	**2**	**4**

For the loading dock backing subtask, neither enhancement differed from baseline significantly in regard to task completion times (Tables 20 and 37). When the two look-down C/VISs were compared to one another using the data in the tables, the t-test did not result in significance. Task completion time averaged 92.1 s.

In regard to final position, the look-down enhancement differed from baseline (Table 21). However the wide-angle rear multipurpose look-down enhancement did not, even though there was a substantial reduction in final position (Table 38). When the two C/VISs were compared using a t-test, the results were not significant. The two means were quite close (10.41 in, 0.264 m for the look down enhancement versus 11.94 in, 0.303 m for the wide-angle rear multipurpose look-down enhancement), so the test result was not unexpected.

Absolute errors in final position were similarly compared for the loading dock backing subtask. Data in Table 22 had shown that for the look-down enhancement the differences from baseline were not too far from significance ($p = 0.087$) using a parametric test, and a Wilcoxon test was indeed significant ($p = 0.004$). A similar finding (Table 39 and Figure 114) was obtained for the wide-angle rear multipurpose look-down enhancement with the parametric test not significant, but with the Wilcoxon demonstrating significance ($p = 0.0375$). When the two C/VISs were compared, the results did not demonstrate significance, as expected, considering that the mean values were relatively close (4.28 in, 10.9 cm for the look down enhancement, and 6.81 in, 17.7 cm for the wide-angle rear multipurpose look-down enhancement).

DISCUSSION

The results of the first set of comparisons suggest that either the merge/re-merge enhancements or the trailer wide-angle rear multipurpose look-down enhancement will "do the job" when it comes to estimating clearance or overlap. However, the merge/re-merge enhancements have the edge because they provide better estimation of distance in regard to amount of clearance or overlap. It should be noted also that the monitors for the merge/re-merge enhancements are near the mirrors, making it possible to scan the mirrors and the monitor (on the appropriate side) relatively easily.

In regard to the comparison of the backing tasks a similar statement could be made; that is, either the rear look-down enhancement or the wide-angle rear multipurpose look-down enhancement could be used. However, based on the results obtained, it appears that the wide-angle rear multipurpose look-down enhancement will result in more direction reversals. This could be caused by the larger FOV and its attendant distortion.

In general, the results of the analysis suggest that there are slight benefits to "more directed" C/VISs. In other words, the rear wide-angle rear multipurpose look-down enhancement does reasonably well, but not quite as well as the competing C/VISs that are intended for fewer and more directed applications.

CHAPTER 14: SUMMARY OF FINDINGS FOR THE FORMAL EXPERIMENTS

This chapter summarizes findings based primarily on the formal tests and corresponding results described in Chapters 7 through 13. There are numerous results, and it seems appropriate to collect them in a summary so that they can be more easily compared. This summary is organized by C/VIS and experimental group.

MERGE/RE-MERGE ENHANCEMENTS (GROUP 2 TESTS)

These enhancements are intended to help the driver determine whether or not there is clearance of a vehicle in the adjacent lane near the back of the trailer. They are intended to help the driver determine if the heavy vehicle is clear when a merge is to be performed. The enhancements are for on-road use only (corresponding to Task A). Figures 69, 70, and 71 show photos of the equipment used. The two round cameras on the outside edges of the trailer were used (Figure 69).

Formal tests (Chapter 8) demonstrated a marked improvement with the C/VISs. Clearance/overlap estimates were 100-percent correct and errors in distance of clearance or overlap were drastically reduced. Also, for the passing/merging subtask, cut-in distances were reduced by nearly 50 percent, indicating greater certainty in the position of the vehicle in the adjacent lane.

Glance analyses indicated that the drivers used the enhancements heavily, with resources taken primarily from the side mirrors. Depending on the subtask, 38 to 59 percent of the total visual resource was used glancing at the monitor. Opinion data show the equivalent of large improvements in ratings compared with baseline. In addition ratings of the enhancements themselves are quite high.

These results taken together indicate that the merge/re-merge enhancements make the driver's task easier and more accurate. Opinion ratings suggest a high level of driver acceptance.

TRAILER REAR LOOK-DOWN ENHANCEMENT (GROUP 2 TESTS)

This enhancement is intended for backing situations only and was tested accordingly (Task B). Equipment for this C/VIS is shown in Figures 69, 72, and 73. The camera at the top center of the trailer was used for this C/VIS (Figure 69). The results are reported in Chapter 9. They show that for the backing (to a parked car) subtask, the presence of the C/VIS resulted in significantly shorter final position distances, and that these distances were much closer to the 5 ft or 60 in (1.52 m) goal. Similarly, for the loading dock backing subtask, the results show that drivers significantly improved their performance with the C/VIS. Final positions averaged very close to the goal of 12 in (0.305 m) when the C/VIS was present, but were close to 4 ft (1.22 m) without it.

Glance probabilities showed that drivers used the C/VIS very heavily during these two backing tasks, close to 50 percent of the visual resource time. The ratings for the two subtasks averaged 7.4, well above the "moderate" values of 5.0. For the four ratings of the C/VIS itself, the ratings averaged 8.00, which is very high. These ratings indicate a strong level of acceptance by the drivers.

It is clear that the look-down enhancement is quite helpful in backing to a fixed object, such as a parked car or a loading dock. However, it should also be mentioned that the enhancement was not helpful in the S-curve task, an expected result.

TRACTOR BACKING/BOBTAILING ENHANCEMENT (GROUP 1 TESTS)

This enhancement is intended to serve as the equivalent of an interior rear-view mirror for a tractor. The enhancement can be used for both on-road and backing tasks, and was therefore tested in both conditions (Task A and Task B). Photos of the equipment are shown in Figures 57 through 62.

Test results for this enhancement are presented in Chapter 11. For the clearance/overlap task, there was no significant improvement in the decision of clearance or overlap over baseline. However, in regard to estimates of amount of clearance or overlap, there was a 42 percent improvement with the enhancement.

Similarly, there was no significant improvement in cut-in distance with the enhancement. However, the glance probability plots show that, for the on-road tasks, drivers used the enhancement very substantially, ranging from 0.29 to 0.45, depending on side and subtask. Apparently, drivers used the rear view in the monitor when it was available.

In regard to ratings for the on-road tests, drivers favored the C/VIS by about 1 rating value over baseline. However, they also rated the C/VIS itself at an average rating value of 7.7 across four scales. These results are well above the "moderate" value of 5, suggesting receptiveness to the backing/bobtailing enhancement.

For the backing subtasks (Task B) there was only one major performance difference between the C/VIS and baseline. In the backing-to-cones subtask, drivers had significantly smaller errors from the instructed final position. There was a 49 percent improvement in final position. Once again, for the various backing subtasks, drivers used the C/VIS extensively (0.25 to 0.35, depending on subtask). In regard to the S-curve backing task, the C/VIS did not provide improvement in performance, as expected.

In terms of ratings for the backing subtasks (Task B), drivers rated the backing (to a parked car) subtask about 1.5 rating points higher (indicating less difficulty) when the C/VIS was present, compared with baseline. Similarly, they rated about 1 point higher for the backing-to-cones subtask when the C/VIS was present. In rating the C/VIS itself, the average of ratings on the four scales was 7.6, well above the moderate value of 5, indicating a general receptiveness to the C/VIS.

TRAILER WIDE-ANGLE REAR MULTIPURPOSE LOOK-DOWN ENHANCEMENT (GROUP 1 TESTS)

As the name of this enhancement implies, this wide-angle rear multipurpose look-down enhancement is intended to perform in several types of maneuvers, some of which are on-road and some of which are for backing. Consequently, the C/VIS was tested in both Tasks A and B. The equipment for this C/VIS is shown in Figures 63 through 68. Note specifically that the monitor was placed at the upper center of the windshield so that the driver did not have a blocked view of the forward scene. Chapter 10 describes the results of the tests with this system.

For Task A, when the C/VIS was present, drivers were 100-percent accurate in determining whether there was clearance or overlap of a vehicle near the back end of the trailer in the adjacent lane. This result alone indicates that the enhancement was helpful. While performing this subtask, drivers used the C/VIS for more than 50 percent of their total glance time, with time taken from the mirrors. This high level of glance time indicates that drivers decided that the C/VIS provided better information than the mirrors for the clearance/overlap tasks.

For the passing/merging task, similar results were obtained. Drivers shortened their cut-in distances by 30 percent compared with baseline. This shortened distance is probably a result of the greater certainty associated with clearing the vehicle in the adjacent lane. Glance analyses indicated that the C/VIS was used an average of 31 percent of the total glance time, once again suggesting that drivers relied on the C/VIS when it was available.

In regard to the opinion ratings, drivers rated the clearance/overlap subtask three rating points higher when the C/VIS was present (7.38 versus 4.38). Similarly, they rated the passing/merging task 2.25 rating points higher when the C/VIS was present (7.38 versus 5.13). When rating the C/VIS itself, they had an average rating of 7.91 across four scales. All of these values indicate that the C/VIS was easy to use and that it was quite well-liked for use in the Task A subtasks.

For Task B, the backing (to a parked car) subtask showed that mean parking position was closer to the 60 in (1.524 m) goal when the C/VIS was available. Glance data indicated drivers used their C/VIS 37 percent of the available visual resource time, with that time taken from the mirrors. For the loading dock backing subtask, final position mean absolute error from the 1 ft (30.5 cm) goal was substantially smaller with the C/VIS than without it (6.81 versus 30 in; 17.3 versus 76.2 cm). Glance analysis for the loading dock task indicated that drivers used the C/VIS when it was available 33 percent of the total time. All of these data indicate that drivers were able to use the C/VIS successfully.

In regard to the S-curve backing subtask, the C/VIS provided no detectable help, as anticipated. Glance analyses show that the C/VIS was used very little for this subtask.

Opinion data for the Task B subtasks were quite favorable. For the backing to a parked car subtask, mean driver ratings were 2.5 rating points higher (7.00 versus 4.50). Similarly, for the loading dock subtask, ratings were 2.62 points higher (7.50 versus 4.88). When queried regarding the C/VIS itself, the additional four ratings averaged 7.78, indicating a high level of acceptance.

These results, overall, suggest that the trailer wide-angle rear multipurpose look-down enhancement was quite useful in both the Task A subtasks as well as the Task B subtasks and that it was well accepted. Therefore, this enhancement can be recommended as viable.

CONVEX MIRROR SURROGATES (GROUP 3 TESTS)

These surrogates replaced the convex mirrors on each side of the tractor. Tests were performed on both sides of the vehicle, as described in Chapter 12, with the Peterbilt tractor and trailer. The C/VIS equipment used is shown in Figures 74 through 79. However, only the upper monitors were activated and the flat mirrors were uncovered for these tests. Similarly, only the round cameras mounted at the front fenders were used. Note that the photos shown in Figures 74 though 79 show the setup for the combined C/VIS condition. To obtain the convex C/VIS condition, it was only necessary to deactivate the larger (lower) monitors and uncover the flat mirrors. Baseline was obtained by deactivating all monitors and *uncovering* all mirrors.

The reporting of summary results for surrogates should be prefaced with certain statements of caution. Note that the convex mirror surrogates *replaced* the actual convex mirrors. Consequently, it would be expected that if the surrogates worked well, performance results should be similar. It would be unlikely that superior results would be obtained for surrogates. All previous C/VIS analyses summarized in this chapter were for enhancements, which were intended to make the driver's task performance easier and more accurate. The surrogates summarized here for the Group 3 tests had the objective of determining whether or not performance could be *maintained*.

The convex mirror surrogates were tested both in the Task A on-road subtasks and in the Task B backing subtasks. In regard to the Task A subtasks, there was very little difference in results for any of the subtasks. It is believed that this occurred because drivers still had their flat mirrors to use. These mirrors would be relied upon for the tasks performed. In general, performance was found to be similar. One exception was the mean cut-in distance for the passing/merging task. It was found that cut-in was a bit shorter for baseline than for the convex surrogate (16 versus 22 ft; 4.88 versus 6.71m). This could be a result of greater driver confidence in the (usual) baseline mirrors. Glance patterns for the convex surrogate condition demonstrated that drivers relied on their flat mirrors and used the surrogates very little. This was an expected result, since the subtasks emphasized estimations of distance rather than detection of targets. Distance estimations would ordinarily require use of the flat mirrors.

Opinion ratings for the Task A subtasks similarly did not show significant differences. Although not statistically reliable, drivers rated the baseline slightly higher than the C/VIS in the clearance/overlap subtasks (6.125 versus 5.00). There was essentially no difference in ratings for the passing/merging subtask.

In regard to the four C/VIS ratings for the on-road subtasks, drivers gave values that could be considered "moderate," with the average being 5.57.

For the Task B backing subtasks, a similar picture emerged. Task completion times were essentially the same for the convex C/VISs and baseline. For the backing (to a parked car) subtask, drivers managed to stop, on average, 61 in (1.55 m) from the parked car with the convex surrogate and 101 in (2.57 m) from the parked car in baseline. The goal was to park at 60 in (1.52m). Nevertheless, the differences in absolute errors were not significant. At the very least it can be said that performance for the convex C/VIS condition was at least as good as for baseline. For the loading dock backing task, there was similarly no significant difference in final position between the convex surrogate and baseline conditions.

Glance data for the Task B subtasks showed that drivers used the convex C/VISs very little during the backing (to a parked car) subtask and not at all during the loading dock subtask. These results underscore the fact that drivers relied on the flat mirrors.

Opinion ratings for Task B were similar to those for Task A. Drivers rated the convex C/VISs within one rating point of the baseline, with results not being significant. In regard to the four ratings of the convex C/VISs themselves, the ratings averaged 5.16, indicating the ratings were again in the "moderate" range.

These results generally suggest that, for the tests performed, drivers found the convex C/VISs to be about the same as the baseline. The tests suggest that convex C/VISs could be interchanged with the convex mirrors without deleterious effects. However, it would probably be wise to perform a bit of additional work on target detection to ensure that convex surrogates perform approximately as well as convex mirrors. This type of testing was not emphasized in the current research. The need for target detection work was only discerned after the results of the current research were examined.

It should be noted, however, that the convex C/VISs have one great potential advantage over convex mirrors. Since the cameras are mounted at the front fenders, there is no chance of another vehicle getting "under" the mirrors undetected, as has been previously explained. A low or small vehicle would definitely appear in one of the convex C/VIS monitors.

COMBINATION OF CONVEX AND FLAT (WEST COAST) MIRROR SURROGATES (GROUP 3 TESTS)

This combination of surrogates (two on each side, four in all) was tested experimentally because it had the potential of dispensing with the mirrors and structures on each side of the tractor. As discussed previously, such an approach would improve aerodynamic performance of the heavy vehicle while providing a sleeker appearance. These tests were performed on both sides of the vehicle in an experiment that examined both convex and combination (called "combined") surrogates, as described in Chapter 12. The Peterbilt tractor and trailer were used. Figures 74 through 79 show the equipment. Note that the rectangular cameras at the front fenders and the larger, lower monitors at the A-pillars were used for the west coast surrogates. In the "combined" conditions all four cameras and all four monitors were activated, and all mirrors were covered so that they could not be used. Consequently, drivers *had* to rely on the combined C/VISs to perform the various tasks. As with the convex C/VIS condition, the baseline condition was obtained by deactivating all four monitors and uncovering all four mirrors. Recall that both the convex C/VIS and the combined C/VIS used the same baseline condition.

Once again, it is important to stress that the major question to be answered was whether the combined C/VISs could compete effectively with the baseline condition; that is, the mirrors. Consequently, ratings improvements over baseline were not expected for the combined C/VISs. Also, it is important to note that drivers were forced to use the C/VISs in the combined C/VIS condition, because all four mirrors were covered. This situation differs from the enhancements tested in Groups 1 and 2 and the convex C/VISs of Group 3 (in which the flat mirrors were still available).

Finally, it is important to point out that because the flat mirror surrogates did not possess stereoscopic capability, a horizontal delineator (black line) was placed on each monitor which designated the ground position at the end of the trailer (Figures 74 and 75). This line was carefully calibrated on a flat roadway. Its correct position did not change throughout the experiment and, as previously described, was independent of driver eye position. The purpose of the line was to help compensate for lack of stereoscopic capability in locating the plane of the rear end of the trailer.

The combined C/VISs were tested in both on-road (Task A) and backing (Task B) subtasks. Results showed that the combined C/VIS resulted in a small reduction in mean absolute error, as compared with baseline, for the clearance/overlap distance estimation subtask. For the passing/merging subtask, the combined C/VIS condition resulted in a 26 percent increase in mean cut-in distance when compared to baseline. This result suggests greater uncertainty when using the combined C/VIS condition.

Glance analyses for the on-road subtasks indicated that the combined C/VISs were used exactly the same amount as the mirrors were used (in baseline): 68 percent of available visual resource time for the clearance/overlap subtask, and 62 percent of available resource time for the passing/merging subtask. Opinion data did not demonstrate any significant differences between combined C/VISs and baseline; however, the mean rating for the clearance/overlap subtask was 4.88 compared with baseline of 6.125. While not significant, this does indicate more than a point in reduction of rating. On the other hand, for the passing/merging subtask, both baseline and combined C/VISs had the same rating value of 6.38. For the four ratings of the combined C/VISs themselves, drivers provided an average rating of 5.57, which is in the "moderate" range. Overall, these ratings suggest roughly equivalent acceptance, with the possible exception of the clearance/overlap subtask comparison.

For the backing subtasks (Task B), completion times for the combined C/VIS condition for backing (to a parked car) were significantly longer than for baseline, a 58-percent increase. Final position was also greater than baseline by 32 percent, but this increase was not significant. It should be mentioned that the combined C/VIS condition did have significantly greater final position values than the convex C/VIS, suggesting that drivers had less ability to position the vehicle when the flat mirrors could not be used.

For the loading dock backing subtask, completion times using the C/VISs were again significantly longer than for baseline by 52 percent. However, final position distances were nearly the same for the combined C/VISs and baseline.

Glance behavior for the backing subtasks showed that drivers relied almost exclusively on the mirrors in baseline and on C/VISs in the combined C/VISs condition. However, for the backing (to a parked car) subtask, in the combined C/VIS condition they relied more heavily on the right side and less on the left side than they did in the baseline condition. This is probably a result of the parked car initially being to the right rear of the trailer. For the loading dock subtask, drivers used the left mirrors much more than the right mirrors in baseline, but used the C/VISs about equally. This could be a result of less familiarity with the use of the C/VISs, requiring more cross-checks.

The opinion data for the Task B subtasks show much the same results as for Task A. The rating for the backing (to a parked car) subtask resulted in a small reduction in the mean rating for the combined C/VIS condition as compared with baseline. A similar finding occurred with regard to the loading dock subtask. These differences were not significant, but suggest that drivers are reluctant to rate as highly when they no longer have their flat mirrors. The four ratings of the combined C/VISs themselves resulted in an average rating of 5.5, which again is similar to that obtained for the on-road tasks.

Collectively, the experiment findings suggest a small reduction in performance and a small reduction in rating values for the combined C/VIS condition. This could be a result of lack of substantial experience with the combined C/VIS or it could be that drivers may continue to perform slightly better with mirrors. In any case, the experiment has shown that the combined C/VISs cause slight reductions in performance and preference, at least initially. In the words of one of the subjects, the combined C/VISs "may take some time to get used to."

DISCUSSION

The results of the experiments taken together show great promise for the enhancements tested and they show that surrogates are by-and-large capable of competing with mirrors. All four enhancements seemed to work well and received high ratings. In regard to performance, the enhancements generally provided improvements, except in the case of the S-curve task. This task was included because it was believed that none of the C/VISs tested would provide improvements and, indeed, that was the way the results turned out. The results with enhancements thus suggest that they are valid, in that they exhibited changes and improvements for some subtasks, but not for others.

In regard to the two surrogate conditions, it appears that the convex C/VISs can be recommended without hesitation because they are capable of producing results similar to the actual convex mirrors (assuming the flat mirrors are present). In addition, the convex C/VISs have a smaller blind spot than the convex mirrors because the cameras are lower and farther forward on the tractor. On the other hand, the combined C/VISs (which replace both the flat and convex mirrors) showed very slight degradation in performance as compared with the actual mirrors; that is, baseline. Of course it must be remembered that the subjects had only a limited amount of time to adapt to the C/VIS conditions. Consequently, the slight degradation found may well be a result of limited practice and familiarity with the combined C/VIS condition. However, to be safe, it is recommended that a field test be run using the combined C/VISs before a final decision is made regarding acceptance of simultaneous replacement of the flat and convex mirrors with these C/VISs.

CHAPTER 15: RECOMMENDATIONS FOR INCLUSION OF THE VARIOUS C/VISs IN THE SPECIFICATIONS AND FOR ADDITIONAL WORK

The combination of information gathering, focus group input, informal preliminary tests, and formal tests allows the development of recommendations for inclusion of the various C/VISs in the final specifications document. It is necessary to include all of the information, because not all configurations were examined in the formal tests. However, the configurations selected were generally representative, and thus allow extrapolation beyond the strict results. An example of this is the similarity between tractor rear view and trailer rear view. Trailer rear view was not specifically tested, except for the wide-angle rear multipurpose look-down C/VIS. Nevertheless, there is sufficient information based on the tractor rear-view C/VIS and the wide-angle rear multipurpose look-down C/VIS to conclude that the trailer rear view would be worthwhile.

Table 9 shows the 13 candidate C/VIS configurations prior to informal preliminary and formal tests. This table can now be updated and considered as final. In the following sections, each candidate is discussed and then a corresponding recommendation is made.

RIGHT-SIDE WIDE-ANGLE BLIND-SPOT ENHANCEMENT

This enhancement was tested in the informal preliminary tests. It was found to be useful in the opinion of the VTTI test drivers. It appears that the 80 to 90^{o} FOV should be retained. This enhancement has the advantage that the camera position is low, preventing a right-side blind spot. At the same time the camera covers virtually all of the area alongside the tractor and front of the trailer. Consequently, the blind spot on the right side of the tractor trailer is eliminated. Both the VTTI drivers and those who participated in the focus group believed that this enhancement would be superior to the passenger-side look-down mirror combined with a lower window. In selecting the horizontal angular FOV, it is once again stressed that the angle should be no larger than is necessary to cover the desired area, so that image distortion is minimized to the extent possible.

Monitor positions were discussed in Chapter 6. Drivers preferred the A-pillar location because it allowed coordination with the outside mirrors, which were in close angular proximity. Of course, this position could only be used if flat and convex mirror surrogates are not being used. If these surrogates are being used, then a location at or above the center IP would be acceptable. Alternatively, a location at the right-side header might also work when surrogates are present at the A-pillar.

LEFT AND RIGHT-SIDE TRAILER VIEW ENHANCEMENTS

The left-side enhancement was similarly tested in the informal preliminary tests, with a camera at the front of the trailer and aimed rearward. VTTI test drivers attempted to use this enhancement during sharp turns to the right (its main intended application). The C/VIS had the goal of providing a view of the blind spot that exists when the tractor is at an angle to the trailer, in which case the view along the outer side of the trailer is not available. Drivers did not find the C/VIS useful. They questioned why it was needed because the trailer does not leave the lane unless the driver first moves to the left before making a turn to the right. If so, the driver assesses lane clearance before moving left. Since this C/VIS does not appear to be needed and does not provide useful information, the recommendation is made that it should be deleted as a viable candidate. Extrapolating from these results, it appears that the right-side trailer-view enhancement should be similarly deleted.

LEFT AND RIGHT MERGE/RE-MERGE ENHANCEMENTS

The left merge/re-merge enhancement was ranked third and the right merge/re-merge enhancement was ranked fifth by the focus group. Considering how close they are in rankings, they are considered together here.

Preliminary tests indicated that the right merge/re-merge enhancement was well-liked by the VTTI drivers and that the enhancement served an important purpose. The drivers wanted a slightly larger FOV. Consequently, in the formal tests a 55^{o} FOV was used.

Formal tests showed that these two enhancements were among the most successful. Clearance/overlap near the back of the trailer was determined with 100 percent accuracy, and errors in distance estimation of clearance or overlap were drastically reduced. Similarly, for passing and merging, cut-in distances were reduced, indicating greater certainty in regard to the position of vehicles alongside. Glance analyses showed that drivers used these enhancements, and opinion data suggested that they liked using them. Essentially, these enhancements take the guesswork out of determining the position of vehicles alongside in the adjacent lane. These enhancements are recommended without further changes.

TRAILER REAR-VIEW ENHANCEMENT

This enhancement was not tested formally, but can be considered to be similar to other enhancements that were tested formally; namely, the tractor rear backing/bobtailing enhancement and, to a lesser extent, the trailer wide-angle rear multipurpose look-down enhancement. In addition, it was tested in the preliminary tests. This enhancement provides a view directly behind the trailer. The main purpose of the enhancement is to improve situation awareness for the heavy-vehicle driver.

The camera horizontal FOV should be set at about 70^{o}, which represents a good compromise between FOV and field distortion. The camera should be mounted approximately 8 ft (2.4 m) above the pavement near the vertical centerline of the trailer. This position allows a view up to the horizon while giving good coverage directly behind the trailer, which drivers felt was important. If the trailer has a roll-up door, care must be taken to ensure the camera is not damaged when the door is being opened or is in the open position. The monitor can be located at the IP wing panel or at the top center of the windshield.

CONVEX MIRROR LEFT AND RIGHT-SIDE MIRROR SURROGATES

The right convex mirror surrogate was very well liked by the VTTI drivers in the preliminary tests. Formal tests showed that there were no significant performance differences between baseline and convex C/VISs on the two sides of the vehicle. The tests indicate that these surrogates can be recommended because they provide essentially the same capability as the convex mirrors.

As mentioned earlier, these surrogates have a large advantage over the convex mirrors. Since the cameras are located at the front fenders, there is no chance that another vehicle could get under the cameras undetected. In other words, the surrogates cover the blind spots on each side of the vehicles substantially better than the mirrors themselves.

There is a second advantage with these enhancements, namely, the fact that the monitors face the driver and are flat. Convex mirrors are angled relative to the driver and they are not flat. Consequently, the FOV is somewhat distorted by the curvature and by the angling.

A point that has not been discussed is whether the convex mirror surrogate on the right (passenger) side is adequate to fully eliminate the blind spot on that side of the heavy vehicle. Drivers in the focus group were very concerned about this blind spot. It is believed that the reason for the number one ranking of the right-side wide-angle blind-spot enhancement was the drivers' concern over blind spots on the right side of the vehicle. Whether or not the right-side convex mirror surrogate with its 45^{o} FOV would be adequate has not been answered by the present research. If it can be shown that the right-side convex mirror surrogate is adequate, then the right-side wide-angle blind-spot enhancement would not be needed when the surrogate is present.

FRONT BLIND-SPOT ENHANCEMENT

This enhancement is intended for standing or "creeping" slowly forward. An example of this would be starting up at a traffic light. The enhancement is specifically not intended for use at any forward speed above approximately 2 mph (3.2 km/h) because drivers could not react in time, and heavy vehicles could not stop in time to avoid a collision with any object viewed in the monitor of the enhancement.

This enhancement was found to be only moderately satisfactory in the preliminary tests. With the camera mounted at the left front bumper, there was success in detecting pedestrians walking in front of the tractor and coming from the right. The camera was most effective when it was aimed so the edge of the radiator could be seen at the right edge of the FOV.

Monitor placement at the top of the center dash (wing panel) was moderately satisfactory as well. A philosophy that can be used here is to place the monitor so that it is close in angular proximity to the direct view of the right front corner of the tractor. If this is done, the driver can take a direct look and can then look down slightly at the monitor.

In developing this enhancement, several alternatives were tried. One of these involved placing the camera on top of the cab just above the right corner of the windshield. However, this location did not work well because it did not completely eliminate the blind spot and was otherwise not as effective as the original position at the left front bumper and aimed to the right.

In summary, while this enhancement has some problems, it nevertheless has value. It might possibly be improved by additional experimentation, but in its present configuration it meets minimum criteria of usefulness and usability.

LEFT AND RIGHT-SIDE WEST COAST (FLAT) MIRROR SURROGATES (COMBINED WITH LEFT- AND RIGHT-SIDE CONVEX SURROGATES)

As described previously, the flat mirror surrogates are only recommended if the convex mirror surrogates are used. The reasoning here is that the convex mirrors perform well and should be used if any surrogates are going to be used. In addition, retaining the convex mirrors themselves would mean that the mirror structures could not be eliminated. Thus, all four essential mirrors (two flat, one on each side, and two convex, one on each side) would be replaced if flat mirror surrogates are going to be used.

The data suggest that the "combined" C/VISs could compete moderately effectively with the mirrors they replace. There were slight degradations with the combined C/VISs, but these were not statistically significant and can probably be attributed to limited experience and practice using them. The flat mirror surrogates should include some form of distance-measuring aid. This could be in the form of the calibrated horizontal line (on the monitors) used in the formal experiments, or some other method of determining accurately where the back end of the trailer is. The reason that this is needed is that conventional video does not contain the stereo depth cue that flat mirrors possess.

To determine the correct FOV for the flat mirror surrogates, the best procedure is to match image width to actual flat mirrors. This can be done by using adjustable telephoto lenses on the cameras and adjusting the image until it is correctly sized when viewed from the driver's nominal seating position. The lenses can then be replaced in production by appropriate fixed focal length lenses.

Once again, it is important to mention that minimizing camera vibration with flat mirror surrogates is a problem requiring careful engineering analysis and design. The problem was only moderately solved in the current research by using a mass at the camera mount to reduce higher frequency vibration. Of course, flat mirrors themselves are subject to vibration due to wind vibration, mirror structure vibration, and cab vibration. Consequently, the problem of vibration is not unique to the flat mirror surrogate cameras.

The recommendation thus made is to include combined C/VISs in the specifications. However, it is also recommended that some on-road work be done to ensure that combined C/VISs do not have shortcomings that were not uncovered in the current research. This is equivalent to saying that a small number of heavy vehicles should be equipped with these surrogates and used in normal operations. If untoward effects are uncovered, these effects should be remedied. If no remedies can be found, testing should be suspended until remedies are found. Any needed changes would have to be included in modifications to the specifications.

LEFT (DRIVER)-SIDE BLIND-SPOT ENHANCEMENT

As discussed in Chapter 5, this enhancement would use the same camera arrangement as the left convex mirror surrogate; that is, the camera would be at the front left fender. While this specific enhancement was not tested, it is really quite similar to the left-side convex mirror surrogate. Therefore, the test results from that surrogate are applicable.

Some additional explanation is necessary here, in regard to the relationship between the surrogate and the enhancement. If conventional side mirrors are maintained, then the left-side blind-spot enhancement can be set up exactly the way the left surrogate would be set up. The camera would be at the left front fender and the monitor would be at the left A-pillar. The driver could then use the combination of the convex mirror and the left-side blind-spot enhancement to ensure that there are no undetected objects along the left side of the vehicle. If, however, convex surrogates are being used, the left-side blind-spot enhancement *becomes* the left-side convex mirror surrogate. It produces an identical image and, thus, the enhancement is redundant. In other words, the left-side blind-spot enhancement is already included as a surrogate.

In the case that the convex mirrors are retained, the left-side blind-spot enhancement appears to provide better coverage of the blind spot because it is lower and, as previously described, immune to having objects get "under" the camera. In addition, the camera is farther forward, giving a second advantage. Thus, the left blind-spot enhancement can and should be included in the specifications.

TRAILER REAR LOOK-DOWN ENHANCEMENT

This enhancement was tested in both the preliminary tests and in the formal tests (Chapter 9). The enhancement was intended for backing use only; therefore, tests were limited to the Task B subtasks. This enhancement used a camera at the top center of the trailer that was aimed so that the bottom edge of the trailer was just visible in the monitor. The enhancement camera is shown in Figure 68 and the monitor is shown in Figures 71 and 72. This enhancement produced results that were superior to baseline, it was used heavily by the subjects, and it was well liked by them. Therefore, it should be included in the specifications as a viable C/VIS.

TRAILER WIDE-ANGLE REAR MULTIPURPOSE LOOK-DOWN ENHANCEMENT

This enhancement was tested in both the preliminary tests and in the formal tests. In the formal tests, it was successful in improving performance in both the Task A on-road subtasks and the Task B backing subtasks. Subjects were able to correctly determine clearance or overlap 100 percent of the time. While they were not quite as accurate at estimating the amount of clearance or overlap as with the merge/re-merge enhancements, they nevertheless did a good job. All other expected aspects of the on-road and backing tasks were improved. In addition, glance analyses indicated that they used the enhancement very substantially during the tests, and they gave the enhancement good ratings as well.

This enhancement used a wide-angle lens on the camera with the lower edge of the trailer appearing at the lower edge of the image on the monitor. Even though there was field distortion resulting from use of a wide-angle lens (Figures 63 through 67), subjects could use the enhancement effectively. Therefore, it should be included in the specifications without requiring image remapping.

TRACTOR REAR BACKING/BOBTAILING ENHANCEMENT

As mentioned, this enhancement was intended to serve as the equivalent of an interior rear-view mirror for the tractor. The enhancement could be used for both Task A (on-road subtasks) and Task B (backing subtasks). Subjects had a 42 percent improvement in estimating amount of clearance or amount of overlap with the enhancement. Subjects favored the enhancement by about 1 rating value, suggesting moderate receptiveness. Subjects also improved their performance for the backing to a parked car subtask and backing to the cone barrier subtask. Ratings also improved for the backing tasks.

Note that in the initial tests it was discovered that the camera was too high on the tractor. As a result, the horizon could not be viewed at the same time that the tractor rear wheels were included in the scene. After the camera was lowered for the formal tests, a much more satisfactory view was obtained (Figures 57 through 16).

This enhancement does a good job of simulating the rear-view mirror and has been shown to be beneficial. Therefore, with the camera location lowered, it is recommended for inclusion as a viable enhancement and should be included in the specifications.

TRAILER REAR MULTI-CAMERA ENHANCEMENT (REVISED)

This enhancement was envisioned as a combination of four C/VISs. However, revisions were made after the preliminary tests because two of the four cameras produced results that appeared "awkward." As a result, they were replaced by the two merge/re-merge cameras. Consequently, all four revised C/VISs were then examined separately in the formal tests. These four were the trailer look-down enhancement (Camera 1), the trailer rear-view enhancement (Camera 2), the left merge/re-merge enhancement (Camera 3) and the right merge/re-merge enhancement (Camera 4). These four enhancements were tested in the formal tests and found to be effective. The only question that remains is whether or not to use a central display for all four.

To answer the question, consider the following: assume the left and right merge/re-merge enhancements have their displays at the left and right headers, respectively, as previously specified. Assume the trailer look-down enhancement and the trailer rear-view enhancement are both to be displayed on a central display. The look-down enhancement is only intended for backing and the rear view is only intended for on-road use. It would seem that switching could occur automatically at 5 mph (8 km/h) of forward speed, with the possibility of manual override. In that case, a three-pushbutton panel could be used with the top position being "auto," the middle position being "rear view," and the bottom pushbutton being "look down." The two merge/re-merge enhancement monitors could be left on at all times, because the monitors would be out of the direct

FOV when looking forward. Note also that if the tractor itself is equipped with a backing/bobtailing enhancement camera, the panel "auto" position could be designed to automatically switch to this camera when the trailer connector is disconnected.

SUMMARY OF RECOMMENDED CONFIGURATIONS

The various recommended C/VISs can now be summarized in a table that is a revision of Table 9. The revised table, shown in Table 82, takes into account focus group driver preferences, preliminary test results, and formal test results. It deletes those configurations found unfeasible in the preliminary tests (none of the configurations was found unfeasible in the formal tests). In all cases, changes recommended are assumed to be included. It is the C/VISs in the table that are used in the revised final specifications document.

Table 82. Revised final configuration summary listing of concepts.

Description
Right-side wide-angle blind-spot enhancement
Left- and right merge/re-merge enhancements
Trailer rear-view enhancement
Convex left- and right-side mirror surrogates
Front blind-spot enhancement
Left- and right "combined" mirror surrogates
Left-side blind-spot enhancement
Trailer rear look-down enhancement
Trailer rear wide-angle multipurpose look-down enhancement
Tractor rear backing/bobtailing enhancement
Trailer rear multi-camera enhancement (revised)

RECOMMENDATIONS FOR ADDITIONAL WORK

In concluding this report, it is important to mention those areas where additional investigation could be helpful. These areas are outlined as follows:

- A comparison should be undertaken between the right-side wide-angle blind-spot enhancement and the camera used for the convex right-side mirror surrogate. Considering that the surrogate camera covers a good deal of the right front blind spot, it may become clear that the right-side wide-angle blind-spot enhancement is not needed as a separate entity. The latter has a large FOV, which as explained, produces some scene distortion. The camera for the right-side convex mirror surrogate could be used as an enhancement; that is, the convex mirror on the right side could be retained. Since the cameras for the right-side wide-angle blind-spot enhancement and the convex right-side mirror surrogate have the same location (on the right front fender) they easily cover the blind spot ordinarily covered by the right-side look-down mirror and lower right-side window.

- Some field testing of the combined left and right surrogates should be undertaken. The convex mirror surrogates have been found to be effective; however, the addition of the flat mirror surrogates to the convex mirror surrogates, while competing reasonably well with the flat mirrors and convex surrogates in the road test experiments performed here, should be further tested. It is possible that small changes may be needed in the final configuration. Such changes might include changing aim point as a function of the angle between the tractor and trailer, or adding some other form of clearance/overlap indication. For example, the combined surrogates might be tested with and without the merge/re-merge enhancements.

- Further work should be undertaken on the front blind-spot enhancement. This standing/very low-speed enhancement was believed to be useful, but a totally satisfactory arrangement for the camera and monitor was not found. Perhaps with more development work, an improved arrangement might be found.

- Flat mirror surrogates are subject to vibration because they use long focal length lenses. Such lenses are quite susceptible to angular vibration. In the current research, the problem was brought under control by using a relatively heavy mass at the camera mounts which smoothed higher frequency vibrations in the "arms" coming up from the tractor frame (Figures 76 and 77). However, a better solution should be found. Such a solution may require redesign of the fenders or a more careful analysis and optimization of the solution used in the current research. It should be mentioned, as discussed earlier, that vibration is also likely to lead to camera failure. Consequently, even cameras that do not use long focal length lenses may need to have isolation mounts.

- Camera protection and camera lens port cleaning should be examined. In the current research, emphasis has been placed on developing configurations, ensuring usefulness, and examining performance. However, practical problems associated with the day to day use of such systems will need to be studied as well. Figure 10 shows one type of camera enclosure, but this type would have to be re-engineered if larger cameras with vibration isolation mounts are needed.

- An all-weather enhancement configuration should be considered. Specifically, an arrangement including two side cameras (similar to the convex mirror surrogate cameras in the current study) should be combined with a trailer rear camera. The purpose of the enhancement configuration would be to extend the driver's ability to determine the situation around the heavy vehicle at nighttime and in inclement weather. The current study has not emphasized problems of this type, but they should be examined.

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APPENDIX A

Informed Consent Draft

Title of Project: On-Road Tests for Camera/Video Imaging Systems (C/VISs)

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I. The Purpose of this Research

Camera/video imaging systems (C/VISs) are expected to become commonplace on heavy vehicles in the future. These are systems with cameras outside the vehicle and with video screens inside the cab that can be viewed by the driver. Generally, they can be used to add views where the driver cannot see very well (where there are blind spots), or they can be used to take the place of certain mirrors. However, before they can be used, tests need to be carried out which determine how well they work and how helpful they are. Virginia Tech Transportation Institute (VTTI) is conducting a study of these systems, and you are being asked to serve as a participant. If you agree to participate, you will drive a heavy vehicle (tractor or tractor trailer) on the Smart Road. We will give you detailed instructions on what to do later, but basically you will perform standard highway maneuvers such as merging and determining clearances with another vehicle that is part of the experiment. In addition, you will perform several backing maneuvers. You will participate by performing the maneuvers in baseline, that is, with the video turned off, and also with the video turned on so you can use it. The order in which these will be presented is different for different participants. After you have completed certain maneuvers, you will stop the vehicle and give us ratings using rating scales that will be shown to you ahead of time. You will participate in the evaluation of two C/VIS systems and corresponding baseline runs. Your participation is expected to take about 2 hours, but may be a bit longer or shorter.

II. Procedures

We will first ask you to show us your CDL. Thereafter we may need to run a simple vision test. Assuming you pass the vision test, we will explain the procedures further. First, we will describe procedures here in the VTTI research building. Thereafter, we will take you to one of our heavy vehicles and you will drive onto the Smart Road where additional procedures will be explained to you.

Here in the building you will first decide if you want to participate. If so, you will sign your name at the end of this form, so indicating. You should only sign after you have read and understood this form and had your questions answered. Next, we will go over the tests to be performed and the order in which they will be presented to you. For each type of run, you will perform what we call highway driving tasks. During most of the time, you will maintain a speed of 30 mph, while another vehicle maneuvers to the rear and sides of your heavy vehicle. In certain cases, you will be instructed to pull forward and merge in front of the other vehicle. In addition, we may ask you to perform clearance tests, which have to do with whether of not there is overlap between your vehicle and the other vehicle. As mentioned, you will also perform backing tasks. Three different types of backing will be used in the tests: S-curve backing, backing to a "fake" loading dock or barrier of cones, and parking in front of a car. Each of these will be explained in detail prior to having you perform the maneuvers. If your video is turned on during these tests, you should try to use it (them) to improve your performance. Of course, we don't know how well they will work, so your job is to just do the best you can. We will take measurements, but there is no grading, so you won't pass or fail. Also, results will be kept confidential, as will be explained.

III. Risks and Discomforts

The risks you will face in this experiment are probably slightly less than you would face in driving a rig on the highway. Speeds will be lower, and the other vehicle in the experiment will be driven by an experimenter who can help avoid problems by getting out of the way if necessary. The fake loading dock, if hit, will simply move. Similarly, the parked car has been lightened and is an old vehicle. If you should back into it, it will simply slide rearward, and any damage doesn't matter. No unauthorized vehicles will have access to the Smart Road during the tests. Consequently, we believe this is a minimum risk experiment.

We don't know of any discomforts associated with the experiment, except possibly your working with equipment you haven't used before. This might cause a little stress, but we think the stress should be mild.

IV. Benefits of this Project

There are no direct benefits to you for participating in this research (other than normal participant payment). No promise or guarantee of benefits has been made to encourage you to participate. You may find the experiment interesting, and your participation may help in the specification of camera/video imaging systems for future heavy vehicles.

V. Extent of Anonymity and Confidentiality

The ratings that you provide and the measurements we take in this experiment will be treated with anonymity. As indicated, your ratings will be filled in on rating scale pages. Also, while you are driving, equipment will record vehicle position and similar data. In addition, we will make some measurements of vehicle final position and similar aspects for the backing tasks. In all cases, your name will be kept separate from your data. Data analysis will be based on the pooled responses of those who complete participation. At this time, it is anticipated that three groups of eight drivers will participate, that is, 24 drivers total. It will be impossible in reporting the results of the experiment to identify any particular participant.

While you drive in this experiment, your glance position may be recorded by video. This is done by aiming a small video-camera at your face. After completion of your participation, the recordings will be used for research purposes only and will be analyzed to extract your glance positions. The recordings will be kept secure until they are no longer needed. They will then be erased.

VI. Compensation

You will receive payment in the amount of $35 per hour for your time and participation. This payment will be made directly to you at the end of your voluntary participation.

VII. Freedom to Withdraw

You should know that you are free to withdraw from the experiment at any time and for any reason without penalty. No one will try to make you continue. If you do not want to continue, you will be paid for the actual amount of time you participated. You are not required to answer any questions or to respond to any research situations, and you will not be penalized for not responding. The experimenter also has the right to end the experiment, if in his opinion it is best to do so.

VIII. Approval of this Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech and by the Virginia Tech Transportation Institute. You should know that these approvals have been obtained.

IX. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty.

______________________________________ ________________________

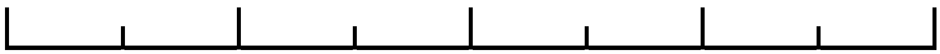
Participant's Signature Date

APPENDIX B
Rating Scales to be Used in the
Formal Road Tests

Highway Driving-Related Ratings

Merging Task

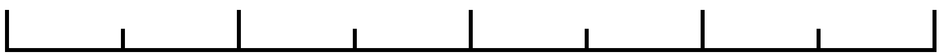
How difficult/easy was it to estimate distance to the other vehicle when merging to the right or left?



Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

Clearance/Overlap Task

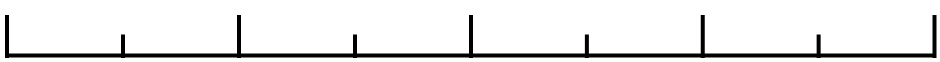
How difficult/easy was it to estimate clearance/overlap when the other vehicle was alongside near the back edge of the trailer?



Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

Observation Directly Behind

How difficult/easy was it to locate and observe the other vehicle when it was in the same lane to the rear, or approaching directly behind the tractor trailer (tractor)?



Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

Backing-Related Ratings

<u>Parking Task</u>

How difficult/easy was the task of backing and parking in front of the parked car?

Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

<u>Loading Dock (Cone Barrier) Task</u>

How difficult/easy was the task of backing to the loading dock (cone barrier)?

Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

<u>S-Curve Task</u>

How difficult/easy was the S-Curve task?

Extremely Difficult	Moderately Difficult	Neutral	Moderately Easy	Extremely Easy

Video System-Related Ratings

Usefulness

How useful or not useful did you find this (these) video system(s)?

Not at All Useful	Slightly Useful	Moderately Useful	Quite Useful	Extremely Useful

Learning Time

How long would it take you to learn to use this (these) video system(s), assuming you drove five days a week?

One Month or More	About Two Weeks	About Five Days	About One Day	One Hour or less

Receptiveness

Would you like to have this (these) video system(s) in the truck you drive each day?

Absolutely No	Probably No	Neutral	Probably Yes	Absolutely Yes

Blind Spot Reduction

Do you feel that the video system(s) reduced your blind spots?

Not at All	A Small Amount	A Moderate Amount	A large Amount	An Extremely Large Amount

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

1.

2.

3.

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U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

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