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Final Report

Rear Cross-View Mirror Performance: Perception And Optical Measurements

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16. Abstract

This document represents the final report of the work performed under contract DTNH22-D-95-07019, "Rear Cross-View Mirror Performance: Perception and Optical Measurements". This project was performed to assess the state of the art in rear cross-view mirror design and to offer guidance in the application and design of such mirrors for van and utility vehicle applications. Delivery vans and utility vehicles often have poor or non-existent vision directly behind them. Rear cross-view mirrors have been applied in some cases to combat this lack of direct view. Typically, a convex mirror of 8-10"in diameter is mounted in the upper left rear corner of the van, within view of the rear area and the left side view mirror. Thus, the driver must look through the side view mirror to detect objects within this mirror's field of view.

This effort measured detection performance of van drivers in a static outdoor setting using low contrast objects and distractors as targets being viewed through conventional and novel mirrors for a controlled period. Detection, recognition, confidence and subjective data were compiled and analyzed. Generally, detection and recognition rates were high for all conditions, suggesting positive value over the alternative of having no such mirror. However, patterns in the data suggest greater difficulty around the fringe of the target area and better performance associated with lower mounting height and minification. Optical measures were taken under this effort and are presented and discussed as well. Efforts to create a model that would allow prediction of behavioral performance using optical measures were unsuccessful, though some general trends and recommendations are discussed.

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1.0 Rear Cross-View Mirror Perception Study

1.1 Background

This research is concentrated on delivery vehicles characterized as utility vans and step vans similar to those used by local package and goods delivery services. These vans often have no windows behind the driver, so visibility is limited to direct views forward and to the side as well as indirect views through the side-view mirrors. Some visibility behind the vehicle is sometimes provided via rear cross-view mirrors. These mirrors, which are typically mounted at the upper rear of the driver's side of a given van, are intended to be visible within the field of view of the driver's side mirror. Similar mirror research and development has been performed on other mirror applications for school buses and postal vehicles, but primarily related to forward and side visibility, rather than behind the vehicle.

1.2 Objective and Rationale

The purpose of this research is two-fold. First, it is intended to quantify the current state of the art in rear cross-view mirror designs in terms of visibility performance. Second, it will provide insights that may be useful for the development of testing protocols for performing evaluations of future rear mirror/visibility systems for use by standards bodies and developers of such systems.

1.3 Overview of the Method

This experiment involved comparing several rear cross-view mirror designs in terms of their effect on the accuracy with which subjects could detect objects behind a utility van. The situation was configured to allow near-threshold detection of objects behind the van. The objects were designed to simulate child pedestrians, manhole covers, and newspapers. The latter objects were meant to provide distraction and a level of recognition to the task in addition to the requirement for detection. Contrived rear object stimuli were placed and removed from view while several mirror configurations were mounted and evaluated by each driver. No driving was required. A sheet of liquid crystal film allowed experimental control of viewing time for each condition through the "driver's" side-view mirror. A computerized acquisition and control system allowed presentation to be controlled and responses to conditions to be collected with ease and accuracy. Essentially, drivers were given a brief view of targets placed behind the van in each experimental condition and then were asked to press buttons corresponding to a standard set of question responses denoting what they saw.

1.3.1 Research Participants

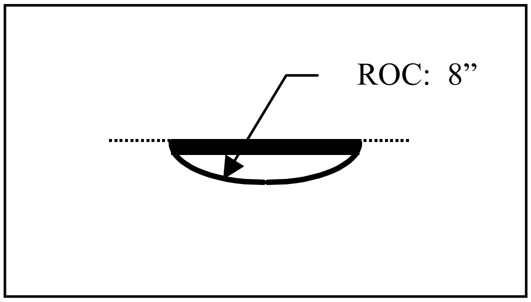
Ten utility truck drivers were recruited to participate in the evaluation. The characteristics of the participants are outlined in the following table.

Session Characteristics				Typical Van Driving Characteristics						
Gender	Age (>40?)	Visual Acuity (direct view)	Visual Acuity (through mirror & LC panel)	Make	Model	Size	Fitted with Rear Mirror?	Weekly Driving Miles	Weekly Backing Quantity	Type of Organization
F	N	20/16	20/16	Ford	Step Van	14'	Yes	100-150	20	Utility
M	N	20/16	20/25	Chevy/Ford	Step Van	varies	Yes	150	40	Utility
M	N	20/18	20/16	Freightliner	Step Van	14'	Yes	200	400	Delivery
M	Y	20/20	20/22	Chevy	Step Van	?	No	1000	125	Vending
M	Y	20/16	20/18	Grumman	Step Van	?	No	500	50	Vending
F	N	20/16	20/18	GMC	Step Van	?	No	300	15+	Vending
F	N	20/20	20/18	Chevy/Ford	Step Van	12-14'	Yes	100	40	Utility
M	Y	20/16	20/20	Ford	Econoline	?	Yes	25	20+	Delivery
M	Y	20/16	20/16	varies	Step Van	?	No	200	90	Bakery
M	Y	20/19	20/22	Chevy	Step Van	12'	No	70	20-25	Vending

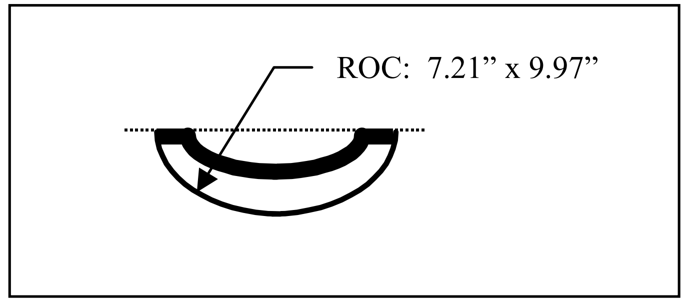
Table 1. Subject Characteristics

1.3.2 Mirror Systems

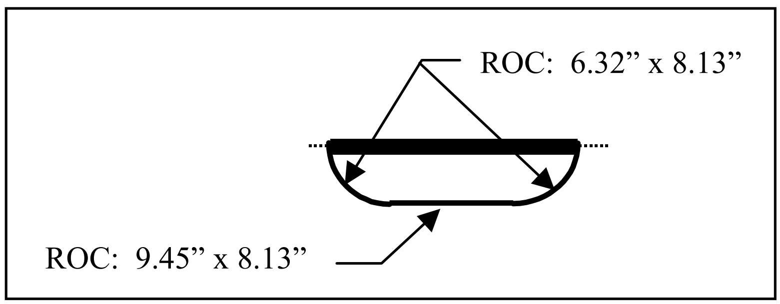
The research design used 4 mirror conditions, based on 3 different mirror systems, one of which was a conventional mirror tested at 2 different mounting locations. The mirror systems were defined at the time of the experiment based on the most unique available alternatives to the conventional spherical mirrors typically used in this application. The mirrors included: (1) conventional, spherical cross-view mirror; (2) LoMar Lookout mirror; (3) Mirror Lite Banana mirror. The conventional mirror is the model most typically used for current step-van applications. The Lookout and Banana mirrors are manufactured for other applications, but were used as unique alternatives for the rear cross-view situation. The Lookout is marketed as a front corner mirror for semi tractor trucks. The Banana mirror is typically used as a replacement for dual spherical mirrors for school bus front cross-view applications. The side view of each mirror lying horizontal and facing downward is provided in Figure 1 as an un-scaled guide to the differences between the mirror types. Front views of the mirrors would show constant radii of curvature from right to left, though the radius and overall size differs between mirrors. These mirrors enabled alternative fields of view and image minifications to be compared with conventional mirrors. The findings have no relevance to the performance of these mirrors in their more typical applications



Conventional
Size: 10” Diameter



Banana
Size: 12” x 6.75”



Lookout
Size: 11” x 8.13”

Figure 1. Mirror Dimensions

1.4 Test Conditions

Participants seated in a stationary van viewed the area behind the vehicle using the driver's side view mirror and a cross-view mirror system. The situation created for this evaluation simulated a relative worst-case situation for detecting objects while performing backing maneuvers. That is, the contrast level between the objects and the background was low, the color contrast was low, and the objects were stationary so there were no motion cues. In the real world, this situation is often exacerbated when the driver location is at a much higher illumination condition than the area behind the van. It should be noted that the level of illumination was not controlled. All trials were performed during daylight hours, but levels varied and shadows varied from trial to trial and session to session. In general, the van faced North with the sun trajectory visible from the rear of the van throughout the trials. This orientation was chosen to minimize the effect of a large shadow that would be cast by the van which would cause large areas of the grid to be in shadows at any given time. Such shadows would also vary with the time of day to create systematic illumination differences among sessions that could be meaningful in the data analysis, but very difficult to assess or control in the outdoor environment. Also, the level of difficulty of the task was increased further by controlling the amount of time that the subject was allowed to view the area and objects for each trial. Viewing time was kept to 3 seconds to avoid an extended period in which the subject could closely study the area. Given enough viewing time, subjects might be expected to have higher detection and recognition rates, making performance differentiation less plausible and ecological validity relative to actual driving situations less likely. For this study, objects that approached the threshold in terms of contrast relative to the ground surface were created using paint with different levels of reflectivity. Levels of target and background reflectivity were measured and documented for this report (see Tables 2 and 3). Both wet and dry pavement conditions are documented in the Table 3, though only dry conditions were used during the actual testing. The wet condition is provided only for reader interest to show magnitude and direction of the change in reflectivity when the background surface is damp. For the road surface, an average of the reflectivity of each of the five grid intersection points (seen in Figure 2) is provided in Table 3 as well as the individual reflectivity measures of each of those points. Since these points were the ones used for the target locations, they were also used for this calibration exercise. Though measuring all nine intersections might have been more representative of the surface, the five collected at the target locations were deemed to be sufficient and logical for the purpose of calibrating the surface. These relative reflectivity (i.e., contrast) levels were used in lieu of creating a reduced (relative to the cab) light level condition (e.g., in natural shadows or being partially covered in a warehouse entry bay) in the area behind the van. Actually, the orientation of the van was adjusted to minimize shadows. That is, the van was placed facing northward so that southerly exposure to the direct sunlight was available throughout the day for all sessions.

Salient driver/vehicle measurements are provided in Figure 3. The van used for this study was a 12' step van (12' cargo area). The driver's side mirror was located at a typical side-view mirror mounting location and angle.

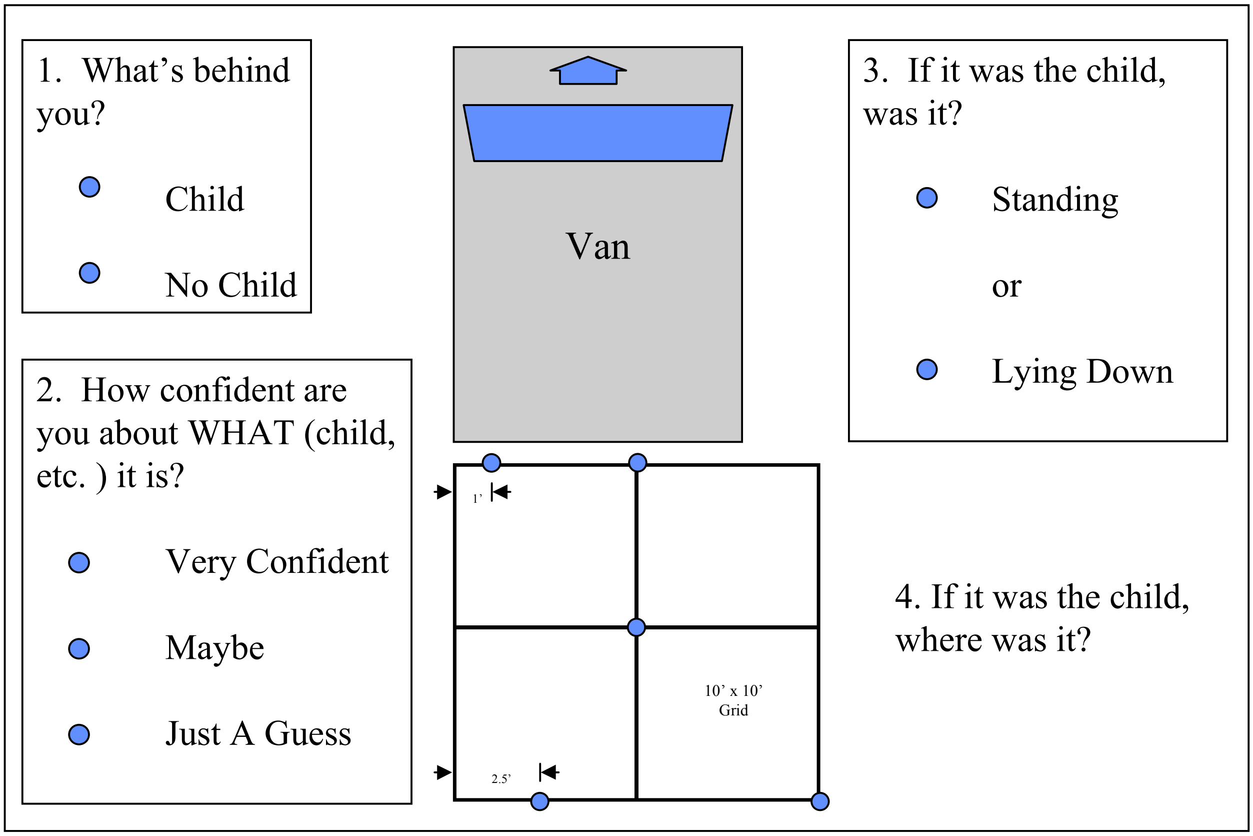


Figure 2. Layout of target locations and response console

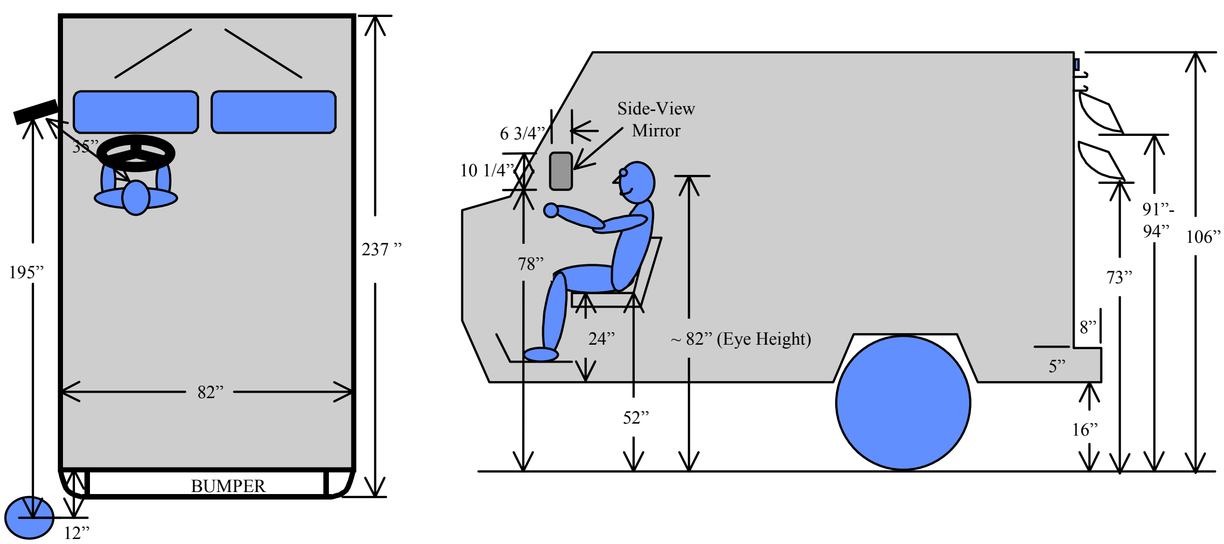


Figure 3. Van feature dimensions

Individual Reflectivity = Average individual reflectivity within the shade group

Group Reflectivity = Target Illuminance / Reference Level Illuminance / 90% (i.e., .9) White Reference correction factor

Group Background Contrast = Group Reflectivity / Background Reflectivity

Shade	Brand	Number	Color	Mixture	Shape	Reference Level Illuminance (90% White Card) (cd/m2)	Target Illuminance (cd/m^2)	Individual Reflectivity	Average Shade Group Reflectivity	Wet Group Background Contrast	Dry Group Background Contrast
Light	Pittsburgh Paints	4755 & 2750	Ebony & Onyx Gray	50:50	Dummy	1475	417	31.41%	32.35%	5.55	**2.24**
					Manhole	1385	422	33.85%			
					Newspaper	1535	439	31.78%			
Medium	Pittsburgh Paints	4750	Corundum	100	Dummy	1370	230	18.65%	18.15%	3.11	**1.26**
					Manhole	1450	230	17.62%			
					Newspaper	1455	238	18.17%			
Dark	Pittsburgh Paints	7750	Shark's Tooth	100	Dummy	1160	137	13.12%	12.85%	2.20	**0.89**
					Manhole	1190	140	13.07%			
					Newspaper	1250	139	12.36%			

Table 2. Target Reflectivity and Contrast Measures

Condition	Location	Reference Level (90% White -cd/m2)	cd/m2	Individual Reflectivity	Group Reflectivity
Dry	@ Mirror	13100	1460	12.38%	**14.43%**
	Center Grid	13400	2010	16.67%	
	Center Bumper	14100	2140	16.86%	
	Back Left	12700	1420	12.42%	
	Farthest (from Mirror)	13600	1690	13.81%	
Wet	@ Mirror	2347	110	5.21%	**5.83%**
	Center Grid	2400	113	5.23%	
	Center Bumper	2345	120	5.69%	
	Back Left	2500	115	5.11%	
	Farthest (from Mirror)	2530	180	7.91%	

Table 3. Background Reflectivity (Wet and Dry)

1.4.1 Visibility Targets

Targets chosen for this study included child-like dummies and geometric shapes used to reduce guessing and require a recognition component within the trial tasks. The dummies were similar in size and shape to those used by Garrott & Kiger (1992) in their evaluation of school bus cross view mirror systems. The distracter shapes were simply meant to provide a more realistic challenge to the participants similar to the real-world case in which non-uniformities exist on the road surface that are irrelevant and distracting from the detection task. That is, since they were similar in color and to some degree in shape, the detection task was made more relevant to real-world backing tasks. The standing and prone orientations were representative of two major types of backing collisions involving young children. Having more than one target orientation and the distracter objects required the participants to conduct a more complete interpretation of the visual scene. The targets included a 3-foot tall Styrofoam dummy and distracter targets that resembled a manhole cover and newspaper (2' circle and square, respectively). To promote repeatability and ease of use with a standard testing protocol, a Styrofoam dummy constructed of geometric forms was used for this evaluation. The dimensions of the dummy are provided in Figure 4. Dummies were weighted at the feet with approximately 1Kg of iron to maintain maximum stability in all but the most blustery conditions. There were three target contrast levels relative to the ground surface behind the van. The targets' reflectivity values fell around the central level of 20% reflective gray, which is typical of pedestrian clothing reflectivity and consistent with current visibility standards (Janoff, Freedman & Koth, 1975). Flat interior latex colors from Pittsburgh Paints were used to create the shades of gray used in the study. Table 2 shows measured values for reflectivity of the targets, individually and collectively, within paint color and Table 3 shows the reflectivity of the road surface against which all of the targets were viewed. Table 2 also lists the paint names, number and mixtures where applicable.

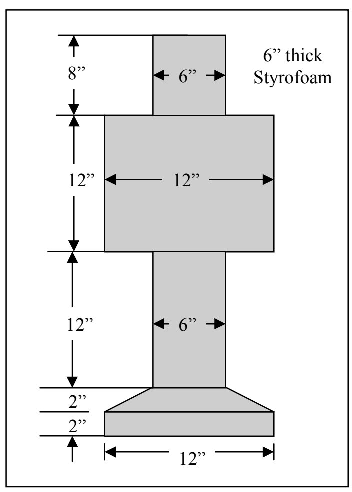


Figure 4. Dimensions of dummy target

1.4.2 Target Locations

Five target locations were used during this evaluation. Using the 10-foot square grid whose origin was at the driver's side of the rear bumper, the five locations corresponded to five of the nine grid intersections.

This grid was defined in earlier FOV measurement procedures. Appendix F reports on those measurements taken for a number of different mirror systems in earlier laboratory exercises. The grid was used in these exercises as a general minimum area directly behind the vans which these mirror systems could be expected to serve. Specifically, the points included those designated by small circles on the grid behind the van in Figure 2. The last two points were located one foot and two feet, respectively, toward the curb side as measured from the driver's side edge of the grid. This slight offset from the grid intersections along the driver's side was aimed at preventing direct visibility of the targets from the driver's side view mirror. Thus, targets were never visible from the side view mirror without the use of the rear cross-view mirror. Additionally, targets placed along the bumper were located to avoid possible obscuration during the viewing exercise.

Targets were always placed in the same orientation for a given target condition. That is, dummy targets placed in the prone orientation were positioned "face down" with the "head" pointed toward the driver's side edge of the grid. Likewise, standing dummy targets always "faced" the rear of the van for target consistency control purposes.

1.4.3 Instrumentation

Instrumentation for this evaluation was computerized to promote ease of randomization and data collection integrity. The instrumentation was based on a Visual Basic program running on a laptop computer. The laptop provided the user interface for the experimenter controlling the study and responsible for selecting and locating the proper target in the proper location and orientation for each trial. Details of target, orientation, location, and reflectivity level (i.e., color) were provided to the experimenter at the beginning of each trial using an interface that closely paralleled that of the participant's response console (see Figure 2). An electro-mechanical time-delay relay provided the control of the viewing time for each trial. This relay had delay times adjustable to one second increments. After some initial piloting, the value used for this evaluation was three (3) seconds. Accuracy was within $\pm$1% of the nominal value. The relay controlled a 14.5" square liquid crystal (LC) sheet mounted between the participant and the driver's side view mirror. This sheet is sold by 3M as Privacy Film™ and provided a means of quickly hiding and exposing vision from either side of it. In this case, each time the relay triggered, the film was clarified for 3 seconds to allow the participant to see the side view mirror and the area behind the van through the rear cross-view mirror. The LC panel was oriented to be perpendicular to the participant's gaze direction to maximize transmissivity of the light through the panel, thereby minimizing its effect on the detection and recognition tasks. Transmissivity of the film was measured with the results documented in Table 4. Subject responses and activations of the relay were captured using a device capable of converting contact closures into characters on the serial port of the PC. Using this system, a record of each trial condition and the participants' responses to it were recorded in an ASCII data file for subsequent analysis.

Transmission Medium	Target Distance	Target	cd/m2	Individual Transmissivity	Group Transmissivity
Mirror	10'	18 % Gray	87.3	56.32%	**57%**
	10'	60W Incandescent Bulb	15000	59.52%	
	10'	90% White	357	54.17%	
Mirror with Unoccluded LC Panel	10'	18 % Gray	104	67.10%	**50%**
	10'	60W Incandescent Bulb	9350	37.10%	
	10'	90% White	292	44.31%	
Straight, Clear Path	10'	18 % Gray	155		**100%**
	10'	60W Incandescent Bulb	25200		
	10'	90% White	659		

Table 4. Liquid Crystal Transmissivity

1.4.4 Session Length

Each session lasted about 2 to 2.5 hours. Each participant viewed 240 trials (described below). This included 60 viewing trials per mirror condition and remounting each mirror or subject debriefing purposes at the end of each session.

1.4.5 Variables

Independent:

- <u>Mirror system</u>: 4 systems (3 mirrors with the conventional mirror mounted at two heights)
- <u>Target location</u>: 5 locations within a 10'X10' grid behind the van
- <u>Target conditions</u>: 4, including 2 child conditions (standing and prone), a no target condition, and a foil condition (using manhole cover [2' circle]or newspaper [2' square] surrogates, equally represented)
- <u>Target contrast</u>: 3 levels near threshold relative to the roadway background reflectivity

Dependent:

- Percent targets missed
- Percent false positives
- Adjusted miss rate (taking false positive rate into account)
- Viewer confidence in judgments
- Image interpretability (target location and type)
- Visibility related to target contrast

1.5 Procedure

Upon arrival at the testing site, the participant was greeted and asked to read and sign an informed consent form outlining the study's procedures, benefits, and risks. Participants were then given a short tour of the site that included an opportunity to look at the target objects directly. The objects were described as the dummy, a newspaper, and a manhole and the reflectivities (i.e., contrast levels) were noted. The participants were invited to view the rear cross-view mirror directly from the ground, standing under the driver's side-view mirror. This allowed a slightly better view of the area behind the van than from the driver's seat and allowed the experimenter to point out features visible in the mirror as well as providing feedback about the level of difficulty that the study tasks would involve. Since some of the drivers did not typically use these types of mirrors, this introduction was useful in providing a more common familiarity level for each of the participants study responses. Mirror adjustment was not necessary in this phase of each session since each mirror was attached to a standard mounting bracket. The mirrors were adjusted once at the beginning of the study and were left in that position for the rest of the subject sessions.

The participant was then given two visual acuity tests. One was performed inside the van with a direct view of the eye chart at 10'. A second test was given from the participants study position, in the driver's seat of the van, looking through the liquid crystal panel and side-view mirror at a second eye chart, again at 10'.

After the results of these acuity tests were tallied, the participant was afforded a practice period that included placement of target objects within the area behind the van, use of the liquid crystal shutter to unocclude vision, and collection of the participant's responses using the response console. The experimenter provided feedback on the object and location as well as reinforcement of the proper response requirements during this practice period (i.e., obligatory versus optional responses and mistake feedback). The practice trials included the following conditions:

1. Dark Dummy – Prone - @ the Mirror
2. Light Manhole – Center Grid
3. Medium Dummy – Farthest from Mirror
4. Dark Newspaper – Far Left
5. No Object

Participants were instructed to tell the experimenter if they weren't ready to view a given scene for some reason or if they needed a break. Essentially, each mirror of the set of four configurations was used for about thirty minutes. No rest breaks were planned, but participants were alerted when mirrors were being changed to afford an opportunity to stand and stretch. Participants were also reassured that the study was not a test of their abilities, but a comparison of the performance of the mirrors for this application.

During the actual trials, the participant was seated in the driver's seat, just as if he or she was driving. No driving was required. The participant's view of the van's side-view mirror was initially occluded. At the start of each trial, the experimenter was cued by the computer to the target shape, location, reflectivity, and orientation to be used for that trial. The experimenter was aware of the importance of ensuring that the participant could not see the objects using only the side view mirror. That is, they were required to use the rear cross-view mirror to see the objects behind the van. The experimenter placed the appropriate target at the specified location and then provided a cue to the participant by way of a knock on the side of the van. This cue notified the participant that his or her view to area behind the van was about to be revealed. The experimenter then pressed a button that activated the sheet of liquid crystal film, making the mirror and area behind the van visible. The participant had a brief time (i.e., 3 seconds) to view the mirror. Though seemingly short, this time is actually longer than typical rearward viewing times recorded in recent naturalistic backing research (Huey, Harpster, & Lerner, 1995). The mirror was occluded again at the end of the interval. The knock ensured that the participant's gaze was oriented toward the side-view mirror when the view was clarified to provide maximum viewing time for each scene.

After a given glimpse of the scene, the participants were instructed to report what they saw, where it was, and to provide a confidence rating about the scene's content. The participants used the response console (see Figure 2) to provide the relevant answers. For each trial, participants were required to, at the very least, answer the first two questions; "What's behind you?", and "How confident are you about what it is?". The other two questions were only for the cases in which participants responded that they saw a child in their answer to the first question. Specifically, the following instructions were provided as guidance for responses:

- *For the first question, we want you to respond with the "**CHILD**" choice only if you see the dummy that I showed you earlier. If you see the round or square objects or nothing, you should be responding with the "**NO CHILD**" button.*
- *For the second question, we want to know how sure of your first answer you are. That is, are you confident that it* **is**, *or* **is not**, *a "child". Sometimes you may be more confident than other times that what you saw was a child behind the van. At times you may be completely sure you saw the child, while other times you may be less sure that's what you truly saw. By giving us your best assessment of how confident you are, you will help us to evaluate how well the mirror is working. The "**VERY CONFIDENT**" button should be pressed when you are absolutely sure about whether there is a child present. The "**MAYBE**" response suggests that you are pretty sure that you recognized a child if it was there. The "**JUST A GUESS**" response suggests that you are not sure at all about what you saw or didn't see. We are evaluating the mirrors here, not your ability to see or recognize objects.*
- *The third question is looking for more detailed information about the "child." Again, this question should only be answered if you say that you saw a child in your response to the first question. Specifically, we want you to tell us whether the child was standing or lying down.*
- *The fourth question, again, should only be answered if you saw a "CHILD" as your response to the first question. Here we want to see how well the location of the "CHILD" can be identified. Note the locations of the buttons that correspond to one of the locations in the area behind the van. [point out the features of the van (i.e., mirrors, grid, driver, bumper, etc)] You will make your response by pressing the button that corresponds to the location where you think the child is.*

Participants were instructed that if they ever felt that they responded incorrectly, they should let the experimenter know so that the nature of the mistake could be noted in the session records. No scenes were redone (i.e., the participant was never given a second chance to see a given scene), but an error log documented any scenes that could be interpreted as inaccurate data.

The sixty scenes required for each mirror were provided in rapid succession with the same routine being practiced by experimenter and participant for presentation and response. After the scenes for that mirror configuration were complete, the next mirror was installed on the fixture at the back of the van and the process was repeated.

At the end of the session, participants' impressions about each of the rear cross-view mirrors were collected using a structured interview questionnaire. To ensure that the subjects were clear on the mirror characteristics that they were evaluating, they were again invited to stand underneath the side-view mirror and view the rear cross-view mirror from that point. Each mirror was mounted to the fixture on the rear of the van and they answered a series of questions (see Appendix D).

After this debriefing, participants were paid and released.

1.6 Experimental Design:

A within-subjects design was used, in which each participant was exposed to all the combinations of all the independent variables. This resulted in 4 mirror conditions by 5 target locations by 4 target conditions, or 80 conditions. Mirror presentation order was randomized using a Latin Square routine and then documented by the experimenter on the PC before each block of 60 trials. The trials within each mirror block were randomized by the program's randomization routine. Mirror conditions were blocked to minimize the number of times the each mirror was required to be mounted during a session while all other conditions (i.e., location and target) were fully randomized within each mirror block. Each condition was repeated using one of the three (3) target reflectivity levels, for a total of 240 trials per participant.

Although the objects only appeared in one of 5 locations, response buttons were present for 9 locations corresponding to the grid intersections. The 5 actual target locations were selected to provide a representative sample of the field of view, while the 9 buttons caused the subject to consider the entire field rather than the abbreviated subset of actual target positions. This also allowed us to determine where the subject perceived the targets to be given the 5 fixed locations. As described earlier, the exceptions to these locations were on the driver's side of the grid in which a setback from the edge eliminated the possibility of seeing the target using only the side mirror instead of the side and rear cross-view combination. The dummy was present for half of the trials, foil objects were present for a quarter of the trials, and no object was in the remainder of the trials. It was necessary to have a meaningful number of "no object" trials in order to keep the false positive rates reasonably low. This also allowed an estimate of the false positive rate to be calculated to provide a correction for guessing to the detection rate calculations. For those trials where there was a target object present, two orientations of the dummy, standing and prone, were included in equal proportions. For the foil trials, flat 2' circular or square blanks (simulating a manhole cover or newspaper, respectively) painted the same colors as the dummy targets were presented, again in equal proportions. Participants were not asked to recognize the presence of these blanks, but only details about the presence of the dummy. Participants were debriefed at the end of the session to get subjective feedback on the relative merit of the different mirrors and mounting locations.

With 10 participants, the study provided 2,400 observations, 600 per mirror system. Of these 600, 300 had the dummy present, 60 at each of the 5 target locations. Thus, the overall target detection rates can be compared among mirrors on the basis of 600 trials per mirror, and more refined analysis can examine the role of target location, orientation, and relative contrast with the background for detection probability. False positive rates can be determined from the "no target" and foil trials. These false positive rates can be used to provide a correction factor for guessing rates in the analysis of the detection data. They also, in themselves, provide another measure of mirror image quality.

Only minor problems with the data that should be noted. Generally, the system of stimulus presentation and collection was quite reliable and intuitive for both participant and experimenter. In some cases the dummy was blown over by the wind during the period in which the LC panel was clear. Trials in which this occurred were removed from the analysis pool since they were not representative of the entire sample. A very small number of errors resulting in data loss (< 0.5%) were committed and one hardware failure caused a slight imbalance to one mirror condition. Otherwise, the data set was clean.

1.7 Results:

The results presented below deal with the detection performance data collected during this study as well as the subjective data related to subject preferences for the various mirror configurations. This discussion of the results also includes consideration of the physical measures collected during the Physical Measurement phase of this effort, described in Section 2.0. Summarized findings and implications for all results are discussed in Section 3.0.

The performance data were analyzed in two ways to determine the magnitude of differences that may be important in measuring the success of future mirrors. The first included a measure of the subjects' confidence in the responses they provided to discern the subtle measures of performance from within the simple detection performance data. The second method looked at the data in terms of basic detection performance.

The first method of analysis was structured to include subject confidence within the detection performance database. By using an index to code not only how successful they were at detecting the targets, but also how strongly they believed that they had been correct in light of their detection performance, a confidence rated index (CRI) was created. The following results are based on the CRI as defined in Table 5. Index values ranged from -2 to 2 a and were defined as follows:

Response Quality	Confidence Level	CRI
Valid	High	2
Valid	Medium	1
Valid	Low	0
Not Valid	High	-2
Not Valid	Medium	-1
Not Valid	Low	0

Table 5. Key to CRI coding

A "Valid" response was defined as the subject being correct in his or her determination of whether or not there was a child target present. A "Not Valid" response was characterized as the subject being incorrect in that determination. Confidence levels of "High", "Medium", and "Low" corresponded to subject responses of "Very Confident", "Maybe", and "Just A Guess", respectively. It is important to note that the CRI is constructed from the presence and confidence responses alone. It does not include any indication of whether the location of target and that identified by the subject were in agreement. Thus, it can only be construed as a measure of the detection accuracy/confidence, not localization accuracy/confidence.

We fitted several models to CRI in terms of mirror type, stimulus (see below), and mirror by stimulus interactions. The models allowed for having repeated measurements on test subjects. Major conclusions about CRI are as follow:

Mirror type significantly affected CRI, best results were achieved with the conventional mirror in the low position, worst results with the Lookout mirror. Table 6 shows the stability of the mean CRI values across situations in which the target was present and when it was not. That is, there was not a large change (within mirror type) of the CRI as a result of the presence of the target, suggesting that the mirror/height combination itself was playing a larger role in defining the confidence and recognition success.

	Mean CRI Level	
Mirror type	Target object present	All tests
Banana	1.19	1.13
Conventional-High	1.01	1.02
Conventional-Low	1.20	1.21
Lookout	0.94	0.96

Table 6. Basic CRI measures for each mirror

Due to the organization of the experiment, it is impossible to tell from this data whether the best performance was due to mounting height or type of mirror across all mirror conditions. That is, “How would the Banana mirror perform at the low position?” The data do suggest, however, that for the conventional mirror, lowering it’s mounting height improved the CRI level in a statistically significant way. It should be noted that this lower mounting height corresponds to the typical mounting height for smaller, conversion van-type delivery vehicles. Thus, this lower height is likely not typical or often recommended for taller step vans as it might interfere with some door and loading operations.

Tables 7 and 8 provide insight into the effects and interactions of the independent variables on the CRI. There was statistically significant variation in average CRI score among subjects so that within subject responses varied less than across subjects. The best and worst scores differed from the overall average by 0.43 (Session = 12) and -0.56 (Session = 15), respectively. Mean CRI levels were calculated and are summarized in Table 7. Generally, there were significant main effects for location and target condition and interactions for location by target condition, location by reflectivity, and target condition by reflectivity.

Effect	MIRROR	LOCATION	CONDITION	REFLECTIVITY	MEAN	Std Error
MIRROR	BANANA				1.12	0.13
MIRROR	CONV-HI				1.01	0.13
MIRROR	CONV-LOW				1.20	0.13
MIRROR	LOOKOUT				0.94	0.13
LOCATION		@MIRROR			1.10	0.14
LOCATION		MID-BUMPER			1.17	0.14
LOCATION		MID-GRID			1.44	0.14
LOCATION		BACK-LEFT			0.75	0.14
LOCATION		FARTHEST			0.88	0.14
TARGET CONDITION			CHILD-PRONE		1.25	0.13
TARGET CONDITION			CHILD-STAND		0.81	0.13
TARGET CONDITION			MANHOLE		1.18	0.14
TARGET CONDITION			NEWSPAPER		1.03	0.14
REFLECTIVITY				DARK	1.10	0.13
REFLECTIVITY				MEDIUM	1.04	0.13
REFLECTIVITY				LIGHT	1.06	0.13

Table 7. CRI distributions of main variables

For the CRI measure, a stimulus was defined as being any target object (child or foil) placed in the 10' X 10' grid or placing nothing. Models of the CRI showed the following:
Subjects scored significantly higher in identifying the absence of any stimulus (CRI = 1.38) than in identifying the presence of a stimulus (CRI = 1.05). The extent to which this was so did not significantly depend on mirror type.

Ability to identify a target object was characterized by several main effects and interactions (this analysis was restricted to having a target object present). The main effects included mirror, location, and object, but not reflectivity. The two-way interactions included: mirror by location, mirror by object, location by object, location by reflectivity, and object by reflectivity. There were two significant three-way interactions: mirror by location by object and location by object by reflectivity.

Significance tests for all effects and interactions included in the best (i.e., best alternative attempted to date, but not fully optimized) model were run. Least squares means (LSM) for main effects were also calculated. The mid-grid position achieved the highest CRI (LSM = 1.44), and the back-left position the lowest (LSM = 0.75). Also noteworthy is that subjects identified the prone-child best (LSM = 1.25) and the standing-child worst (LSM = 0.81).

An analysis of the detection performance data (without consideration of the confidence ratings) was performed as well. Generally, the results were analogous to the CRI results. These analyses were performed to attempt to describe the level of contribution of each variable in predicting the detection success rate of the targets. This analysis used the SAS procedure GENMOD to estimate and test logistic regression models for error proportions in terms of target condition, reflectivity, location, and mirror, and their 2-way interactions.

A modeling exercise was conducted using the linear minification ratio (minification) and the distortion value (distortion). Since these measures corresponded to a mirror/location pair, mirror and location were not specifically included in this model. This analysis was performed in an attempt to isolate predictors of performance related to the physical characteristics of the mirrors in conjunction with the independent variables (i.e., target condition and reflectivity). These measures were calculated from the physical measures of the mirror described in Section 2 of this report. For the analysis, these variables were categorized into 5 levels (0-4) using equal frequency distributions for each level. A single value for each of these measures was calculated for each mirror/location pair and was based on the minification and/or distortion of a standard one foot square target as measured at the driver's side-view mirror.

All of the variables used in this model (condition, reflectivity, minification, and distortion) were determined to be main effects at the 5% significance level. This suggests that distortion and minification do play a key role in detection performance. However, the relationship among these physical and performance measures is not a trivial one. The figures and discussion that follow provide some further insight into the relationship, but an optimized predictive model was beyond the scope of this effort.

Tables 8-12 provide an overview of the detection performance levels under various conditions. Hits, misses, correct rejections, and false positives were tabulated for each major variable category as described below. Each table provides frequency counts within the category listings for row and column headings. Table 8 compares the detection rate (i.e., hits) by mirror configuration for each target type. A somewhat collapsed version of this is provided in Table 11. Table 9 provides a similar tabulation of the effect on detection caused by target reflectivity. Contrast is outlined in Table 2 and is defined as the relative reflectivity between the target and the background. Like Table 11, Table 12 collapses the target categories to give a cleaner look at detection rates with respect to target reflectivity. Table 10 contrasts the detection rates for the various target locations within the 10’ x 10’ grid. Note that the “No Target” conditions were not given a contrived target location, so their correct rejections and false positive results are summarized in a “(blank)” row near the bottom of Table 10.

Mirror	Condition	Responses: Child	Responses: No Child	Grand Total	Hits	Correct Rejections	Misses	False Positives
Banana	Child-Prone	128	22	150	**85%**		**15%**	
	Child-Standing	116	33	149	**78%**		**22%**	
	Manhole	14	58	72		**81%**		**19%**
	Newspaper	22	55	77		**71%**		**29%**
	None	17	133	150		**89%**		**11%**
Banana Total		297	301	598				
10" Spherical-High	Child-Prone	128	23	151	**85%**		**15%**	
	Child-Standing	106	43	149	**71%**		**29%**	
	Manhole	22	53	75		**71%**		**29%**
	Newspaper	18	58	76		**76%**		**24%**
	None	17	128	145		**88%**		**12%**
Conventional-High Total		291	305	596				
10" Spherical-Low	Child-Prone	136	13	149	**91%**		**9%**	
	Child-Standing	110	39	149	**74%**		**26%**	
	Manhole	13	62	75		**83%**		**17%**
	Newspaper	17	58	75		**77%**		**23%**
	None	18	132	150		**88%**		**12%**
Conventional-Low Total		294	304	598				
Lookout	Child-Prone	112	38	150	**75%**		**25%**	
	Child-Standing	107	43	150	**71%**		**29%**	
	Manhole	15	61	76		**80%**		**20%**
	Newspaper	23	51	74		**69%**		**31%**
	None	34	116	150		**77%**		**23%**
Lookout Total		291	309	600				
Grand Total		1173	1219	2392				

Table 8. Detection Performance by Mirror

Reflectivity Level	Condition	Response: Child	Response: No Child	Grand Total	Hits	Correct Rejections	Misses	False Positives
Dark	Child-Prone	163	39	202	**81%**		**19%**	
	Child-Standing	168	29	197	**85%**		**15%**	
	Manhole	20	78	98		**80%**		**20%**
	Newspaper	31	73	104		**70%**		**30%**
	None	22	176	198		**89%**		**11%**
Dark Total		404	395	799				
Medium	Child-Prone	161	38	199	**81%**		**19%**	
	Child-Standing	139	63	202	**69%**		**31%**	
	Manhole	19	80	99		**81%**		**19%**
	Newspaper	24	77	101		**76%**		**24%**
	None	34	166	200		**83%**		**17%**
Medium Total		377	424	801				
Light	Child-Prone	180	19	199	**90%**		**10%**	
	Child-Standing	132	66	198	**67%**		**33%**	
	Manhole	25	76	101		**75%**		**25%**
	Newspaper	25	72	97		**74%**		**26%**
	None	30	167	197		**85%**		**15%**
Light Total		392	400	792				
Grand Total		1173	1219	2392				

Table 9. Detection Performance by Reflectivity

Location	Condition	Response		Grand Total	Hits	Correct Rejections	Misses	False Positives
		Child	No Child					
@Mirror	Child-Prone	92	27	119	**77%**		**23%**	
	Child-Standing	70	50	120	**58%**		**42%**	
	Manhole	5	54	59		**92%**		**8%**
	Newspaper	6	53	59		**90%**		**10%**
@Mirror Total		173	184	357				
Back-Left	Child-Prone	100	19	119	**84%**		**16%**	
	Child-Standing	93	25	118	**79%**		**21%**	
	Manhole	23	36	59		**61%**		**39%**
	Newspaper	29	32	61		**52%**		**48%**
Back-Left Total		245	112	357				
Farthest	Child-Prone	104	17	121	**86%**		**14%**	
	Child-Standing	86	32	118	**73%**		**27%**	
	Manhole	18	42	60		**70%**		**30%**
	Newspaper	26	35	61		**57%**		**43%**
Farthest Total		234	126	360				
Mid-Bumper	Child-Prone	98	22	120	**82%**		**18%**	
	Child-Standing	80	42	122	**66%**		**34%**	
	Manhole	7	53	60		**88%**		**12%**
	Newspaper	8	54	62		**87%**		**13%**
Mid-Bumper Total		193	171	364				
Mid-Grid	Child-Prone	110	11	121	**91%**		**9%**	
	Child-Standing	110	9	119	**92%**		**8%**	
	Manhole	11	49	60		**82%**		**18%**
	Newspaper	11	48	59		**81%**		**19%**
Mid-Grid Total		242	117	359				
(blank)	None	86	509	595		**86%**		**14%**
(blank) Total		86	509	595				
Grand Total		1173	1219	2392				

Table 10. Detection Performance by Target Location

Mirror	Collapsed Condition	Response		Grand Total	Hits	Correct Rejections	Misses	False Positives
		Child	No Child					
Banana	Child	244	55	299	**82%**		**18%**	
	Foil	36	113	149		**76%**		**24%**
	None	17	133	150		**89%**		**11%**
Banana Total		297	301	598				
10" Spherical-High	Child	234	66	300	**78%**		**22%**	
	Foil	40	111	151		**74%**		**26%**
	None	17	128	145		**88%**		**12%**
Conventional-High Total		291	305	596				
10" Spherical-Low	Child	246	52	298	**83%**		**17%**	
	Foil	30	120	150		**80%**		**20%**
	None	18	132	150		**88%**		**12%**
Conventional-Low Total		294	304	598				
Lookout	Child	219	81	300	**73%**		**27%**	
	Foil	38	112	150		**75%**		**25%**
	None	34	116	150		**77%**		**23%**
Lookout Total		291	309	600				
Grand Total		1173	1219	2392				

Table 11. Dection Performance by Mirror (Collapsed Target Categories)

Reflectivity	Collapsed Condition	Response		Grand Total	Hits	Correct Rejections	Misses	False Positives
		Child	No Child					
Dark	Child	331	68	399	**83%**		**17%**	
	Foil	51	151	202		**75%**		**25%**
	None	22	176	198		**89%**		**11%**
Dark Total		404	395	799				
Medium	Child	300	101	401	**75%**		**25%**	
	Foil	43	157	200		**79%**		**22%**
	None	34	166	200		**83%**		**17%**
Medium Total		377	424	801				
Light	Child	312	85	397	**79%**		**21%**	
	Foil	50	148	198		**75%**		**25%**
	None	30	167	197		**85%**		**15%**
Light Total		392	400	792				
Grand Total		1173	1219	2392				

Table 12. Detection Performance by Reflectivity (Collapsed Target Categories)

For the simple measures of detection performance, there were a number of interesting effects. Among all the cases in which a child was present, there were main effects for mirror, location, child orientation and color. Among the mirrors, the Lookout was less effective than the Banana and conventional mirror mounted at the low height. Since the only mirror tested at the lower height was the conventional, spherical version, it is impossible to discern whether mounting height is a key factor for mirror performance in general. However, it did perform better than its high-mounted counterpart in most cases. The overall radius of curvature of the mirror seemed to be indicative of performance with the smaller radii performing worse. There were also detection performance differences amongst the target locations. The mid-grid location had lower miss rates than all the other locations. And, the point directly under the mirror was worse than the other locations. Figure 5 reflects the detection performance differences (depicted as the miss rate) among the various locations. Figures 6 and 7 add detail to the detection performance picture by differentiating child orientations and mirror differences respectively. The child standing orientation was more difficult to detect than its prone counterpart. This is especially so at the target conditions close to the van/mirror. Figure 7 shows that different mirrors performed worse based on the location. The Lookout, for instance, was especially bad at the locations close to the rear bumper. The targets were more difficult to detect at the medium reflectivity level than either the light or dark reflectivities. Thus, as contrast with the background increased, positively or negatively, detection rate improved.

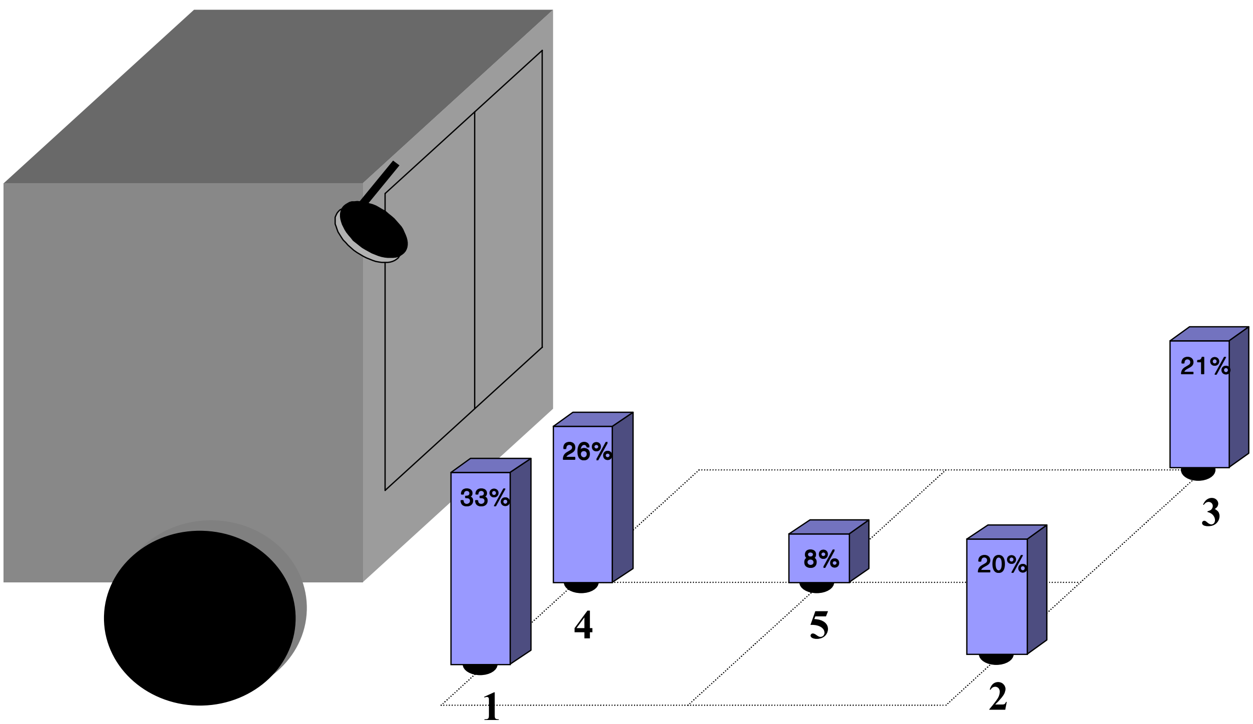


Figure 5. Miss rate by target location

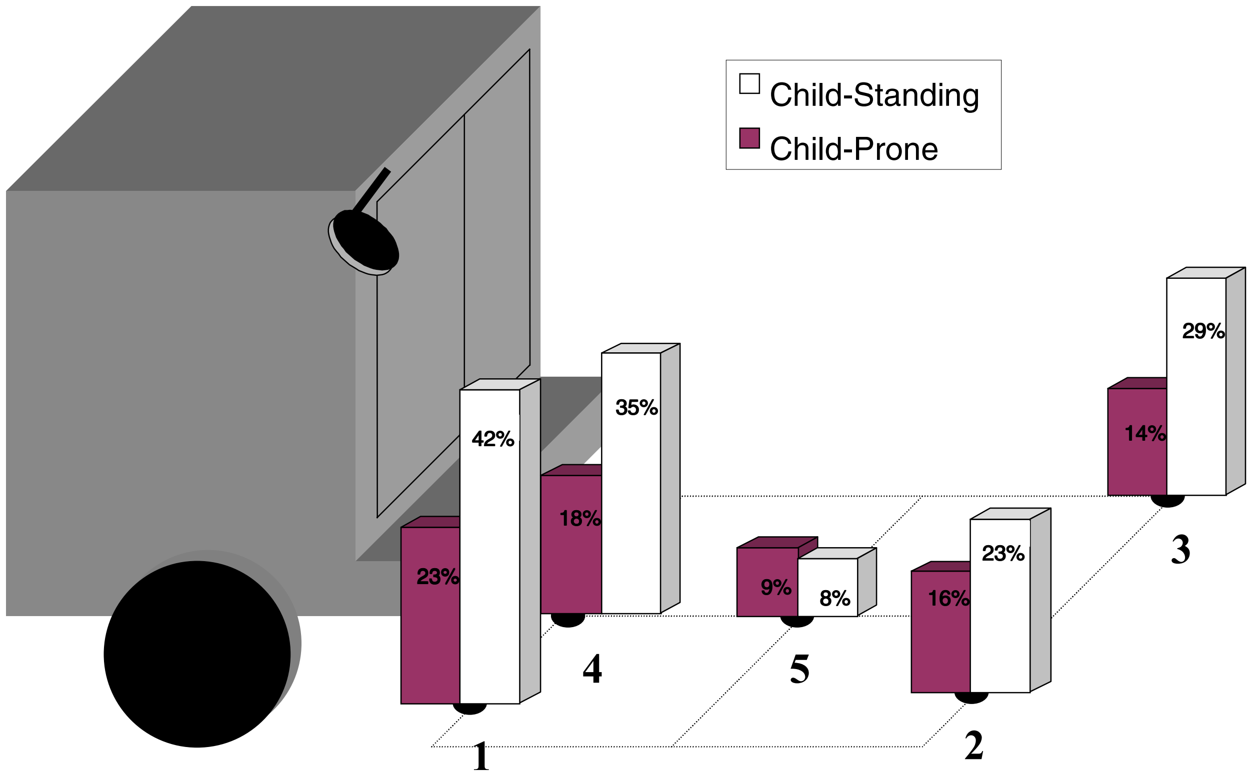


Figure 6. Miss rate by location and target orientation

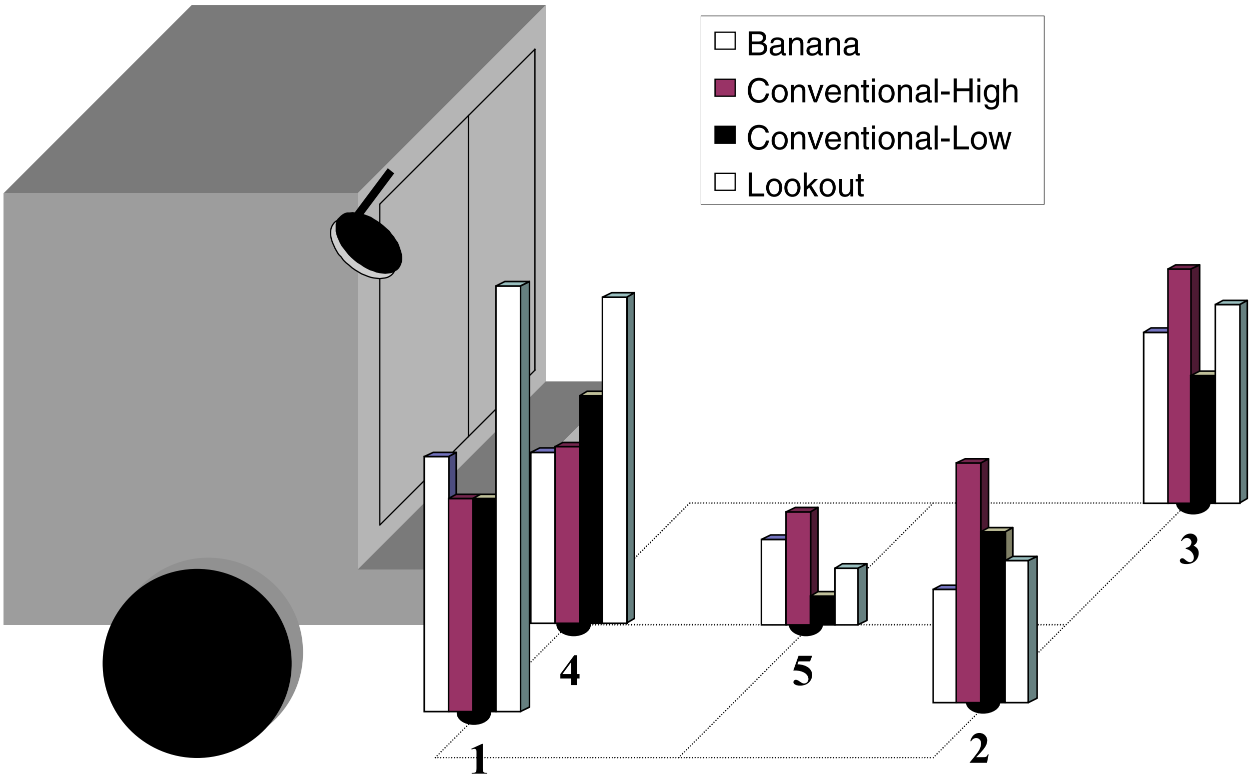


Figure 7. Miss Rate by Mirror and Location

Mirror	Location				
	@Mirror - 1	Back-Left - 2	Farthest - 3	Mid-Bumper - 4	Mid-Grid - 5
Banana	30%	13%	20%	20%	10%
Conventional-High	25%	28%	27%	21%	13%
Conventional-Low	25%	20%	15%	27%	3%
Lookout	50%	17%	23%	38%	7%

Table 13. Miss Rate by Mirror and Location for Figure 7

Since there were differences in the mirrors and by location within the grid area, we expected to find patterns related to the measured levels of minification and distortion for each mirror/target location condition pair. The effects were not clear-cut along these lines. There was a tendency for larger radii of curvature to improve detection and for reduced distortion to have a lesser, but also positive, effect on detection and recognition of the target. These two factors must typically be traded off in the design process. It is interesting to note that the Lookout mirror was better in terms of distortion of the image, though it minified the images at each location more than its counterparts. However, it performed worse than the others in terms of detection performance, confidence-weighted detection, and subjective ratings of goodness seen below.

Some interaction effects were also evident during the analysis. There did not appear to be an effect for the child-prone condition, but the child-standing condition was easier to detect at the mid-grid location than the other four locations. This suggests that for mirror effectiveness testing in future applications, the edges of the mirror are the areas that are most indicative of mirror shortcomings. A reflectivity by location interaction was also evident. This suggests that the medium reflectivity was the most difficult to detect, especially when combined with locations such as those near the mirror and the rear of the van. Targets located on the fringe of the mirrors' fields of view were more difficult to detect when they were light in contrast to the background surface. This may have been a function of the color of the weather-strip material around the edge of the mirror, though a detailed analysis of this possibility was not investigated thoroughly during this effort. The weather-strip around the conventional mirror was white, while the other mirrors had black ones.

Subjective impressions were collected at the end of each session. These impressions included ratings of image quality, distortion and minification on a 1 to 10 scale with high numeric values being assigned to higher levels of goodness. Questions were also asked regarding whether they would like to have each mirror on the vehicle they drive, whether they would use it, how much they would pay for it if they had to buy one, and what could be done to improve each mirror's performance. The data provided by each subject are presented in Table 14. Ratings for image quality, distortion and minification were reduced to interpretable numbers by averaging ambiguous responses (e.g., an answer of "2-3" became 2.5). Likewise, for the amount they would be willing to pay, the upper figure of a given range was taken as the value (e.g., if they said either "\$70-80" or "up to \$80", \$80 was used as their response) and this figure was used for all further computations. Subjective responses were relatively consistent with the detection performance data. The conventional mirror applications were liked the best and the Lookout mirror was typically rated near the bottom in most respects. For instance, Table 15 shows the rankings of the mirrors by the three performance criteria for which subjects rated them.

	CONVENTIONAL HIGH							CONVENTIONAL LOW						
SUBJECT	IMAGE QUALITY	DISTORTION	MINIFICATATION	WOULD YOU LIKE TO HAVE THIS MIRROR? WHY?	WOULD YOU USE THIS ONE?	HOW MUCH WOULD YOU PAY?	HOW COULD IT BE IMPROVED IMPROVED?	IMAGE QUALITY	DISTORTION	MINIFICATATION	WOULD YOU LIKE TO HAVE THIS MIRROR? WHY?	WOULD YOU USE THIS ONE?	HOW MUCH WOULD YOU PAY?	HOW COULD IT BE IMPROVED IMPROVED?
1	5	4	4	no, very distorted	yes	$ -	more clarity, less distortion, larger field of view	10	7	5	yes, good for what's close	yes	$ 200.00	less distortion, larger field of view
2	7.75	8	9	yes, can see almost the whole back of the van	yes	$ 50.00	tilt it differently	7	7	8	no, can see better w/it mounted high	yes	$ 30.00	move it to high position
3	5	4	4	yes, broad spectrum	yes	$ 100.00	little larger	6	5	5	yes, less distortion than conv. High	yes	$ 100.00	
4	3	3	3	no, didn't serve much purpose, check behind van before moving anyway	no, very little	$ 25.00	put it lower	6	6	5	no, didn't serve much purpose, check behind van before moving anyway	no	$ 50.00	
5	7.5	8	7	yes, depth is better than others, at quick glance can tell how far away objects are	yes	$ 50.00		9	6	8	no, too close to bumper, can't see as far back	yes	$ 30.00	move it to high position
6	9	9	9	yes, clear, can tell what's back there, but not as well as banana	yes	$ 100.00		5	5	5	no, don't like at all. Limits view, looking almost directly at bumper	yes	$ 30.00	move it to high position
7	4	3	1	no, not clear enough	yes	$ 20.00	larger, clearer	8	10	10	yes, see bumper very well	yes	$ 20.00	bigger
8	9	8	8	Yes, Good view of what's back ther	yes	$ 100.00		10	8	8	yes, Good view of what's back there	yes	$ 100.00	
9	9	9	9	Yes, Shows bigger area	yes	$ 40.00		7	7	7	no, rather have it hight	yes	$ 35.00	
10	8	6	5	Yes, because not oval	yes	$ 49.95	larger	8	5	6	No, not wide enough range of view	yes	$ -	
						$ 53.50	Average Stated Value						$ 59.50	Average Stated Value
	6.7	6.2	5.9	<== Averages				7.5	6.6	6.7	<== Averages			
	9.0	9.0	9.0	<== Maximums		$ 39.86	Actual Retail Price	10.0	10.0	10.0	<== Maximums		$ 39.86	Actual Retail Price
	3.0	3.0	1.0	<== Minimums			(head only)	5.0	5.0	5.0	<== Minimums			(head only)

Table 14. Subjective Questionnaire Data

	BANANA							LOOKOUT						
SUBJECT	IMAGE QUALITY	DISTORTION	MINIFICATATION	WOULD YOU LIKE TO HAVE THIS MIRROR? WHY?	WOULD YOU USE THIS ONE?	HOW MUCH WOULD YOU PAY?	HOW COULD IT BE IMPROVED IMPROVED?	IMAGE QUALITY	DISTORTION	MINIFICATATION	WOULD YOU LIKE TO HAVE THIS MIRROR? WHY?	WOULD YOU USE THIS ONE?	HOW MUCH WOULD YOU PAY?	HOW COULD IT BE IMPROVED IMPROVED?
1	7	6	7	yes, like better quality of image & field of view	yes	$ 300.00	perfect image quality	3	3	3	no, difficult to use (strain)	yes	$ 100.00	less distortion & minification
2	7	5	8	no, not enough peripheral view (sides)	no	$ 10.00	wider (too small)	10	8	10	yes, see more dead center and side to side	yes	$ 50.00	
3	7	7	6	yes, widest range, can see more	yes	$ 150.00		6	4	4	No, too much distortion	yes	$ 75.00	rounder, too long
4	3	2	2	no, absolutely no benefit	no	$ 10.00		1	1	1	no, the worst mirror	no	$ -	maybe bigger, wider
5	6	6	9	yes, image is more clear & even, can see equally on both sides & center of van	yes	$ 50.00	slightly wider	3	2.5	2	no, far corner ver distorted, right behind van ok, but farther back harder to see/center is best	no	$ -	nothing, it's just lousy
6	10	10	10	yes, easily viewed, can tell what it is back there	yes	$ 100.00		6	7	7	yes, still can see, better than nothing	yes	$ 50.00	better image, different curvature
7	4	5	5	no, can't see around to passenger side	yes	$ 20.00	tilt & turn	5	2	2	no, image, minification & too much distortion	yes	$ 15.00	less minification & clearer image
8	1	1	1	no, can't see anything	no	$ -	clear it up	9	1	5	no, makes things look too small	no	$ -	not so small
9	8	8	9	Yes, can see what's behind me	yes	$ 45.00		7	6	7	maybe, can see what's back there	yes	$ 40.00	
10	3	4	6	No, don't like oval	yes	$ 49.95		10	5	1	No, don't like oval (maybe once familiar w/it)	yes	$ 39.00	larger
						$ 73.50	Average Stated Value						$ 36.90	Average Stated Value
	5.6	5.4	6.3	<== Averages				6.0	4.0	4.2	<== Averages			
	10.0	10.0	10.0	<== Maximums		$ 38.66	Actual Retail Price (head only)	10.0	8.0	10.0	<== Maximums		$ 60.00	Actual Retail Price (head only)
	1.0	1.0	1.0	<== Minimums				1.0	1.0	1.0	<== Minimums			

Table 14 (Cont.) Subjective Questionnaire Data

	Banana	Conventional-Low	Conventional-High	Lookout
Image Quality	5.6	7.5	6.7	6.0
Distortion	5.4	6.6	6.2	4.0
Minification	6.3	6.7	5.9	4.2
Would use it?	7/10	9/10	9/10	7/10
Worth	$73	$59	$53	$37

Table 15. Subjective Quality Rankings

The Lookout was the only mirror whose average ratings fell below the 5.0 level in any of the ratings with distortion at 4.0 and minification at 4.2. The conventional mirrors had higher ranges of ratings with the low-mounted version never falling below 5.0. Rating ranges for the Banana and Lookout were much more diverse with subjects either loving or hating them and providing ratings that reflected those sentiments. More subjects said that they would use the conventional mirrors than the Lookout or Banana. Subjects said that they would be more willing to pay more for the Banana than the others, especially the Lookout which fell at the bottom of this measure. The suggested improvements most often included making the mirror larger, though the low-mounted conventional also had several suggestions to move it higher.

2.0 Physical Measurements

2.1 Introduction

Measurements of field of view (FOV), distortion, visual angle, and minification for the rear cross-view mirrors were compiled to quantify the state-of-the-art in rear cross-view mirror design. These convex mirrors project an image from behind the vehicle on which they are mounted to the side-view mirror. The driver views the image in the rear cross-view mirror by looking in the side-view mirror. The driver is looking at the image of an image in this two-mirror system. The amount of minification depends on three main factors, the line of sight distance of the driver to the rear cross view mirror, the distance of the object from the rear cross-view mirror, and the radius of curvature of the mirror. There is generally a tradeoff between field of view and minification, and field of view and distortion.

The goal of this measurement exercise was to tie mirror measurement characteristics to detection and recognition performance levels from the perception performance study described in the first part or this document. The results allow the mirror design characteristics to be compared with detection and recognition performance.

2.2 Experimental Conditions

In this study, the following parameters were varied as the measurements were made:

- Mounting Height
- Mirror (included size & radius of curvature (ROC))

2.2.1 Mounting Height

Two mounting heights were used for this analysis. These heights corresponded to rear cross-view mirror mounting heights on two different van types for which mounting heights were measured. The "small" van type was based on models such as the Ford Econoline and other full-size utility and conversion vans. The "large" van was based on step vans such as those used by Federal Express and UPS, typically with sufficient headroom to allow users to stand erect inside their cargo areas. Having visited a number of fleet operators and measured the dimensions of many vans, it was clear that there is a great variation in the size of the vans. Table 16 depicts representative dimensions of the two van types as well as relevant measures of the actual van used in the perception study.

Dimension	Typical Small Van (in)	Typical Large Van (in)	Actual Van (in)
Side view mirror height (top)	72	89	88
Rear cross-view mirror height (bottom)	71	86	73 & 91-94
Distance between mirrors	120	180	195
Driver eye height	72	82	82
Driver eye to side mirror distance	25	30	35

Table 16. Van measurements

This portion of the study was performed in a laboratory, and real vans were not used. The mirrors were located at positions, relative to the grid, identical to those used in the perception portion of the study and the measurements were taken.

2.2.2 Mirror Alignment

The alignment of the mirrors was a difficult problem. None of the mirrors used in this study came with instructions on how they should be aimed. Some came with recommendations such as, “make sure the back bumper is visible in the mirror.” But, having the back bumper in view does not define a unique adjustment for the mirror, and in many cases does not provide the “best” alignment for the mirror.

When talking to fleet operators and the drivers of these vehicles it was obvious that they had no formal alignment procedure. The most common alignment procedure was called “the buddy system.” Using this procedure the driver sits in the driver’s seat and his “buddy” adjusts the back mirror until it is in a position the driver likes. This procedure results in a variety of different adjustments.

There are two general alignment strategies that are commonly used. The first scheme maximizes the field of view. Using this procedure, the mirror is adjusted so that the back bumper is just visible in the lower part of the mirror. This permits the remainder of the mirror to capture the largest possible area behind the vehicle. However, the large field of view may suffer substantial distortion and minification. The other scheme involves capturing the area of interest behind the van with the center of the mirror. This tends to reduce the distortion and increase image size for the area of major concern, but will also reduce the field of view. The former method was used in this exercise. It was accomplished by tilting the mirror so that the entire length of the bumper was visible on the edge of the mirror. Further tilting would move the bumper off the mirror. This was called the 'bumper' adjustment.

The viewing position was the drivers eye position. Additionally, the mirror was adjusted laterally such that the center of the image was at the centerline of the vehicle.

2.2.3 Mirror Size and Radius of Curvature

Three mirrors were measured. Table 17 outlines the key dimensions of the mirrors that were measured. Two were studied and measured only at the higher mounting level, while the conventional spherical mirror sample was mounted at two different heights to get feel for the implications that mounting height has on perception performance and static feature measurement characteristics.

Manufacturer	Model	Size	ROC	Retail Cost (Head only)
Rosco	3797SSP	10"	8"	$40.00
Mirror Lite	Banana	12" x 6.75"	7.21" x 9.97"	$38.66
Lo Mar	Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	$60.00

Table 17. Mirror Specs

2.3 Method

The methods used in this study are described in this section. These include the

- General Setup
- Photographic Techniques
- FOV Measurements
- Minification Measurements
- Distortion Measurements

2.3.1 General Setup

This portion of the study was performed in a laboratory setting. No actual vans were used. Mirrors were mounted on a fixture at the position described hereafter. A 10 foot by 10 foot grid was laid out in the area behind the 'van' with 5' crossbars bisecting each side and intersecting at the center of the grid, creating 5' square quadrants. One foot square blocks were placed at the center of each quadrant. A 6.5 foot metal bar was covered with black and yellow checkered tape and was placed in a position representing the bumper of the van. The bumper was 22 inches off the floor. Figure 8 shows the major dimensions of the lab measurement setup including the camera position.

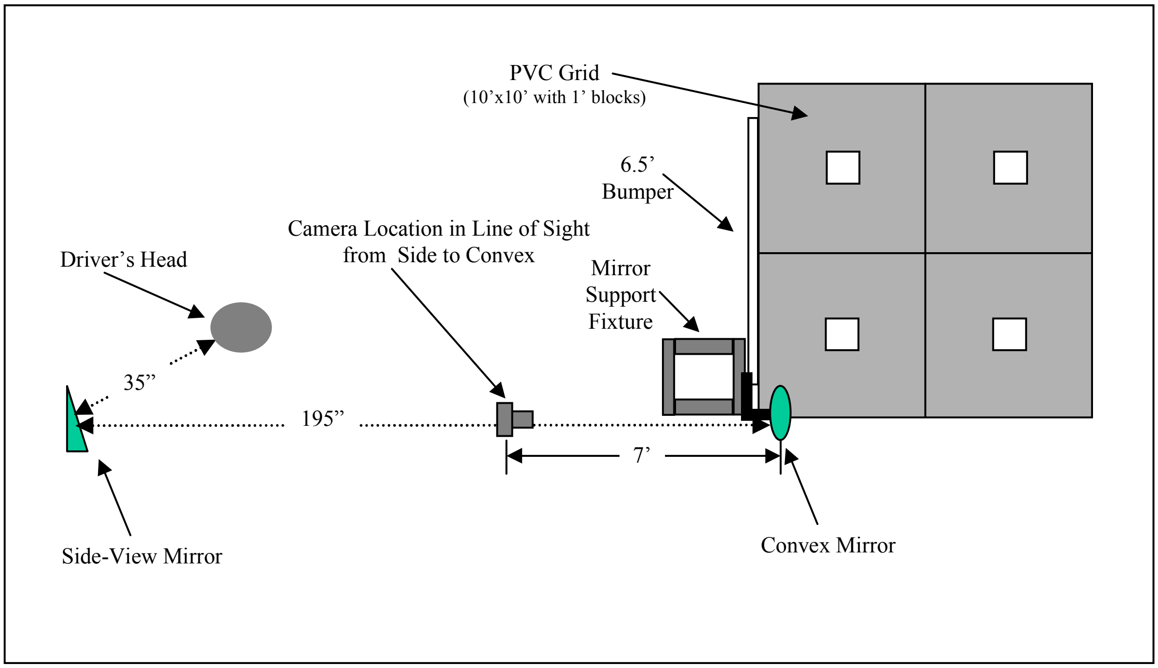


Figure 8. Lab measurement configuration

When used on a van, the image from the cross-view mirror is projected to the side-view mirror, which in turn reflects the image to the driver eye position. Measurement of the image might be made from anywhere along this chain. For this effort, the cross-view mirror was photographed directly, from a camera positioned along the line of sight between the cross-view mirror and the side-view mirror. This improved the image quality and size for purposes of data reduction. Correction factors were then applied to transform the findings to the appropriate scale for images at the side view mirror. The camera was placed 7 feet from the cross-view mirror along the line of sight between the two mirrors. The appropriate correction factors were computed (described below) to make absolute size measurements.

As mentioned earlier, determining the alignment of the rear cross-view mirror was a difficult problem. The "bumper" adjustment, described earlier, produced a large FOV by placing the edge of the bumper on the edge of the mirror. There are many other possible adjustments for these mirrors, but this adjustment provided a reasonable estimate of the mirrors' performance while providing a point of vehicle reference and maximum ground FOV coverage of the mirror for detection tasks.

All of the mirrors were mounted on wooden mounting arms for purposes of quick mounting during the perception performance study. The Lookout mirror had a fixed orientation mounting stud on it's back plate. The Banana had two pivoting mounting studs, though only one was used, and the conventional mirror had a single pivoting mounting screw.

2.3.2 Mirror Adjustment

All of the mirrors were adjusted as follows:

1. Mirrors were attached to the fixture at the same height and orientation during both portions of the study. A common mounting fixture was attached to the rear of the van or a vertical support fixture during the perception and lab measurement portions, respectively.
2. Each mirror was permanently attached to a smaller fixture that included a mounting plate, a horizontal support arm and an angled mirror mounting arm as can be seen in Figure 9. There were several key measures that distinguished each mirror mount from the others. Table 18 lists the key features as labeled in Figure 9. These features were set during the initial design of the study apparatus and were not changed during the duration of both portions of the study.
3. A fixed position bolt was used to attach the smaller individual mirror fixtures to the larger vertical fixture at either the high or low positions during the testing and measurement exercises. Only the conventional spherical convex mirror was mounted at both heights. The other mirrors were only used at the upper height.
4. The Lookout mirror included a fixed mounting stud, whereas the Banana and conventional mirrors included studs that could be adjusted from the default position with the mirror face directly adjacent to the stud being orthogonal to the stud.
5. The conventional mirror was further adjusted to be orthogonal to the plane bisecting the mirror and the centerline of the van. It was also rotated away from the back of the van as far as possible using the pivoting capability of the adjustable stud. This point corresponded to the bumper adjustment described earlier.
6. The Banana mirror included two pivoting studs since it was actually designed for another application. Only one of the studs was used. The stud used was the forward-most stud on the mirror. This mirror, like the conventional, was rotated as far away as possible from the back of the van using the pivoting capability of the adjustable stud. It, too, was adjusted so that its longitudinal centerline was coplanar with the plane defined by the mirror and the centerline of the van.

Manufacturer & Model	1 (inches)	2 (deg.)	3 (inches)	4 (deg.)	5 (inches)
Rosco (#3799SSP)	8.50	26	10.75	55	8
Lo Mar Lookout	8.00	26	10.75	71	9
Mirror Lite Banana	8.25	27	10.75	55	11

Table 18. Mirror adjustment parameters from Figure 9.

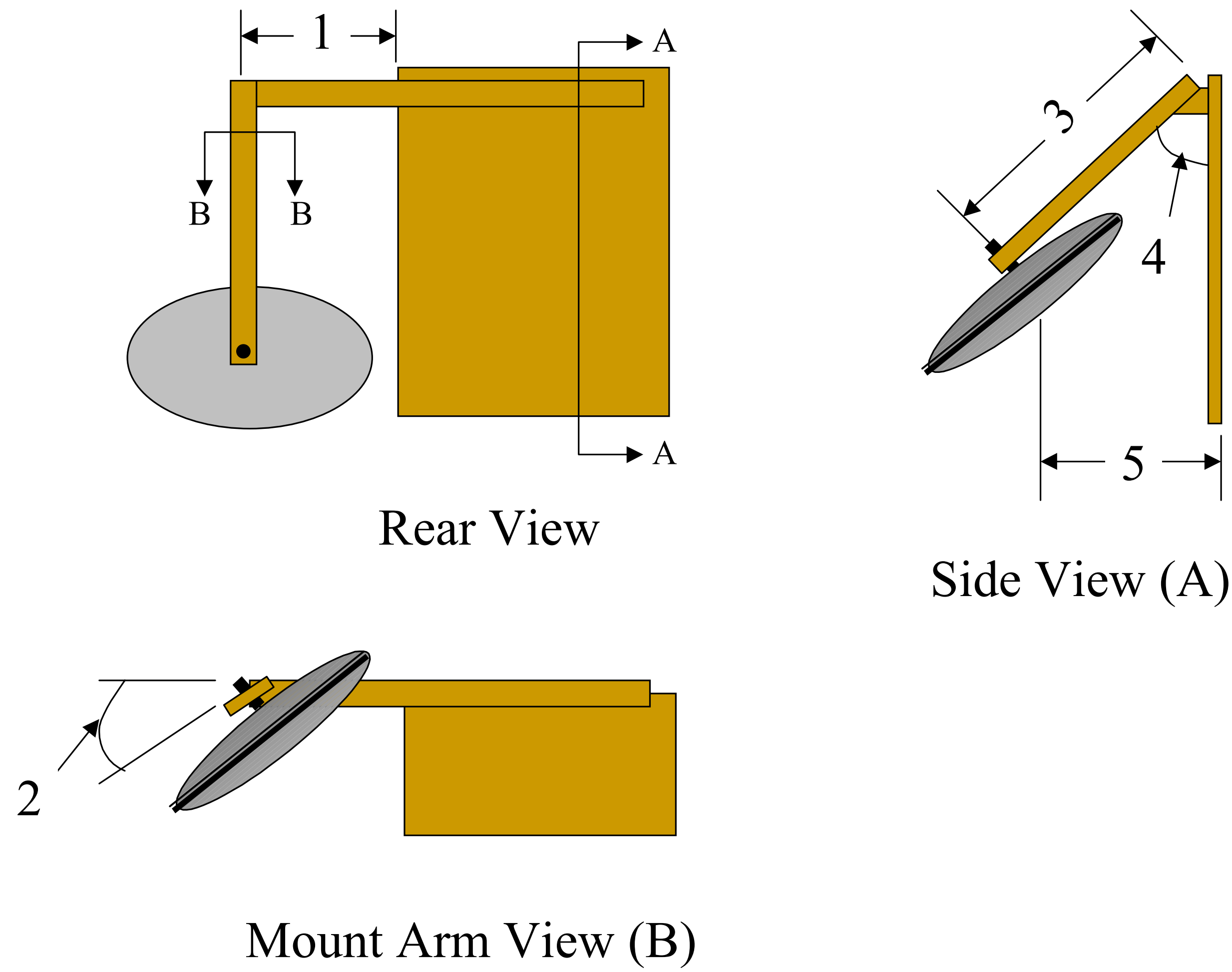


Figure 9. Mirror Adjustment Key

2.3.3 Photographic Techniques

All of the pictures were taken with a 35mm camera. All pictures were taken with the lens zoomed to 210mm. The close-up pictures of the convex mirrors were taken with an f-8 f-stop. The film was Kodak Ektachrome 400 slide film. Slide film was used so that the images could be projected to a large size, making the measurements easier to record.

As described earlier, the camera was placed in the line of sight between the side-view mirror and the rear cross-view mirror. This allowed the maximum image size to be photographed. The camera was placed seven feet from the cross-view mirror. The camera was zoomed in so that the image filled the majority of the slide.

2.4 Measurements

2.4.1 Field of View

The field of view was not measured during this exercise because the entire 10' x 10' grid was visible in all the mirror conditions tested. The grid, used in both phases of this study, was completely visible in all of the mirrors with them adjusted as described above. The 10' x 10' area represents a minimum area behind the van which should be visible to the driver to allow avoidance of objects or pedestrians that come into it during backing. It allows the driver to see the full length of the rear bumper as well as 10' behind the van. This area provides a small safety margin over the stopping distance norms as measured in Harpster, Huey, Lerner, and Steinberg (1996). Only ground level coverage was considered for this metric of mirror performance. It is unlikely and undesirable to expect that future mirror designs would provide a field of view less than the 10' x 10' area used in this exercise.

2.4.2 Minification

Minification is defined as the ratio of the actual size object to the image size on the side view mirror. Minification measurements were taken for the following:

- The entire 10 by 10 foot grid
- Each quadrant of the 10 by 10 foot grid (5 by 5 foot areas)
- The center square in each quadrant (1 by 1 foot areas)
- At each of the five target locations (1 by 1 foot areas)
- At each of the five target locations (child-standing silhouette)
- At each of the five target locations (child-prone silhouette)

The calculation of the minification factor is a simple ratio of two areas (the area on the grid and the area on side view mirror). Due to various distortions in the optics, the "squares" visible on the side view mirror were not perfectly square. In order to calculate the area of these "squares" the following approximation was used. Measurements were made between endpoints of a given "square's" side, ignoring the curvature of the connecting line. Opposite sides of the squares were summed and averaged. The averaged values were then multiplied which resulted in the approximate area for the square at the side-view mirror location. The set of measurements at each of the target locations was used to get the location-specific minification and distortion measures used in the analysis of detection performance.

Since the camera position was not at the driver's eye position, but closer to the convex mirror, correction factors were needed to convert the photographic image sizes to the size at the side-view mirror. The correction factors were determined and applied using the following procedure.

1. A photograph was taken of an object of a known length (e.g., a ruler). The object was placed next to the convex mirror. (The same camera position was used for the rest of the close-up photographs.)
2. The close-up image of this object at the convex mirror was used to create the first correction factor. The first correction factor expressed the magnification of the projected image at the position of the

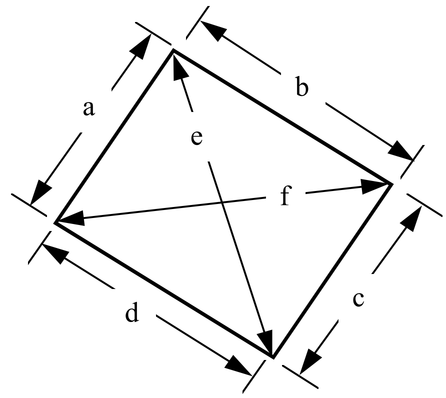
convex mirror. (e.g. One inch on a ruler (absolute size) is equivalent to 3.5 inches on the projected slide.)

3. A second photograph was taken of an object of know length (e.g., a ruler) located near the side-view mirror. This shot was difficult since it required not only the side-view mirror to be in focus, but also the convex mirror and its subject, the grid. This photograph was necessary because it was very difficult to accurately measure the grid or convex mirror size at the side view mirror without binocular parallax and other optic phenomena causing significant errors.
4. Next, the second correction factor was calculated. The second correction factor measured the enlargement of the projected convex mirror and grid image versus the actual image size at the side view mirror.
5. Then, photographs of the grid taken (and projected) from the same location as the first correction factor photograph (and projection) were corrected using the following steps.
6. Each grid line was measured and documented on a coding sheet from the projected image of the grid within the close-up photo of a given convex mirror.
7. These projected measures were then corrected to actual dimensions at the convex mirror using the first correction factor. This correction involved multiplying the projected grid dimensions by 0.539.
8. These corrected dimensions were then corrected a second time to convert them from actual size at the convex mirror to actual size at the side-view mirror. This correction involved multiplying the actual dimensions at the convex mirror by 0.1403.
9. Thus, for calculating the actual side-view mirror dimension from the projected close-up photograph at the convex mirror, those dimensions could have simply been multiplied by 0.07566.
10. The first correction factor measured the magnitude of the magnification due to projection of the image, and the second correction factor measured the minification due to the distance from the side-view mirror. The product of correction factors defined the equivalent minification of the 10' x 10' grid at the side-view mirror, a commonly accepted metric of minification.

2.4.3 Distortion

There are many possible ways to calculate distortion values for the images produced by the convex mirrors. The method used here was developed by Satoh, Yamanaka, Kondoh, Yamashita, Matsuzaki, and Akizuki (1983). There are two steps to this procedure. The first is to calculate the quantitative shape change ε. Second, the qualitative shape change is related to psychological perceptual categories.

The quantitative shape change is calculated as follows.



$\varepsilon_1 = (a + c)/(b + d)$ $\qquad \varepsilon_2 = 1/\varepsilon_1$

$\varepsilon_3 = e/f$ $\qquad \varepsilon_4 = 1/\varepsilon_3$

ε = Maximum of ε_1, ε_2, ε_3, and ε_4.

Figure 10. Computation of change shape factor (from Satoh, et al., 1983)

The perceptual implications associated with various of ε are shown in Table 19, which is also taken from Satoh, et al., 1983.

Level	Degree of Image Form	Degree of Image Shape Change	Shape Change Factor ε
5	Excellent	No Image Shape Change	1 2
4	Good	Visible but no Problem	3 4
3	Fair	Visible but Possible to Judge	5 6
2	Poor	Large and Hinders Judgement	7 8
1	Very Poor	Impossible to Judge	9

Table 19. Shape change factor versus psychological category

Measurements were calculated for the following squares.

- The entire 10 by 10 foot grid
- Each quadrant of the 10 by 10 foot grid (5 by 5 foot areas)
- The center square in each quadrant (1 by 1 foot areas)

Squares were assigned the following numbers.

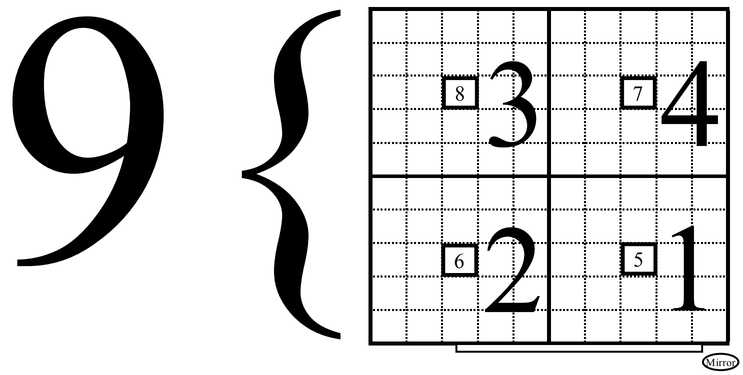


Figure 11. Square numbering scheme.

2.4.4 Visual Angle

The visual angle is the angle subtended by an object at the drivers' eye. The visual angle has some relationship to the minification. Each is affected by increasing the distance from the viewer to the object. However, the relative measure of minification is not related to the size of the object. It expresses the amount of size reduction from the actual object to the reflected image at the side-view mirror. On the other hand, the absolute measure of the visual angle of an object increases with the size of the object. The visual angle will tell you how large the image will be at the observer's eye and in effect the visibility of the object.

In this study, the visual angle for each of the squares was collected and documented in Table 21 and Table 22. However, the critical measures are for the smallest squares (i.e., 5-8) which measured one square foot in real life. These measures were calculated for each of the mirror conditions. The size of the image on the cross-view mirror was measured in the photographs, and the visual angle calculated by using the trigonometric relationship of the image size and the distance to the driver's eye position. Satoh et al., 1983, developed a psychological scale relating the visual angle to the image visibility. This scale is shown in Table 20 below.

Level	Degree of image form	Degree of image size	Visual Angle (min)
1	Excellent	No image small	51+
2	Good	Small, but no problem	21-50
3	Fair	Small, but possible to judge	11-20
4	Poor	Small and hinders judgment	5-10
5	Very Poor	Impossible to judge	<5

Table 20. Subtended visual angle versus psychological category

															Average Projected Image Size			
									Side Measures (in cm)						Metric		English	
									Left	Top	Right	Bottom	\	/	Verticals	Horizontals	Verticals	Horizontals
Condition	Mirror Model	Size	ROC	Height	Adj	Square#	Shelley's #	Area	a	b	c	d	e	f	(cm)	(cm)	(inches)	(inches)
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	1	5	25	6.4	16.3	7.2	13.8	15.7	17.2	6.80	15.05	2.67716	5.92519
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	2	6	25	4.9	10.5	6.4	8.8	10.3	11.9	5.65	9.65	2.22441	3.79921
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	3	7	25	3.1	11.4	3.3	10.5	10.3	12.3	3.20	10.95	1.25984	4.31102
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	4	8	25	3.3	16.6	3.0	16.3	16.6	17.0	3.15	16.45	1.24016	6.47637
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	5	1	1	1.4	3.3	1.4	3.1	3.2	3.2	1.40	3.20	0.55118	1.25984
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	6	2	1	1.1	2.1	1.2	2.0	2.1	2.5	1.15	2.05	0.45276	0.80709
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	7	4	1	0.6	3.6	0.7	3.6	3.5	3.7	0.65	3.60	0.25591	1.41732
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	8	3	1	0.6	2.4	0.7	2.4	2.3	2.8	0.65	2.40	0.25591	0.94488
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	9	9	100	8.0	27.4	10.3	22.3	25.2	27.4	9.15	24.85	3.60236	9.78345
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	1	5	25	6.8	20.1	8.2	16.5	19.5	20.0	7.50	18.30	2.95275	7.20471
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	2	6	25	5.0	11.0	6.8	9.1	11.0	12.1	5.90	10.05	2.32283	3.95669
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	3	7	25	3.0	11.6	3.0	11.0	11.2	12.3	3.00	11.30	1.18110	4.44881
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	4	8	25	3.0	20.7	2.7	20.1	21.0	20.1	2.85	20.40	1.12205	8.03148
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	5	1	1	1.5	4.0	1.6	3.9	4.1	4.4	1.55	3.95	0.61024	1.55512
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	6	2	1	1.1	2.0	1.3	2.0	2.2	2.4	1.20	2.00	0.47244	0.78740
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	7	4	1	0.6	4.3	0.6	4.3	4.6	4.6	0.60	4.30	0.23622	1.69291
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	8	3	1	0.6	2.4	0.6	2.4	2.3	2.6	0.60	2.40	0.23622	0.94488
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	9	9	100	7.9	31.3	10.6	25.3	29.4	30.0	9.25	28.30	3.64173	11.14171
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	1	5	25	5.4	14.1	6.3	11.4	13.2	14.5	5.85	12.75	2.30315	5.01968
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	2	6	25	4.0	8.8	5.4	7.4	8.8	9.7	4.70	8.10	1.85039	3.18897
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	3	7	25	2.9	9.5	2.9	8.8	8.7	10.3	2.90	9.15	1.14173	3.60236
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	4	8	25	2.9	15.0	2.8	14.1	14.4	15.2	2.85	14.55	1.12205	5.72834
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	5	1	1	1.2	2.6	1.8	2.5	2.7	3.0	1.50	2.55	0.59055	1.00394
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	6	2	1	0.9	1.6	1.1	1.5	1.7	2.0	1.00	1.55	0.39370	0.61024
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	7	4	1	0.5	2.9	0.5	2.9	2.9	3.0	0.50	2.90	0.19685	1.14173
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	8	3	1	0.6	1.8	0.6	1.8	1.7	2.1	0.60	1.80	0.23622	0.70866
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	9	9	100	6.8	24.0	9.0	18.5	21.2	23.7	7.90	21.25	3.11023	8.36613
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	1	5	25	5.6	9.0	6.6	7.8	10.0	10.2	6.10	8.40	2.40157	3.30708
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	2	6	25	4.0	6.5	5.6	5.2	6.0	8.8	4.80	5.85	1.88976	2.30315
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	3	7	25	3.1	7.0	3.6	6.5	5.7	9.0	3.35	6.75	1.31890	2.65748
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	4	8	25	3.6	9.7	3.7	9.0	9.4	10.5	3.65	9.35	1.43701	3.68110
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	5	1	1	1.3	1.8	1.4	1.7	2.1	2.2	1.35	1.75	0.53150	0.68898
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	6	2	1	0.9	1.2	0.9	1.2	1.2	1.7	0.90	1.20	0.35433	0.47244
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	7	4	1	0.7	2.0	0.7	2.0	1.9	2.1	0.70	2.00	0.27559	0.78740
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	8	3	1	0.7	1.5	0.7	1.5	1.1	1.9	0.70	1.50	0.27559	0.59055
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	9	9	100	7.6	16.0	10.3	12.7	14.7	18.4	8.95	14.35	3.52362	5.64960

Table 21. Individual Mirror Component and Grid Measurements

			At the Side-View Mirror									
			Minified Image Size									
Condition	Square#	Area	Verticals (inches)	Horizontals (inches)	Minified Area (square inches)	Square Minification Ratio (percent)	Linear Minification Ratio (percent)	Distortion (V/H) (percent)	Shape Distortion Factor (E)	Degree of Image Form Rating	Visual Angle Subtended (minutes)	Subtended Angle Rating
Conventional - High	1	25	0.20255	0.44829	0.0908011	0.0025%	0.5022%	45%	2.2	Good	29.6	Good
Conventional - High	2	25	0.16830	0.28744	0.0483750	0.0013%	0.3666%	59%	1.7	Excellent	21.6	Good
Conventional - High	3	25	0.09532	0.32616	0.0310892	0.0009%	0.2939%	29%	3.4	Good	17.3	Fair
Conventional - High	4	25	0.09383	0.48999	0.0459750	0.0013%	0.3574%	19%	5.2	Fair	21.1	Good
Conventional - High	5	1	0.04170	0.09532	0.0039749	0.0028%	0.5254%	44%	2.3	Good	6.2	Poor
Conventional - High	6	1	0.03425	0.06106	0.0020917	0.0015%	0.3811%	56%	1.8	Excellent	4.5	Very Poor
Conventional - High	7	1	0.01936	0.10723	0.0020762	0.0014%	0.3797%	18%	5.5	Fair	4.5	Very Poor
Conventional - High	8	1	0.01936	0.07149	0.0013841	0.0010%	0.3100%	27%	3.7	Good	3.7	Very Poor
Conventional - High	9	100	0.27255	0.74020	0.2017405	0.0014%	0.3743%	37%	2.7	Good	44.1	Good
Conventional - Low	1	25	0.22340	0.54510	0.1217749	0.0034%	0.5816%	41%	2.4	Good	34.3	Good
Conventional - Low	2	25	0.17574	0.29936	0.0526094	0.0015%	0.3823%	59%	1.7	Excellent	22.5	Good
Conventional - Low	3	25	0.08936	0.33659	0.0300777	0.0008%	0.2890%	27%	3.8	Good	17.0	Fair
Conventional - Low	4	25	0.08489	0.60765	0.0515847	0.0014%	0.3785%	14%	7.2	Poor	22.3	Good
Conventional - Low	5	1	0.04617	0.11766	0.0054322	0.0038%	0.6142%	39%	2.5	Good	7.2	Poor
Conventional - Low	6	1	0.03574	0.05957	0.0021294	0.0015%	0.3845%	60%	1.7	Excellent	4.5	Very Poor
Conventional - Low	7	1	0.01787	0.12808	0.0022891	0.0016%	0.3987%	14%	7.2	Poor	4.7	Very Poor
Conventional - Low	8	1	0.01787	0.07149	0.0012776	0.0009%	0.2979%	25%	4.0	Good	3.5	Very Poor
Conventional - Low	9	100	0.27553	0.84296	0.2322596	0.0016%	0.4016%	33%	3.1	Good	47.3	Good
Banana	1	25	0.17425	0.37978	0.0661777	0.0018%	0.4288%	46%	2.2	Good	25.3	Good
Banana	2	25	0.14000	0.24127	0.0337776	0.0009%	0.3063%	58%	1.7	Excellent	18.1	Fair
Banana	3	25	0.08638	0.27255	0.0235432	0.0007%	0.2557%	32%	3.2	Good	15.1	Fair
Banana	4	25	0.08489	0.43340	0.0367920	0.0010%	0.3197%	20%	5.1	Fair	18.8	Fair
Banana	5	1	0.04468	0.07596	0.0033937	0.0024%	0.4855%	59%	1.7	Excellent	5.7	Poor
Banana	6	1	0.02979	0.04617	0.0013752	0.0010%	0.3090%	65%	1.6	Excellent	3.6	Very Poor
Banana	7	1	0.01489	0.08638	0.0012865	0.0009%	0.2989%	17%	5.8	Fair	3.5	Very Poor
Banana	8	1	0.01787	0.05362	0.0009582	0.0007%	0.2580%	33%	3.0	Good	3.0	Very Poor
Banana	9	100	0.23532	0.63297	0.1489469	0.0010%	0.3216%	37%	2.7	Good	37.9	Good
Lookout	1	25	0.18170	0.25021	0.0454626	0.0013%	0.3554%	73%	1.4	Excellent	20.9	Good
Lookout	2	25	0.14298	0.17425	0.0249140	0.0007%	0.2631%	82%	1.2	Excellent	15.5	Fair
Lookout	3	25	0.09979	0.20106	0.0200629	0.0006%	0.2361%	50%	2.0	Good	13.9	Fair
Lookout	4	25	0.10872	0.27851	0.0302796	0.0008%	0.2900%	39%	2.6	Good	17.1	Fair
Lookout	5	1	0.04021	0.05213	0.0020961	0.0015%	0.3815%	77%	1.3	Excellent	4.5	Very Poor
Lookout	6	1	0.02681	0.03574	0.0009582	0.0007%	0.2580%	75%	1.3	Excellent	3.0	Very Poor
Lookout	7	1	0.02085	0.05957	0.0012421	0.0009%	0.2937%	35%	2.9	Good	3.5	Very Poor
Lookout	8	1	0.02085	0.04468	0.0009316	0.0006%	0.2544%	47%	2.1	Good	3.0	Very Poor
Lookout	9	100	0.26659	0.42744	0.1139516	0.0008%	0.2813%	62%	1.6	Excellent	33.2	Good

Table 22. Mirror Performance Metrics

2.5 Results

The result of this study are divided in the following categories:

- Field of View Measurements
- Minification Measurements
- Distortion Measurements
- Visual Angle Measurements

Tables 21 through 24 display the raw measurements from the projected images and the calculated metrics, respectively, from each of the categories listed above. Individual descriptions of the metrics are provided below under the category headings. Tables 21 and 22 correspond to the grid-concentric measurements, while Tables 23 and 24 correspond to the target location-specific measurements used in the later analyses.

2.5.1 Field of View

As described above, FOV measurements were not made for this study.

2.5.2 Minification

Table 22 displays the minification ratio for each of the squares defined in Figure 10 for each of the mirror/height conditions. The minification ratio is the ratio of the actual size of a square on the grid to the size of the image on the side view mirror. The linear ratio is the square root of the area minification ratio. To provide insight about the magnitude of the minification, the length of the longest (because of distortion) dimension of the 10' x 10' grid at the side view mirror was almost an inch. The smaller of these 10' x 10' grid dimensions was less than a quarter inch in length. Thus, the one foot squares were on the order of one tenth of an inch along their major dimension at the side-view mirror. This is obviously quite small and seems to be a dimension that could and should be improved within future innovations. Table 24 is analogous to Table 22 except that it provides details of the measurements associated with the one foot squares and the standing and prone child silhouettes and the amount of minification that they were subjected to during the detection performance evaluation portion of the study.

2.5.3 Distortion

Table 22 also shows the results of the distortion measurements for each of the mirrors. The distortion measurements are shown for each of 9 squares in the 10 by 10 grid delineated in Figure 10. This measure showed a pattern that was interesting when contrasted with minification and visual angle results. Essentially, it showed that the area behind the right rear wheel of the van was the least distorted of any of the quadrants for all of the mirror/height combinations. In contrast, the minification and visual angle metrics appeared to be at their best directly beneath the mirror location, since that was the point closest to the convex mirror and minification is inversely proportional to viewing distance. This suggests that it may be possible to optimize the distortion characteristics of a mirror applied to this task. If such optimization could occur within the constraints of the necessary FOV requirements, then one could concentrate on the task of improving the visual angle deficiencies. Again, Table 24 is analogous Table 22 except for its target location-based measures.

									Side Measures (in cm)				Average Projected Image Size			
													Metric		English	
									Left	Top	Right	Bottom	Verticals	Horizontals	Verticals	Horizontals
Condition	Mirror Model	Size	ROC	Height	Adj	Location	Shape	Area	a	b	c	d	(cm)	(cm)	(inches)	(inches)
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	@Mirror	Square	1	2.1	3.3	2.2	3.5	2.15	3.40	0.84646	1.33858
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Bumper	Square	1	1.8	2.5	2.0	2.6	1.90	2.55	0.74803	1.00394
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Grid	Square	1	1.2	2.9	1.3	3.0	1.25	2.95	0.49213	1.16142
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Farthest	Square	1	0.6	1.7	0.6	1.7	0.60	1.70	0.23622	0.66929
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Back-Left	Square	1	0.6	3.8	0.8	3.7	0.70	3.75	0.27559	1.47638
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Big Square	Square	100	9.8	24.2	13.4	27.1	11.60	25.65	4.56692	10.09841
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	@Mirror	Dummy-Standing	0.5	5.3	1.8	5.3	1.8	5.30	1.80	2.08661	0.70866
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Bumper	Dummy-Standing	1.5	8.0	1.8	8.0	1.8	8.00	1.80	3.14960	0.70866
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Grid	Dummy-Standing	3	9.5	1.8	9.5	1.8	9.50	1.80	3.74015	0.70866
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Farthest	Dummy-Standing	3	7.9	1.1	7.9	1.1	7.90	1.10	3.11023	0.43307
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Back-Left	Dummy-Standing	3	8.1	1.9	8.1	1.9	8.10	1.90	3.18897	0.74803
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	@Mirror	Dummy-Prone	3	9.9	2.6	9.9	2.6	9.90	2.60	3.89763	1.02362
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Bumper	Dummy-Prone	3	7.3	2.1	7.3	2.1	7.30	2.10	2.87401	0.82677
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Mid-Grid	Dummy-Prone	3	9.3	1.7	9.3	1.7	9.30	1.70	3.66141	0.66929
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Farthest	Dummy-Prone	3	5.8	1.8	5.8	1.8	5.80	1.80	2.28346	0.70866
Conventional - High	Rosco - 3797SSP	10"	8 "	High	Bumper	Back-Left	Dummy-Prone	3	11.8	1.2	11.8	1.2	11.80	1.20	4.64566	0.47244
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	@Mirror	Square	1	2.4	4.3	2.5	4.6	2.45	4.45	0.96457	1.75197
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Bumper	Square	1	2.0	2.9	2.1	3.0	2.05	2.95	0.80709	1.16142
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Grid	Square	1	1.3	3.6	1.2	3.6	1.25	3.60	0.49213	1.41732
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Farthest	Square	1	0.6	1.7	0.6	1.7	0.60	1.70	0.23622	0.66929
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Back-Left	Square	1	0.7	5.2	0.8	5.0	0.75	5.10	0.29528	2.00787
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Big Square	Square	100	9.9	28.8	14.8	33.2	12.35	31.00	4.86220	12.20470
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	@Mirror	Dummy-Standing	0.5	8.2	2.0	8.2	2.0	8.20	2.00	3.22834	0.78740
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Bumper	Dummy-Standing	1.5	11.0	2.0	11.0	2.0	11.00	2.00	4.33070	0.78740
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Grid	Dummy-Standing	3	13.4	2.0	13.4	2.0	13.40	2.00	5.27558	0.78740
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Farthest	Dummy-Standing	3	8.4	0.6	8.4	0.6	8.36	0.60	3.29015	0.23622
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Back-Left	Dummy-Standing	3	12.9	1.1	12.9	1.1	12.90	1.10	5.07873	0.43307
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	@Mirror	Dummy-Prone	3	13.5	2.8	13.5	2.8	13.50	2.80	5.31495	1.10236
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Bumper	Dummy-Prone	3	8.7	2.2	8.7	2.2	8.70	2.20	3.42519	0.86614
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Mid-Grid	Dummy-Prone	3	10.9	2.2	10.9	2.2	10.90	2.20	4.29133	0.86614
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Farthest	Dummy-Prone	3	6.3	1.1	6.3	1.1	6.30	1.10	2.48031	0.43307
Conventional - Low	Rosco - 3797SSP	10"	8 "	Low	Bumper	Back-Left	Dummy-Prone	3	14.0	1.1	14.0	1.1	14.00	1.10	5.51180	0.43307
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	@Mirror	Square	1	1.8	2.8	1.8	3.0	1.80	2.90	0.70866	1.14173
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Bumper	Square	1	1.5	2.3	1.6	2.3	1.55	2.30	0.61024	0.90551
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Grid	Square	1	1.1	2.6	1.1	2.6	1.10	2.60	0.43307	1.02362
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Farthest	Square	1	0.6	1.6	0.6	1.6	0.60	1.60	0.23622	0.62992
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Back-Left	Square	1	0.6	3.4	0.6	3.4	0.60	3.40	0.23622	1.33858
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Big Square	Square	100	8.5	21.2	10.8	25.1	9.65	23.15	3.79921	9.11416
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	@Mirror	Dummy-Standing	0.5	4.3	1.9	4.3	1.9	4.30	1.90	1.69291	0.74803
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Bumper	Dummy-Standing	1.5	7.0	1.2	7.0	1.2	7.00	1.20	2.75590	0.47244
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Grid	Dummy-Standing	3	8.4	1.5	8.4	1.5	8.40	1.50	3.30708	0.59055
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Farthest	Dummy-Standing	3	7.3	0.9	7.3	0.9	7.30	0.90	2.87401	0.35433
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Back-Left	Dummy-Standing	3	8.0	1.9	8.0	1.9	8.00	1.90	3.14960	0.74803
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	@Mirror	Dummy-Prone	3	8.5	2.1	8.5	2.1	8.50	2.10	3.34645	0.82677
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Bumper	Dummy-Prone	3	6.5	1.6	6.5	1.6	6.50	1.60	2.55905	0.62992
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Mid-Grid	Dummy-Prone	3	8.2	1.9	8.2	1.9	8.20	1.90	3.22834	0.74803
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Farthest	Dummy-Prone	3	5.9	1.2	5.9	1.2	5.90	1.20	2.32283	0.47244
Banana	Mirror Lite - Banana	12" x 6.75"	7.21" x 9.97"	High	Bumper	Back-Left	Dummy-Prone	3	10.2	1.0	10.2	1.0	10.20	1.00	4.01574	0.39370
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	@Mirror	Square	1	1.7	1.9	1.8	2.0	1.75	1.95	0.68898	0.76772
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Bumper	Square	1	1.4	1.6	1.6	1.6	1.50	1.60	0.59055	0.62992
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Grid	Square	1	1.3	1.9	1.2	1.9	1.25	1.90	0.49213	0.74803
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Farthest	Square	1	0.6	1.4	0.6	1.4	0.60	1.40	0.23622	0.55118
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Back-Left	Square	1	0.6	2.2	0.5	2.3	0.55	2.25	0.21654	0.88583
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Big Square	Square	100	8.3	14.8	12.4	17.4	10.35	16.10	4.07480	6.33857
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	@Mirror	Dummy-Standing	0.5	3.0	1.4	3.0	1.4	3.00	1.40	1.18110	0.55118
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Bumper	Dummy-Standing	1.5	5.1	1.2	5.1	1.2	5.10	1.20	2.00787	0.47244
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Grid	Dummy-Standing	3	5.6	1.8	5.6	1.8	5.60	1.80	2.20472	0.70866
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Farthest	Dummy-Standing	3	5.0	1.4	5.0	1.4	5.00	1.40	1.96850	0.55118
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Back-Left	Dummy-Standing	3	4.1	1.3	4.1	1.3	4.10	1.30	1.61417	0.51181
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	@Mirror	Dummy-Prone	3	5.8	1.8	5.8	1.8	5.80	1.80	2.28346	0.70866
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Bumper	Dummy-Prone	3	4.8	1.8	4.8	1.8	4.80	1.80	1.88976	0.70866
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Mid-Grid	Dummy-Prone	3	6.0	1.5	6.0	1.5	6.00	1.50	2.36220	0.59055
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Farthest	Dummy-Prone	3	4.7	0.8	4.7	0.8	4.70	0.80	1.85039	0.31496
Lookout	Lo Mar - Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Bumper	Back-Left	Dummy-Prone	3	6.4	0.9	6.4	0.9	6.40	0.90	2.51968	0.35433

Table 23. Target Location-Based Individual Mirror Component and Grid Measurements

							At the Side-View Mirror										
							Minified Image Size			Square	Linear	Distortion	Distortion	Shape Distortion	Degree of	Visual Angle	Subtended
							Verticals	Horizontals	Minified Area	Minification Ratio	Minification Ratio	(V/H)	(1/V/H)	Factor (Max of	Image Form	Subtended	Angle
Condition	**Size**	**ROC**	**Height**	**Location**	**Shape**	**Area**	(inches)	(inches)	(square inches)	(percent)	(percent)	(percent)		Distortion) (E)	Rating	(minutes)	Rating
Conventional - High	10"	8 "	High	@Mirror	Square	1	0.06404	0.10127	0.0064858	0.0045%	0.6711%	63%	1.6	1.6	Excellent	7.9	Poor
Conventional - High	10"	8 "	High	Mid-Bumper	Square	1	0.05659	0.07596	0.0042987	0.0030%	0.5464%	75%	1.3	1.3	Excellent	6.4	Poor
Conventional - High	10"	8 "	High	Mid-Grid	Square	1	0.03723	0.08787	0.0032717	0.0023%	0.4767%	42%	2.4	2.4	Good	5.6	Poor
Conventional - High	10"	8 "	High	Farthest	Square	1	0.01787	0.05064	0.0009050	0.0006%	0.2507%	35%	2.8	2.8	Good	3.0	Very Poor
Conventional - High	10"	8 "	High	Back-Left	Square	1	0.02085	0.11170	0.0023290	0.0016%	0.4022%	19%	5.4	5.4	Fair	4.7	Poor
Conventional - High	10"	8 "	High	Big Square	Square	100	0.34553	0.76403	0.2639921	0.0018%	0.4282%	45%	2.2	2.2	Good	50.5	Good
Conventional - High	10"	8 "	High	@Mirror	Dummy-Standing	0.5	0.15787	0.05362	0.0084644	0.0118%	1.0843%	294%	0.3	2.9	Good	9.0	Poor
Conventional - High	10"	8 "	High	Mid-Bumper	Dummy-Standing	1.5	0.23829	0.05362	0.0127764	0.0059%	0.7691%	444%	0.2	4.4	Fair	11.1	Fair
Conventional - High	10"	8 "	High	Mid-Grid	Dummy-Standing	3	0.28297	0.05362	0.0151720	0.0035%	0.5926%	528%	0.2	5.3	Fair	12.1	Fair
Conventional - High	10"	8 "	High	Farthest	Dummy-Standing	3	0.23532	0.03277	0.0077102	0.0018%	0.4225%	718%	0.1	7.2	Poor	8.6	Poor
Conventional - High	10"	8 "	High	Back-Left	Dummy-Standing	3	0.24127	0.05659	0.0136548	0.0032%	0.5622%	426%	0.2	4.3	Fair	11.5	Fair
Conventional - High	10"	8 "	High	@Mirror	Dummy-Prone	3	0.29489	0.07745	0.0228378	0.0053%	0.7271%	381%	0.3	3.8	Good	14.8	Fair
Conventional - High	10"	8 "	High	Mid-Bumper	Dummy-Prone	3	0.21744	0.06255	0.0136015	0.0031%	0.5611%	348%	0.3	3.5	Good	11.5	Fair
Conventional - High	10"	8 "	High	Mid-Grid	Dummy-Prone	3	0.27702	0.05064	0.0140274	0.0032%	0.5698%	547%	0.2	5.5	Fair	11.6	Fair
Conventional - High	10"	8 "	High	Farthest	Dummy-Prone	3	0.17276	0.05362	0.0092629	0.0021%	0.4631%	322%	0.3	3.2	Good	9.5	Poor
Conventional - High	10"	8 "	High	Back-Left	Dummy-Prone	3	0.35148	0.03574	0.0125634	0.0029%	0.5393%	983%	0.1	9.8	Very Poor	11.0	Fair
Conventional - Low	10"	8 "	Low	@Mirror	Square	1	0.07298	0.13255	0.0096732	0.0067%	0.8196%	55%	1.8	1.8	Excellent	9.7	Poor
Conventional - Low	10"	8 "	Low	Mid-Bumper	Square	1	0.06106	0.08787	0.0053656	0.0037%	0.6104%	69%	1.4	1.4	Excellent	7.2	Poor
Conventional - Low	10"	8 "	Low	Mid-Grid	Square	1	0.03723	0.10723	0.0039926	0.0028%	0.5266%	35%	2.9	2.9	Good	6.2	Poor
Conventional - Low	10"	8 "	Low	Farthest	Square	1	0.01787	0.05064	0.0009050	0.0006%	0.2507%	35%	2.8	2.8	Good	3.0	Very Poor
Conventional - Low	10"	8 "	Low	Back-Left	Square	1	0.02234	0.15191	0.0033937	0.0024%	0.4855%	15%	6.8	6.8	Poor	5.7	Poor
Conventional - Low	10"	8 "	Low	Big Square	Square	100	0.36787	0.92339	0.3396833	0.0024%	0.4857%	40%	2.5	2.5	Good	57.2	Excellent
Conventional - Low	10"	8 "	Low	@Mirror	Dummy-Standing	0.5	0.24425	0.05957	0.0145509	0.0202%	1.4216%	410%	0.2	4.1	Fair	11.8	Fair
Conventional - Low	10"	8 "	Low	Mid-Bumper	Dummy-Standing	1.5	0.32765	0.05957	0.0195195	0.0090%	0.9506%	550%	0.2	5.5	Fair	13.7	Fair
Conventional - Low	10"	8 "	Low	Mid-Grid	Dummy-Standing	3	0.39914	0.05957	0.0237783	0.0055%	0.7419%	670%	0.1	6.7	Poor	15.1	Fair
Conventional - Low	10"	8 "	Low	Farthest	Dummy-Standing	3	0.24893	0.01787	0.0044488	0.0010%	0.3209%	1393%	0.1	13.9	Very Poor	6.6	Very Poor
Conventional - Low	10"	8 "	Low	Back-Left	Dummy-Standing	3	0.38425	0.03277	0.0125901	0.0029%	0.5398%	1173%	0.1	11.7	Very Poor	11.0	Fair
Conventional - Low	10"	8 "	Low	@Mirror	Dummy-Prone	3	0.40212	0.08340	0.0335380	0.0078%	0.8811%	482%	0.2	4.8	Fair	18.0	Fair
Conventional - Low	10"	8 "	Low	Mid-Bumper	Dummy-Prone	3	0.25914	0.06553	0.0169819	0.0039%	0.6270%	395%	0.3	4.0	Good-Fair	12.8	Fair
Conventional - Low	10"	8 "	Low	Mid-Grid	Dummy-Prone	3	0.32468	0.06553	0.0212762	0.0049%	0.7018%	495%	0.2	5.0	Fair	14.3	Fair
Conventional - Low	10"	8 "	Low	Farthest	Dummy-Prone	3	0.18766	0.03277	0.0061486	0.0014%	0.3773%	573%	0.2	5.7	Fair	7.7	Poor
Conventional - Low	10"	8 "	Low	Back-Left	Dummy-Prone	3	0.41701	0.03277	0.0136636	0.0032%	0.5624%	1273%	0.1	12.7	Very Poor	11.5	Fair
Banana	12" x 6.75"	7.21" x 9.97"	High	@Mirror	Square	1	0.05362	0.08638	0.0046314	0.0032%	0.5671%	62%	1.6	1.6	Excellent	6.7	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Bumper	Square	1	0.04617	0.06851	0.0031630	0.0022%	0.4687%	67%	1.5	1.5	Excellent	5.5	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Grid	Square	1	0.03277	0.07745	0.0025375	0.0018%	0.4198%	42%	2.4	2.4	Good	4.9	Very Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Farthest	Square	1	0.01787	0.04766	0.0008518	0.0006%	0.2432%	38%	2.7	2.7	Good	2.9	Very Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Back-Left	Square	1	0.01787	0.10127	0.0018100	0.0013%	0.3545%	18%	5.7	5.7	Fair	4.2	Very Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Big Square	Square	100	0.28744	0.68956	0.1982092	0.0014%	0.3710%	42%	2.4	2.4	Good	43.7	Good
Banana	12" x 6.75"	7.21" x 9.97"	High	@Mirror	Dummy-Standing	0.5	0.12808	0.05659	0.0072488	0.0101%	1.0034%	226%	0.4	2.3	Good	8.4	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Bumper	Dummy-Standing	1.5	0.20851	0.03574	0.0074529	0.0035%	0.5874%	583%	0.2	5.8	Fair	8.5	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Grid	Dummy-Standing	3	0.25021	0.04468	0.0111793	0.0026%	0.5087%	560%	0.2	5.6	Fair	10.4	Fair
Banana	12" x 6.75"	7.21" x 9.97"	High	Farthest	Dummy-Standing	3	0.21744	0.02681	0.0058292	0.0013%	0.3673%	811%	0.1	8.1	Very Poor	7.5	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Back-Left	Dummy-Standing	3	0.23829	0.05659	0.0134862	0.0031%	0.5587%	421%	0.2	4.2	Fair	11.4	Fair
Banana	12" x 6.75"	7.21" x 9.97"	High	@Mirror	Dummy-Prone	3	0.25319	0.06255	0.0158374	0.0037%	0.6055%	405%	0.2	4.0	Good-Fair	12.4	Fair
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Bumper	Dummy-Prone	3	0.19361	0.04766	0.0092274	0.0021%	0.4622%	406%	0.2	4.1	Fair	9.4	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Mid-Grid	Dummy-Prone	3	0.24425	0.05659	0.0138233	0.0032%	0.5657%	432%	0.2	4.3	Fair	11.5	Fair
Banana	12" x 6.75"	7.21" x 9.97"	High	Farthest	Dummy-Prone	3	0.17574	0.03574	0.0062817	0.0015%	0.3813%	492%	0.2	4.9	Fair	7.8	Poor
Banana	12" x 6.75"	7.21" x 9.97"	High	Back-Left	Dummy-Prone	3	0.30382	0.02979	0.0090499	0.0021%	0.4577%	1020%	0.1	10.2	Very Poor	9.3	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	@Mirror	Square	1	0.05213	0.05808	0.0030277	0.0021%	0.4585%	90%	1.1	1.1	Excellent	5.4	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Bumper	Square	1	0.04468	0.04766	0.0021294	0.0015%	0.3845%	94%	1.1	1.1	Excellent	4.5	Very Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Grid	Square	1	0.03723	0.05659	0.0021072	0.0015%	0.3825%	66%	1.5	1.5	Excellent	4.5	Very Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Farthest	Square	1	0.01787	0.04170	0.0007453	0.0005%	0.2275%	43%	2.3	2.3	Good	2.7	Very Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Back-Left	Square	1	0.01638	0.06702	0.0010980	0.0008%	0.2761%	24%	4.1	4.1	Fair	3.3	Very Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Big Square	Square	100	0.30829	0.47957	0.1478468	0.0010%	0.3204%	64%	1.6	1.6	Excellent	37.8	Good
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	@Mirror	Dummy-Standing	0.5	0.08936	0.04170	0.0037264	0.0052%	0.7194%	214%	0.5	2.1	Good	6.0	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Bumper	Dummy-Standing	1.5	0.15191	0.03574	0.0054300	0.0025%	0.5014%	425%	0.2	4.3	Fair	7.2	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Grid	Dummy-Standing	3	0.16681	0.05362	0.0089435	0.0021%	0.4550%	311%	0.3	3.1	Good	9.3	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Farthest	Dummy-Standing	3	0.14893	0.04170	0.0062107	0.0014%	0.3792%	357%	0.3	3.6	Good	7.7	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Back-Left	Dummy-Standing	3	0.12213	0.03872	0.0047290	0.0011%	0.3309%	315%	0.3	3.2	Good	6.8	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	@Mirror	Dummy-Prone	3	0.17276	0.05362	0.0092629	0.0021%	0.4631%	322%	0.3	3.2	Good	9.5	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Bumper	Dummy-Prone	3	0.14298	0.05362	0.0076658	0.0018%	0.4212%	267%	0.4	2.7	Good	8.6	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Mid-Grid	Dummy-Prone	3	0.17872	0.04468	0.0079852	0.0018%	0.4299%	400%	0.3	4.0	Good-Fair	8.8	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Farthest	Dummy-Prone	3	0.14000	0.02383	0.0033361	0.0008%	0.2779%	588%	0.2	5.9	Fair	5.7	Poor
Lookout	11" x 8.13"	6.32"-9.45" x 8.13"	High	Back-Left	Dummy-Prone	3	0.19064	0.02681	0.0051106	0.0012%	0.3439%	711%	0.1	7.1	Poor	7.0	Poor

Table 24. Target Location-Based Mirror Performance Metrics

2.5.4 Visual Angle

The visual angle subtended by each of the squares defined in Figure 10 was computed for each of the mirror/height combinations. This angle is provided in Table 22 in minutes of visual angle. The subtended angle ratings of the 1' x 1' squares can be seen as lying between poor and very poor in the scaling scheme described in Table 20. This suggests that the size of the typical images in question (i.e., dummies with a major lateral dimension of one foot) would be small and difficult, if not impossible, to judge what they are. This is a significant problem and suggests that enhancements to increase the visual angle subtended for this application could add much to the perceived image quality. Again, Table 24 is analogous to Table 22 except for its target location-based measures.

2.5.5 Physical Measurement Results Overview

The data reveal several insights for the mirrors measured under this portion of the study. The distortion does not vary greatly from mirror to mirror or for variations in mounting height. Distortion appears to be least pronounced for the grid quadrant closest to the van on the opposite side of the van from the convex mirror mounting location. This is opposite the location showing the least minification, which occurs in the quadrant nearest the convex mirror mounting location. To a mirror designer, this result should suggest a focus for optimizing the curvature of the mirror based on the goal of maintaining the minimum FOV while equalizing distortion among the grid quadrants. Preservation of the FOV should obviously be a key concern and can be ensured by designing curvature and aiming parameters for the lower mounting heights. That is, if you design/optimize for the lower mount, the upper mount will also be satisfied, but not necessarily vice versa. This will mean a slight degree of wasted field around the edges of optimized convex mirrors when raised to the upper mounting height, but will ensure that use on lower mounting heights will satisfy FOV requirements.

Visual angle measures at the side-view mirror are clearly unacceptable based on the metrics provided by Satoh et al (1983). For these devices to be more useful in providing information about what's behind the van, the size of the images at the side-view mirror need to be increased. There are several theoretical ways that this improvement could be accomplished. The more practical of these are discussed with the implications of this experiment below.

Another important consideration in the design of future systems should be mounting flexibility or the lack thereof. The variety of mounting hardware and the seemingly endless locations and orientations in which these convex mirror systems can be mounted is demonstrated by the complexity of the description of the mounting calibration described for the systems used for this study. This flexibility and potential confusion is quite unnecessary and counterproductive. Once a viable mirror is developed, a mount that does not allow rotation or reorientation should be provided to the users of that system. For instance, if the mirror mount structure included a verifiable orientation component (e.g., a member that must be plumb in both forward and sideward orientations) and a fixed mirror orientation relative to that component, proper mounting should be repeatable and reliable. Such a mount would minimize the likelihood that it could be installed incorrectly and maximize the potential to prevent pedestrian back-over accidents from occurring.

3.0 Summary & Implications:

In general, the mirrors tested in this study differed from each other in several respects. There was general agreement among behavioral, subjective, and physical measures of performance. The Lookout, was worst in terms of detection performance and subjective responses. It had relatively small radii of curvature compared to the other mirror configurations. The low-mounted conventional (i.e., spherical mirror) generally faired the best, even over its own higher-mounted condition. Ideally, the data would have pointed to a manner in which detection performance could be predicted using only physical measures. That is, by measuring the minification and distortion of a standard object image at various locations, a metric of detection performance could be calculated. Such a predictive model would allow preliminary assessment of mirror effectiveness without the cost and complexity of a behavioral study similar to the one performed within this effort. There do seem to be some indications that such a model could be created, but the complexity of the interactions made it impossible to adequately define the model during this data analysis effort. Perhaps if there is sufficient interest, this could be performed under a future effort. However, it would likely require additional data (i.e., conditions and subject sample size) to adequately define a reliable model of the salient factors. Though this study was valuable in terms of documenting performance and analytical mirror characteristics side by side and suggesting links between features and performance, more could be done. Using the existing data, other measures and transforms could be hypothesized that might better predict performance. The data, however, are complex and will likely lead to a complex model. An alternative would be to collect more data to combat shortcomings in the existing data set. For instance, a larger sample of mirrors, a larger subject sample,a fully crossed design, or greater range of mounting heights might add depth and understanding to the measures and improve the probability of creating a predictive model. Also, better control of the viewing situations may also affect the results. Lighting in this study was a function of the sun position and brightness. And, although target-to-background contrast remained constant and near threshold, shadows and lighting changed within and between trials.

Differences among mirrors were most pronounced at the locations closest to and furthest from the back of the van. The location at the center of the grid (and the mirrors' fields of view) was generally best among all the mirrors. This suggests that these outer locations are more indicative of problematic situations than the most central (to the field of view) locations.

These mirrors are generally useful. They provide relatively high levels of performance for even this intentionally difficult task of near-threshold target detection. At the center of the field, detection for most of the alternative mirrors was near 100% and relatively high over the rest of the field as an average. However, there were problems at some locations. At the bumper, a key spot for safety due to its very limited potential to provide adequate reaction time or distance, the prone child was missed 42% of the time. And, at the point furthest from the mirror, the miss rate was still more than 1 in 5. The danger in this pattern lies in the potential for false confidence to be instilled in users of these systems. The detection task is not an easy one, contrary to the implication of the relatively high detection rates. And, the potential to miss a real object, especially in the area near the bumper is a very real concern and suggests a serious need for improvement of the visibility in this area. Unfortunately, contrast between the object and the bumper does not appear to be the critical factor, so designing or requiring a special bumper treatment would likely be in vain. Regardless of bumper/object contrast, the viewer must still differentiate the object from the background under varying lighting conditions.

The results outlined above from objective and subjective performance data and measurements of the physical characteristics of the sampled mirror designs and implementations suggest several implications for design and performance-based testing.

3.1 For Mirror Visibility in General:

- The field of view provided by such mirror systems should never be less than the width of the vehicle and should extend to at least ten (10) feet back from the rear bumper. This will ensure that if drivers are backing at typical speeds (e.g., 3.3mph for young drivers in a recent study), they will have time to detect an object at ten feet and stop in time to avoid an impact. (Harpster, Huey, Lerner, and Steinberg, 1996)
- It is not clear from this effort whether minification or distortion plays a greater part in determining the effectiveness of a given mirror configuration. The mirror with the greatest overall minification and least overall distortion (i.e., the Lookout) had the worst performance in terms of detection, CRI level, and subjective ratings. However, the relationships in the data were not powerful enough (i.e., results were not statistically significant) to suggest that one of those factors should be optimized at the expense of the other.
- Designers should concentrate on the areas near the perimeter of the desired detection area. Any mirror seems capable of detecting and recognizing targets near the center of the field of view. However, detection and recognition are difficult at the edges of the mirror where curvature changes rapidly and which may have dark or light weather-stripping material that could detract or blend with the object to reduce its contrast.
- Mounting height seems to better serve detection and recognition when it is kept lower. Although there is a measurable difference in image size at the side view mirror for the two mounting heights, the differences are quite small (e.g., .01-.03" for major dimensions of a 1' square object). It is not clear why this is the case. It may be a function of the portion of the mirror used for seeing various features (e.g., a portion further away from the back rolled edge and weather-strip for the lower position) that makes these tasks more effective. Further research is needed to better define the phenomenon that improves performance at the lower level and to determine whether it follows to other mirror designs.
- Aim of the mirrors is crucial. To the degree possible, the aim of each mirror was fixed for these exercises, but aiming in the real world is more critical to safety and more difficult to perform and maintain with the daily rigors of driving. In fact, it typically should be performed with two people to allow fine tuning and verification of coverage. Good human factors principles suggest that the process should be made more simple, fool-proof and ideally, possible to perform by a single individual, if it must be performed at all. The ideal mirror should not require precise, difficult, frequent, or repeated adjustment. One or more generally, universal, fixed orientation mounting brackets should fit most applications with minimal requirements for further care.
- The length of side-view mirrors should also be considered a critical link in the performance of the system. The geometry of mounting a mirror high on the back of a van requires a slightly higher aim for the side-view mirror. Unless this side-view mirror is sufficient in length to provide this auxiliary view in addition to the necessary level of low, direct view to keep objects, lane markings, and pedestrians beside it safely in view, the system will fail. Many of the side-view mirrors used for

smaller utility or conversion vans may not fit this requirement and may, in turn, leave one of the flanks underprotected.

- Attempts to maximize image size may result in improved detection effectiveness. This might be done by adjusting the curvature of the mirror to cover only the area of interest plus a small buffer to avoid edge roll-off or weather-strip interference. Alternatively (or additionally), some method of magnifying the image from the convex mirror may also provide a substantial improvement to the image size, perceived image utility, and perception performance. However, vibration, distortion, and focal lengths will likely play a large role in the determination of feasibility for such alternatives. And again, it is not clear whether distortion, which is often traded off for increased image size (i.e., reduced minification) will work to offset any benefits.

3.2 For Mirror Performance Standards:

The behavioral methods employed in the experiment were successful in that they were sensitive to differences among mirrors and target conditions and could statistically discriminate them. The method was also successful in terms of subject performance, data acquisition, and other procedural considerations. A behaviorally-based protocol using procedures similar to the present one therefore is feasible. However, collecting adequate target recognition data under controlled conditions is more time consuming and expensive than evaluation protocols based on the objectively measurable optical properties of the mirror, such as minification, distortion, and field of view. The findings of this study indicated that there was no simple relationship between the optical measures and the behavioral data; the relationship depends on a variety of target factors and their complex interactions. Additional, systematic research would be required to develop a predictive model capable of using only objectively-measured mirror properties. There is no basis for an evaluation protocol based solely on optical properties at this time. Another alternative to a target detection study is a protocol based on subjective judgments about the mirrors. Subjective ratings and other judgments from subjects in this experiment were correlated with the behavioral data on target recognition. Since subjective judgments can be acquired more quickly and at less cost than a target detection experiment, it may be feasible to base the protocol on subjective ratings. Additional research would be required to develop a refined set of subjective items that can be shown to be strongly correlated with the behavioral data. At this point, then, there is a behavioral technique for measuring target recognition that may provide a basis for a standard evaluation protocol. There is a potential for protocols based on subjective judgments or mirror optical properties, but these would require additional research in order to refine and validate them.

Some further considerations for standard evaluation of future mirror configurations are provided below.

- For new mirrors being considered for this application, it is recommended that this grid area be used as a minimum standard for field of view with the primary measures of performance being based on detection performance, minification and distortion. The width easily covers all truck widths with some overlap and the depth behind the van provides sufficient reaction time/distance for normal backing (Harpster, et.al, 1996)
- The perimeter of the critical area appears to be the most difficult to cover and the most telling in terms of performance for a given mirror. Concentration of detection conditions should occur in these areas of the minimum field of view area.
- The shade of the targets should probably be kept close to the 20% gray level used for the medium reflectivity targets in this study as they represent typical reflectivities of children's winter garb.

Alternatively, it is desirable to select a background surface that provides relatively low contrast with the targets to ensure that detection performance is based on near-threshold detection of objects.

- All mirrors should be tested at all mounting heights that are likely to be used to allow measurement and verification of performance based on those heights.
- Since detection performance was most difficult for the standing child condition, it should be stressed in future similar trials.
- Ideally, future studies of this kind should be conducted indoors under controlled lighting conditions. It was infeasible to consider this alternative for this study, but consistency of lighting and shadows would have been much more desirable than the outdoor scenario. These factors undoubtedly affected the results in this study, though it is impossible to discern to what degree.
- Performance specifications should be provided at multiple points in the field of view. That is, a minimum criterion for each critical location should be defined as well as some overall criterion.
- Contrast matters. It is important to specify a standard roadway reflectivity level along with the definition of a standard target reflectivity. Alternatively, a standard contrast level between the targets and background may be defined. This is necessary to maintain a contrast level that remains near threshold and ensures differentiable results for detection performance measures.
- It may be desirable to reduce the number of condition variants for purposes fabrication and presentation complexity if performance testing is to be the norm for future evaluations. Perhaps the shade variations are the best to consider for this condition thinning exercise as long as the level of contrast with the background is kept low. It is important, however, to include distractor targets in the study design if detection performance is to be evaluated. Making subjects recognize that the object they see is, in fact, the target (i.e., child) and not a foil object is important in determining the overall measure of mirror effectiveness. That is, do they know what they are seeing or do they simply see something. Recognition reduces false positives, improving the real-world effectiveness of a given system.

5.0 References

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Appendix A

Consent Form

CONSENT FORM

Rear Cross-View Mirror Perception Study

Purpose of the Research: Thank you for volunteering to participate in this study. The purpose of this study is to evaluate rear cross-view mirrors used on delivery vans.

Research Procedures: You are invited to participate in this study of rear cross-view mirrors. This experiment will involve sitting in the driver's seat of a utility van in a parking lot. No driving will be required. We will ask you to view a number of scenes through the drivers' side mirror and the rear cross-view mirror. We will ask you to tell us what you saw, where it was, and how confident you are about what you saw. You will respond using a computerized response console. At the end of the session we will ask you for your impressions about the rear cross-view mirrors that you experience with some final questions. The study should take less than 2 hours.

Foreseeable Risks: There are no foreseeable risks associated with the research procedures other than those associated with sitting in a stationary step van in a normal parking lot. Since no driving is necessary, your risk will be minimal. Safety is always primary. No other traffic will be allowed into the test area while you are using it. WESTAT or the National Highway Traffic Safety Administration (NHTSA) can not assume any of the risk associated with your participation in this study. In the case of injury resulting from your participation in this study, neither WESTAT nor NHTSA will be responsible for any further compensation beyond the customary participation payment.

Benefits of the Research: The findings of this study will be used to evaluate the adequacy of current and future implementations of rear cross-view mirror systems and to develop a standard research protocol. As a result of the research, design standards or recommendations related to the design of these devices could be changed. This could result in rear visibility systems that are safer, more effective, and less annoying than some current versions. Your personal benefit from the study will be $50. If you decide to terminate your participation before the study is complete, you will be paid on a prorated basis. No further expenses to you as a participant related to expenses are anticipated or reimbursable by WESTAT.

Confidentiality: We will be asking you for some basic descriptive information about yourself. This includes your age, your driving history and habits (how long have you been driving, how much do you drive, etc.), and certain questions about physical status or health that may relate to driving (your vision, medicines that may affect driving, etc.). This information is important in helping us to interpret the research findings. This information is confidential, and no published reports of the research will identify you as a participant.

Contact Person: If you have questions about the research or your rights as a research participant, you may contact Richard Huey, Project Director, at WESTAT, Inc., 1650 Research Blvd., Rockville, MD 20850 or by phone at (301) 315-5961.

Voluntary Withdrawal from the Experiment: Your cooperation in this study is entirely voluntary. You may withdraw participation at any time. If you withdraw from the study, you will be paid on a prorated basis for the time you did participate.

AUTHORIZATION: I have read the above and recognize the risks and benefits of this study. I agree to participate as a research participant in this study. I agree that during the study, I must not be under the influence of alcohol, drugs, or any other substances that might impair my abilities. I have been given the opportunity to ask questions about the research and my questions have been answered to my satisfaction. I understand that participation is voluntary and I may withdraw from the study without harm or prejudice at any time.

Signature of Participant: ________________________________ Date: _________

Signature of Investigator: ________________________________ Date: _________

Appendix B

Recruiting Script

Recruitment Phone Script for the
Rear Cross-View Mirror Perception Study

Hello, my name is ________________________ with WESTAT. I'm calling to follow up with additional information on our research study evaluating rear cross-view mirrors and to see if you would be interested and qualified to participate. The work is being sponsored by the National Highway Traffic Safety Administration. You may recall that you:

responded to a recent ad in __________________________{publication}

The end product of this work will be a report that documents differences in perceptions and preferences related to the various rear cross-view mirror configurations that you might encounter on a utility van. There are no special abilities required, though we are looking for current utility van drivers that deliver goods. You will be asked to sit in a specially outfitted utility van in a local parking lot and provide responses to various scenes visible in the side and rear cross-view mirrors. We expect that the session will last about 3 hours and we would pay you $50 for your participation. If you think you might be interested I can tell you some more about it. . . .

[If they say NO:]
OK. Thank you for your time. I should mention that we are involved in some other research and development projects that might interest you more. Would you like us to consider you for other studies? We do a lot of recruiting for this type of research. Do you know anyone else who might be interested in this or similar projects?

Name: ________________________________ Phone: (___)_______-_____________

Name: ________________________________ Phone: (___)_______-_____________

Thank you. Good-bye.

[If they say YES:]
As I mentioned before, this study is investigating the design of rear cross-view mirror systems. This study will take place in a local parking lot with you sitting behind the wheel of a utility van. No driving will be required. All the trials will take place during the daylight hours. We will ask you to view a number of scenes through the drivers' side mirror and the rear cross-view mirror. The scenes will encompass a square area directly behind the van. After a glimpse of the area through the mirror, we will ask you to tell us what you saw, where it was, and how confident you are about what you saw. This is not a test of your abilities, but a comparison of the performance of the mirrors that we are evaluating. We will then pay you for your participation.

We need to get some information from you before we can include you in the study.

Session: ____________

Demographic Information:

Name: ___________________________ Daytime Phone: (______)______-______

Address: _________________________________ Evening Phone: (______)______-______

_________________________________ Date of Birth: ______/______/______

Valid Driver's License: *Yes* / *No* Gender: *Male* / *Female*

Are you required to wear glasses/contact lenses while driving? *Yes* / *No*

Do you have any visual impairments? *Yes* / *No* Describe - ______________________

____

Utility Vehicle Driven:

Make: ______________ Model/Style: ________ Year: _______ Size: 12', 14', other

Is it equipped with a rear cross-view mirror? __________ When do you use it? ________

Driving Level (**MAIN CRITERIA FOR QUALIFICATION**):

What do you use your utility van for (hauling tools, delivery, storage)? ________________

Criteria (**DELIVERY ONLY**)

About how far do you drive during a given week? __________________________

Criteria (**AT LEAST 50 MILES**)

About how many times during the week do you back up? ____________________

Criteria (**AT LEAST 20 TIMES**)

Day of Week (weekdays or weekends) and Time Availability (mornings or afternoons):

___________________ ___________________________ ___________________

[If this person meets the criteria (i.e., age, gender, vehicle driven, and availability during the day):]
OK. It looks like we will be able to include you in this study. Let me give you an overview of the scheduling that we anticipate and we can try to match your availability with it. **[Discuss schedule]** Thank you for volunteering. Someone will be back in touch to schedule you shortly. In the mean time, if you have any questions, please feel free to call Rick Huey, the project director, at (301) 517-4034 during business hours. Good-bye.

[Other wise:]
Unfortunately, it looks like we will be unable to use you for this study due to our restrictions driver characteristics, the number of participants, and schedule. Thank you for taking the time to talk to me. If you'd like we can keep you in mind for other studies and call you when they come along.
Would you like us to do that? *Yes* / *No*

Thank you. Good-bye.

Appendix C

Participant Instructions

Participant Instructions

Thank you for participating in this study today. I'm going to tell you about what you'll be doing. As I explain the study to you, please feel free to ask questions at any time. As I've mentioned before, this study is investigating the design of rear cross-view mirror systems. This study will take place with you sitting behind the wheel of this utility van. No driving will be required. The study is designed to test the worst case of a low contrast object behind the van. We will ask you to view a number of scenes through the drivers' side mirror and the rear cross-view mirror. The scenes will encompass a square area directly behind the van. This area would typically be invisible unless some type of system is used to provide a view of this area. In this case, we will be using a variety of rear cross-view mirrors in conjunction with the drivers' side-view mirror to attempt to see this area behind the van.

We will be using a set of props instead of real children and other objects. Here's what they look like [*show the participant the dummy, manhole, newspaper*]. We will also have some cases in which nothing will be placed in the area. These items are painted in shades of gray that correspond to the reflectivity (that is, brightness) of typical winter clothing. As you can see, the objects will be pretty tough to see behind the van, but we would like you to try your best.

You will be sitting up here in the driver's seat, just as if you were driving *[seat the participant in the driver's seat*]. As you can see, the driver's side window is blocked so you can not see the drivers' side-view mirror and the passenger side mirror is also blocked. Using a special film over the drivers' side window, we can make the mirror visible and then invisible again [*demonstrate the LCD film for the participant*]. We will be using a variety of rear cross-view mirrors and placing the objects that I showed you before in the field of view of the mirrors to see if you can identify what, if anything, is there. Using the film, we will give you a short period of time in which to view each scene. After a given glimpse of the scene, we will ask you to tell us what you saw, where it was, and your confidence about what you saw. You will use this response console [*hand them the response console*] to give us your answers. As you can see, there are a number of buttons on this console that correspond to a set of questions that we want to know about each scene. **At the very least, you will always answer the first two questions**; What's behind you?, and How confident are you about what it is? **The other two questions are only for the cases in which you say that you saw a child according to your answer to the first question**.

- For the first question, we want you to respond with the "**CHILD**" choice only if you see the dummy that I showed you earlier. If you see the round or square objects or nothing, you should be responding with the "**NO CHILD**" button.
- For the second question, we want to know how sure of your first answer you are. That is, are you confident that it **is**, or **is not**, a "child". Sometimes you may be more confident than other times that what you saw was a child behind the van. At times you may be completely sure you saw the child, while other times you may be less sure that's what you truly saw. By giving us your best assessment of how confident you are, you will help us to evaluate how well the mirror is working. The "**VERY CONFIDENT**" button should be pressed when you are absolutely sure about whether there is a child present. The "**MAYBE**" response suggests that you are pretty sure that you recognized a child if it was there. The "**JUST A GUESS**" response suggests that you are not sure at all about what you saw or didn't see. We are evaluating the mirrors here, not your ability to see or recognize objects.

- The third question is looking for more detailed information about the "child." Again, this question should only be answered if you say that you saw a child in your response to the first question. Specifically, we want you to tell us whether the child was standing or lying down.
- The fourth question, again, should only be answered if you saw a "CHILD" as your response to the first question. Here we want to see how well the location of the "CHILD" can be identified. Note the locations of the buttons that correspond to one of the locations in the area behind the van. [*point out the features of the van (i.e., mirrors, grid, driver, bumper, etc)*] You will make your response by pressing the button that corresponds to the location where you think the child is. ***Experimenter Note: It is important to ensure that the participant can not see the objects using only the side view mirror. They must be using the rear cross-view mirror to see the objects behind the van.***

If you ever feel that you responded incorrectly, please let me know so the I can make a note of it in my records. We will not be redoing any scenes, but I need to keep good records regarding anything that could be interpreted as inaccurate data.

I will alert you with a knock on the side of the van that I am about to show you the next scene so that you will not be surprised. I want to make sure that you are afforded the maximum amount of time to view each scene. You can tell me if you aren't ready for some reason or if you need a break. We will be doing quite a number of trials for each mirror. No breaks are planned, but I will let you know when I am changing mirrors so that you can stand and stretch.

This is not a test of your abilities, but a comparison of the performance of the mirrors. We have a fairly large number of scenes to go through for each mirror condition. At the end of the session I would also like to get your impressions about the rear cross-view mirrors that you experienced with some final questions. I will then get some information from you to arrange payment for your participation and let you go.

Do you have any questions?

OK. Let's do some practice trials so that you can see what it's like and get an idea about how the study will run. Again, I'll set up the target condition, knock on the van to let you know that I'm about to clear your vision, the film will clear for about 3 seconds, you will answer at least the first two questions and all four if the object you see is the dummy. We'll do a couple of these and I'll give you some feedback about how you did with each one [*provide color, orientation, and location feedback after they respond to each practice trial*].

Practice Trials:

1. Dark Dummy – Prone - @ the Mirror
6. Light Manhole – Center Grid
7. Medium Dummy – Farthest from Mirror
8. Dark Newspaper – Far Left
9. Nothing

OK. We should be ready to start now. There will be 60 trials before we change the first mirror. If you don't have any more questions, let's begin.

Appendix D

Debriefing Questions

Session: ______

Debriefing Questions

Banana

- How would you rate the image quality of this mirror (1 to 10, 10 being perfect)? _______________
- How would you rate the distortion of this mirror (1 to 10, 10 being perfect)? ___________________
- How would you rate the minification (i.e., making the objects appear smaller) of this mirror (1 to 10, 10 being perfect)? ________________
- Would you like to have this mirror on your van? Why? ____________________________________

____

____

- Would you use this mirror? ____

____

____

- How much would you pay to have this mirror? ____
- What would make this mirror better? ____

____

____

Lookout

- How would you rate the image quality of this mirror (1 to 10, 10 being perfect)? _______________
- How would you rate the distortion of this mirror (1 to 10, 10 being perfect)? ___________________
- How would you rate the minification (i.e., making the objects appear smaller) of this mirror (1 to 10, 10 being perfect)? ________________
- Would you like to have this mirror on your van? Why? ____________________________________

____

____

- Would you use this mirror? ____

____

____

- How much would you pay to have this mirror? ____
- What would make this mirror better? ____

____

____

Session: ______

Conventional - High Mount

- How would you rate the image quality of this mirror (1 to 10, 10 being perfect)? _______________
- How would you rate the distortion of this mirror (1 to 10, 10 being perfect)? __________________
- How would you rate the minification (i.e., making the objects appear smaller) of this mirror (1 to 10, 10 being perfect)? ________________
- Would you like to have this mirror on your van? Why? ____________________________________

____

____

- Would you use this mirror? ____

____

____

- How much would you pay to have this mirror? ____
- What would make this mirror better? ____

____

____

Conventional - Low Mount

- How would you rate the image quality of this mirror (1 to 10, 10 being perfect)? _______________
- How would you rate the distortion of this mirror (1 to 10, 10 being perfect)? __________________
- How would you rate the minification (i.e., making the objects appear smaller) of this mirror (1 to 10, 10 being perfect)? ________________
- Would you like to have this mirror on your van? Why? ____________________________________

____

____

- Would you use this mirror? ____

____

____

- How much would you pay to have this mirror? ____
- What would make this mirror better? ____

____

____

Appendix E

Cross-View Mirror Evaluation Study Event Log

Cross-View Mirror Evaluation Study
Event Log

Session: ___________ **Date:** _____________ **Time:** ___________________

Experimenter: ______________________________

Illumination Level (lux) at:

Where / When	Before Session	After Session
Front Windshield		
Grid Center		

Trial Number	Problem		Description
	Stimulus	Response	

Page _______ **of** _________

Session: __________ **Date:** ____________ **Time:** __________________

Experimenter: ____________________________

Trial Number	Problem		Description
	Stimulus	Response	

Appendix F

Field of View, Minification, Visual Angle and Distortion Measurements of Various Rear Cross-view Mirrors

Introduction

Measurements of field of view (FOV), distortion, visual angle, and minification of several rear cross-view mirrors were made and the results compiled. Rear cross-view mirrors are typically found on delivery vans. These mirrors are convex in shape, and they are used to view the area behind the van which cannot be seen with the conventional side view mirrors. These convex mirrors act to minify the image behind the van and project it to the side-view mirror next to the driver. The driver views the image in the convex mirror by looking in the side view mirror. The driver is looking at the image of an image in this two mirror system. The amount of minification depends on three main factors, the line of sight distance of the driver to the rear cross view mirror, the distance of the object from the rear cross-view mirror, and the radius of curvature of the mirror. There is generally a tradeoff between field of view and minification, and field of view and distortion.

The goal of this study was to examine a reasonable sample of off-the-shelf rear cross-view mirrors and determine their performance characteristics for different size vans. This was accomplished by measuring FOV, distortion, visual angle and minification for two van sizes and a total of six different mirrors. The results allow the mirrors to be compared, and they provide a baseline for the comparison of new mirror designs in the future.

Experimental Conditions

In this study several parameters were varied as the measurements were made. These parameters included:

- Van Dimensions
- Mirror Alignment
- Mirror Size
- Mirror Radius of Curvature (ROC)

Van Size

Measurements were taken for two van types which were called "small" and "large". The "small" van type was based on models such as the Ford Econoline and other full-size utility and conversion vans, and the "large" van was based on step vans such as those used by Federal Express and UPS, typically with sufficient headroom to allow users to stand erect inside their cargo areas. Having visited a number of fleet operators and measured the dimensions of many vans, it was clear that there is a great variation in the size of the vans. We used the following representative dimensions in this study.

Dimension	Small Van (in)	Large Van (in)
Side view mirror height (top)	72	89
Rear cross-view mirror height (bottom)	71	86
Distance between mirrors	120	180
Driver eye height	72	82
Driver eye to side mirror distance	25	30

Table 1 - Van sizes.

This study was performed in a laboratory, and real vans were not used. The mirrors were placed at the appropriate three dimensional locations and the measurements were taken.

Mirror Alignment

The alignment of the mirrors is difficult problem. None of the mirrors used in this study came with instructions on how they should be aimed. Some came with recommendations such as, "make sure the back bumper is visible in the mirror." But, having the back bumper in view does not define a unique adjustment for the mirror, and in many cases does not provide the "best" alignment for the mirror.

When talking to fleet operators and the drivers of these vehicles it was obvious that they had no formal alignment procedure. The most common alignment procedure was called "the buddy system." Using this procedure the driver sits in the driver's seat and his "buddy" adjusts the back mirror until it is in a position the driver likes. This procedure results in a variety of different adjustments.

There are two general alignment strategies that are commonly used. The first scheme maximizes the field of view. Using this procedure, the mirror is adjusted so that the back bumper is just visible in the lower part of the mirror. This permits the remainder of the mirror to capture the largest possible area behind the vehicle. However, the large field of view may suffer substantial distortion and minification. The other scheme involves capturing the area of interest behind the van with the center of the mirror. This tends to reduce the distortion and increase image size for the area of major concern, but will also reduce the field of view.

These two general strategies were used in this study. However, in order to create repeatable mirror alignments, the following procedure was used. The mirrors were adjusted according to the two heuristics based on the methods described above.

Heuristic 1 - The mirror was tilted so that the entire length of the bumper was visible on the edge of the mirror. Further tilting would move the bumper off the mirror. This was called the 'bumper' adjustment.

Heuristic 2 - The mirror was tilted so that the center of the mirror was centered upon a point 2 feet from the back of the bumper, provided that the entire bumper was visible. If necessary it was adjusted so the entire bumper was visible. This was called the 'center' adjustment.

For both heuristics the viewing position was the drivers eye position. Additionally, the mirror was adjusted laterally such that the center of the image was at the centerline of the vehicle. After adjustment the mirror tilt angle was measured. This will facilitate replicating the test with the same mirror geometry.

(from the driver's eye position)

Mirror Size and Radius of Curvature

A variety of mirrors were tested. The following table outlines the mirrors that were tested.

Manufacturer	**ROC (in)**	**Shape**	**Size Diameter (in)**	**Van Size**
Sure Plus (#390)	13	Round	10	Large
Velvac (#713406)	7	Round	10	Large
Velvac (#713406)	7	Round	10	Small
Mirror Lite (Tail Watcher)	5-8	Football	12 x 8	Small
Sure Plus (#570)	11	Round	8	Small
Velvac (#713120)	5.5	Round	8	Small

Table 2 - Mirrors that were tested.

Method

The methods used in this study are described in this section. These include the

- General Setup
- Photographic Techniques
- FOV Measurements
- Minification Measurements
- Distortion Measurements

General Setup

This study was performed in a laboratory setting. No actual vans were used. Mirrors were mounted on a pole at the position described hereafter. A 10 foot by 10 foot grid was laid out in the area behind the 'van'. The grid was marked off in one foot increments using electrical tape. A 6.5 foot metal bar was covered with black and yellow checkered tape and was placed in a position representing the bumper of the van. The bumper was 22 inches off the floor. Figure 1 shows the major dimensions of the setup.

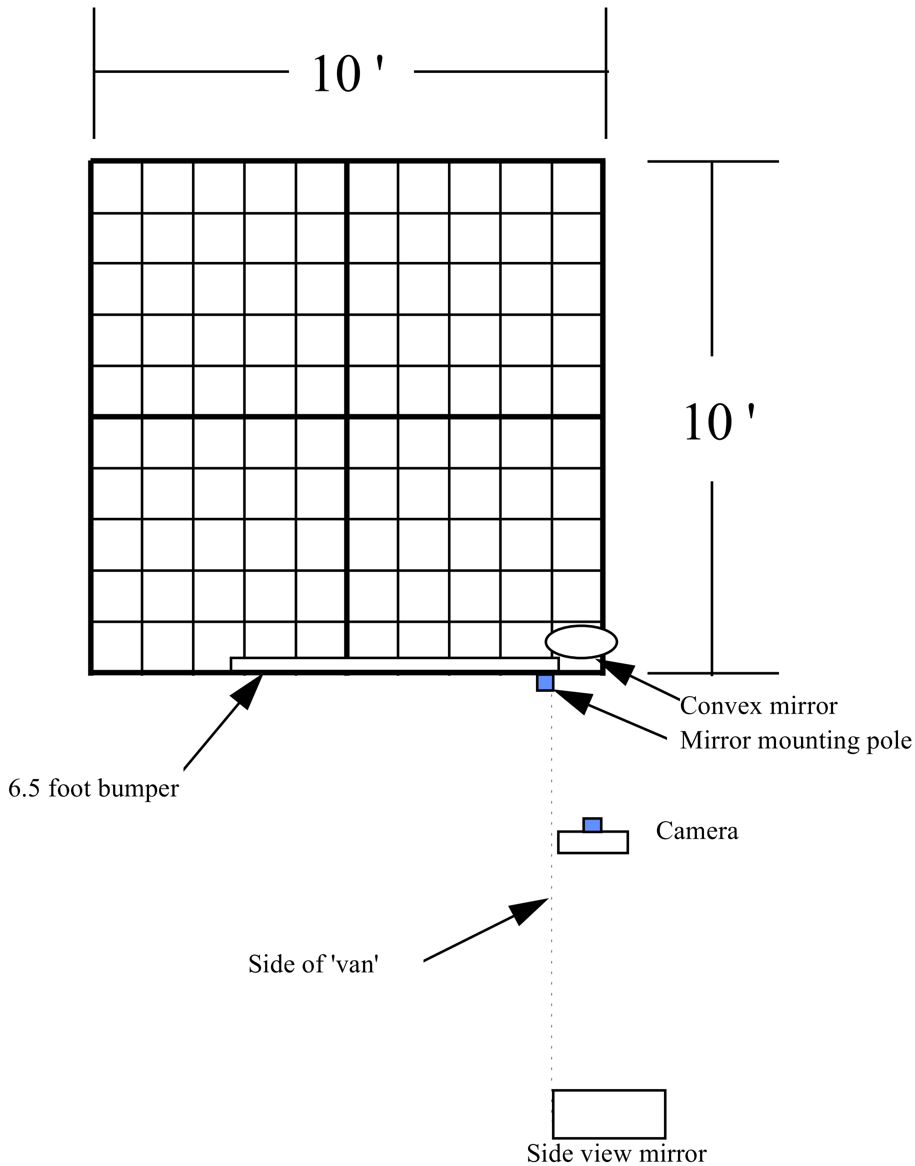


Figure 1 - Top view of lab setup.

When used on a van, the image from the cross-view mirror is projected to the side-view mirror, which in turn reflects the image to the driver eye position. Measurement of the image might be made from anywhere along this chain. For this study, the cross-view mirror was photographed directly, from a camera positioned along the line of sight between the cross-view mirror and the side view mirror. This optimized the image quality for purposes of data reduction, and correction factors were applied to transform the findings to the appropriate scale for images at the actual location of the side view mirror or the driver's eye. For the large 10 inch diameter mirrors, the camera was placed 7 feet from the cross-view mirror and for the smaller 8 inch diameter mirrors it was placed 5 feet from the cross-view mirror. The camera was placed in the line of sight between the two mirrors. A test of photographs showed that the image of the cross view mirror was the same (only larger) in the close up position as in the driver's eye position. The large image was easier to measure. The appropriate correction factor was computed (described below) to make absolute size measurements.

As mentioned earlier, determining the alignment of the rear cross-view mirror was a difficult problem. For this study it was decided to use two 'good' adjustment heuristics (described earlier) and record the three-dimensional position of the alignments so that the measurements could be repeated. The two adjustments were referred to as 'bumper' and 'center'. The bumper adjustment produced a large FOV by placing the edge of the bumper on the edge of the mirror. The center adjustment produced a less distorted image of the critical area by placing the bumper closer to the center of the mirror. There are many other possible adjustments for these mirrors, but these two adjustments provided a reasonable estimate of the mirrors' performance.

All of the mirrors except the Tailwatcher mirror had two separate adjustments. The Tailwatcher was only adjusted in one position, since an acceptable second position could not be achieved.

Adjustment of the round mirrors - All of the mirrors except the Tailwatcher were adjusted as follows.

1. Mirrors were attached to the vertical pole as shown on the drawing below. The "L"-shaped bar used for attachment was bent at a right angle and the dimensions shown correspond to when the bar was parallel to the floor.

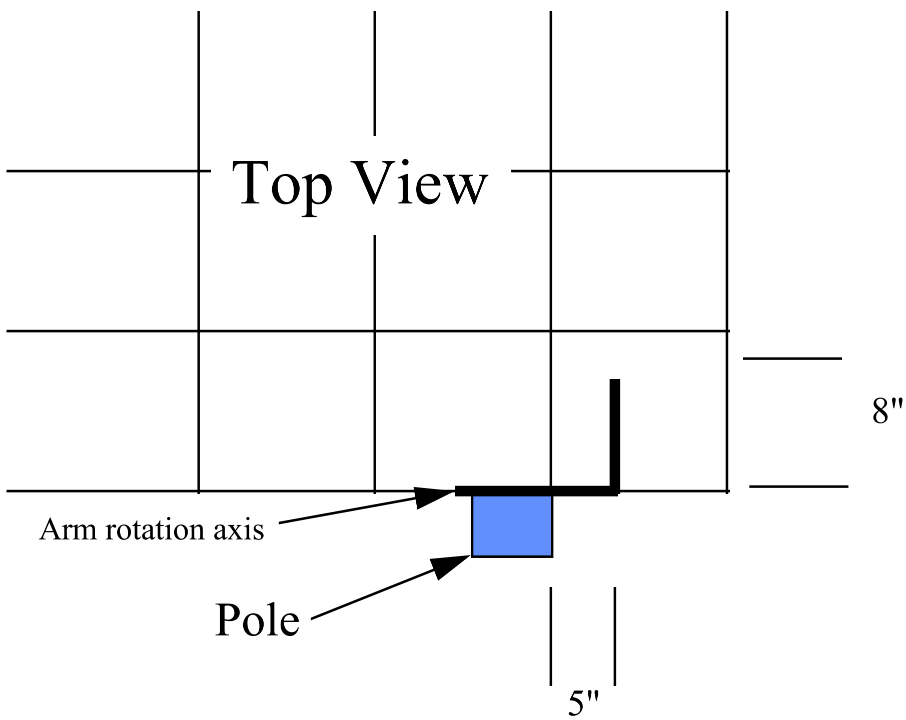


Figure 2 - Location of the attachment arm.

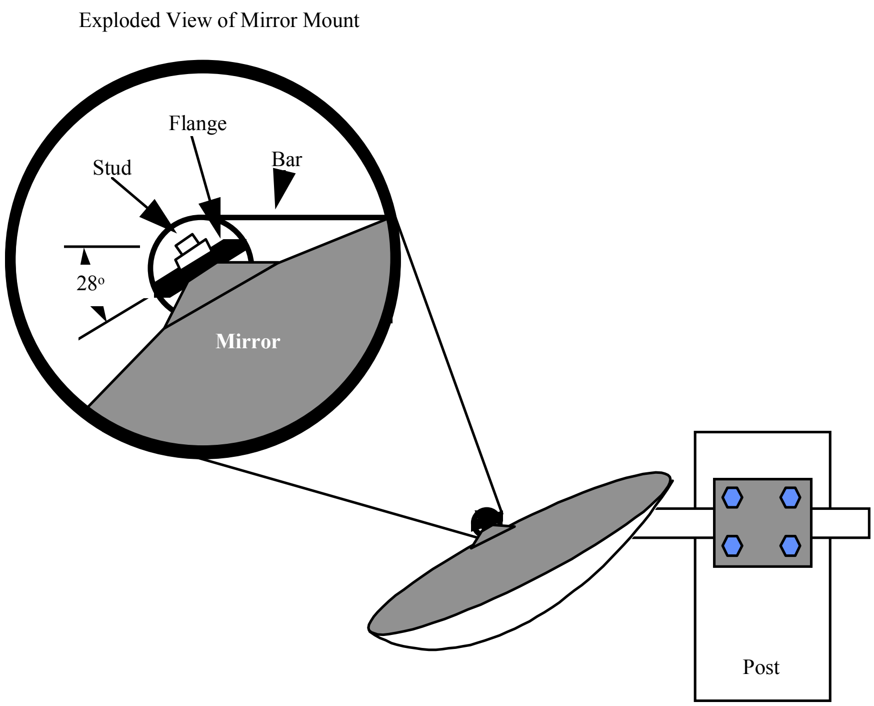


Figure 3 - Exploded view of the mirror mount.

2. The mounting flange at the end of the 8 inch arm of the attaching bar was rotated 28 degrees. Therefore, when the attaching bar was parallel to the floor a mirror with a stud extending straight out of the back of it was not looking straight down at the floor. Rather it was turned up 28 degrees toward the center of the back of the van (see figure 3).
3. The mirrors were attached to end of the 8 inch arm by a single stud which fit into the single hole at the end of the flanged arm.
4. In order get achieve the proper adjustment the entire mounting bracket was rotated downward about the axis of the bracketed portion of the "L" shaped arm shown in figure 2. The amount of the rotation is shown in the following table.

Note: All of the mirrors were attached with a single stud. Most of the mirrors could be adjusted by rotating the single stud about a ball and socket joint. For this study, all of the studs were adjusted in the straight (perpendicular) position.

Manufacturer	Angle of Rotation from Horizontal (deg)	Adjustment	ROC (in)	Shape	Size (in)	Van Size
Sure Plus (#390)	40	Bumper	13	Round	10	Large
Sure Plus (#390)	45	Center	13	Round	10	Large
Velvac (#713406)	15	Bumper	7	Round	10	Large
Velvac (#713406)	25	Center	7	Round	10	Large
Velvac (#713406)	17	Bumper	7	Round	10	Small
Velvac (#713406)	24	Center	7	Round	10	Small
Sure Plus (#570)	32	Bumper	11	Round	8	Small
Sure Plus (#570)	44	Center	11	Round	8	Small
Velvac (#713120)	8	Bumper	5.5	Round	8	Small
Velvac (#713120)	20	Center	5.5	Round	8	Small

Table 3 - Mirror adjustments.

Adjustment of the Tailwatcher mirror - The Tailwatcher mirror was only tested in one configuration. This configuration used the standard Tailwatcher mount. The standard mount is shown in a pre-adjustment position in the top view below in figure 4. The mount shown in the adjusted position is shown in side view of the same figure. This corresponded to about the same relative mounting height as that used for the small van size measurements of the other mirrors.

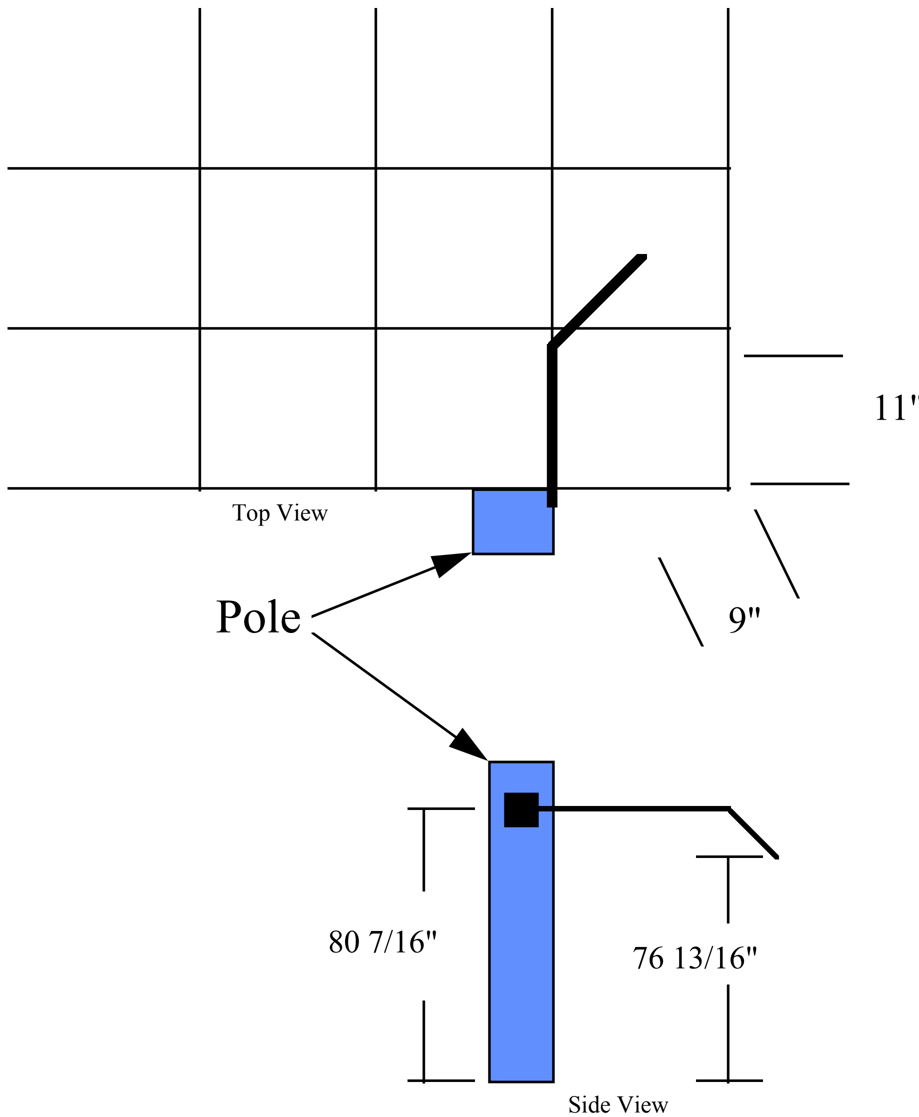


Figure 4 - Tailwatcher adjustment. Top view is view of the arm before adjustment (entire arm parallel to the ground), and the side-view is after adjustment.

Photographic Techniques

All of the pictures were taken with a Minolta X-700 35mm camera. The lens was a CPC Phase 2 80-200mm f4/5.6 with an adjustable focal length. All pictures were taken with the lens zoomed to 200mm. Pictures were taken with an f-8 F stop. The film was Kodak Ektachrome 400 slide film. Slide film was used so that the images could be projected to a large size, making the measurements easier to record.

As described earlier, the camera was placed in the line of sight between the side-view mirror and the rear cross-view mirror. This allowed the maximum image size to be photographed. The camera was placed at either 5 or 7 feet from the cross-view mirror. The camera was zoomed in so that the image filled the majority of the slide.

Field of View Measurements

The rear field of view was measured both at ground level and using three foot high child-size objects. The ground level test was conducted as follows:

Slides were taken of the rear cross-view mirror image as described earlier. The images from the slides were projected onto a screen. The image of the 10 foot by 10 foot grid was analyzed to determine which of the 100 squares were visible. A square was counted as being visible if 50 percent or more of the square could be seen. The field of view was recorded for each mirror and adjustment combination.

Slides were also created with 3 foot high child-size objects placed at 9 different positions on the 10 by 10 grid. The child-size objects were placed in the following locations.

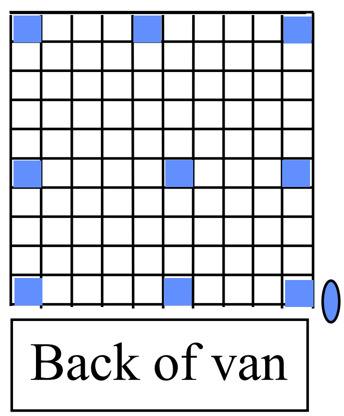


Figure 5 - Locations of child size objects.

The child-size objects were marked in one foot increments along their height. At each of the 9 locations, the number of one foot segments that were visible was recorded. This constitutes a rough approximation of the three-dimensional field of view for the mirror system.

Minification Measurements

Minification is defined as the ratio of the actual size object to the image size on the side view mirror. Minification measurements were taken for the following:

- The entire 10 by 10 foot grid
- Each quadrant of the 10 by 10 foot grid (5 by 5 foot areas)
- The center square in each quadrant (1 by 1 foot areas)

Measurements were only recorded if all of the square was visible.

The calculation of the minification factor is a simple ratio of two areas (the area on the grid and the area on side view mirror). Do to various distortions in the optics the "squares" visible on the side view mirror were not perfectly square. In order to calculate the area of these "squares" the following approximation was used. Opposite sides of the squares were summed and averaged. The averaged values were then multiplied which resulted in the approximate area for the square.

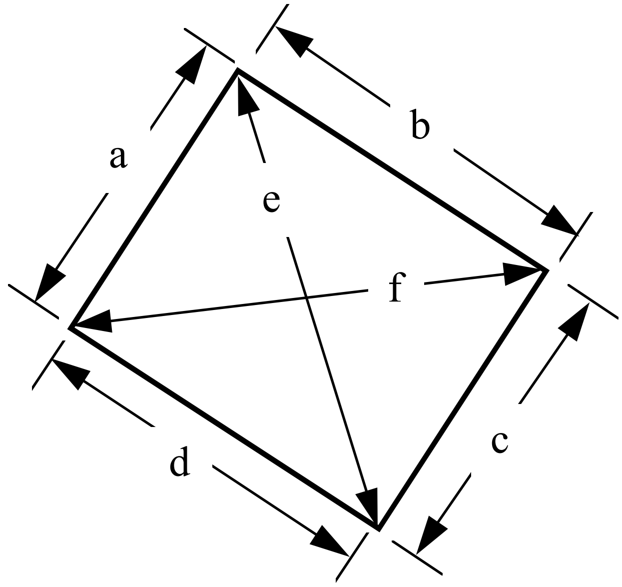
Since the camera position was not at the driver's eye position, but closer to the convex mirror, correction factors were needed to calculate the minification from the photographic images. The correction factors were determined using the following procedure.

1. A photograph was taken of an object of a known length (a ruler). The ruler was placed next to the convex mirror. (The same camera position was used for the rest of the photographs.)
2. The image of this ruler was used to create correction factor 1. The first correction factor expressed how large the projected image was at the position of the convex mirror. (e.g. One inch on the ruler (absolute size) is equivalent to 3.5 inches on the projected slide.)
3. Next, the second correction factor was calculated. The second correction factor measured the reduction in image size from the convex mirror to the planar side-view mirror.
4. A ruler was again placed next to the convex mirror, and the size of the ruler was measured in the side-view mirror.
5. The ratio of the two sizes (actual to image) is correction factor 2 (e.g. the image was reduced by a 10 to 1 ratio.)
6. The first correction factor measured the size of the magnification due to projection of the image, and the second correction factor measured the minification due to the distance from the side-view mirror. The product of correction factors 1 and 2 is the necessary correction factor for determining the equivalent minification at the side-view mirror, a commonly accepted metric of minification.

Distortion Measurements

There are many possible ways to calculate distortion values for the images produced by the convex mirrors. The method used here was developed by Satoh, Yamanaka, Kondoh, Yamashita, Matsuzaki, and Akizuki (1983). There are two steps to this procedure. First is to calculate the quantitative shape change ε. Second, the qualitative shape change is related to psychological perceptual categories.

The quantitative shape change is calculated as follows.



$\varepsilon_1 = (a + c)/(b + d)$

$\varepsilon_2 = 1/\varepsilon_1$

$\varepsilon_3 = e/f$

$\varepsilon_4 = 1/\varepsilon_3$

ε = Maximum of ε_1, ε_2, ε_3, and ε_4.

Figure 6 - Computation of change shape factor (from Satoh, et al., 1983)

The perceptual implications associated with various of ε are shown in the following table, which is also taken from Satoh, et al., 1983.

Level	Degree of Image Form	Degree of Image Shape Change	Shape Change Factor ε
5	Excellent	No Image Shape Change	1
			2
4	Good	Visible but no Problem	3
			4
3	Fair	Visible but Possible to Judge	5
			6
2	Poor	Large and Hinders Judgement	7
			8
1	Very Poor	Impossible to Judge	9

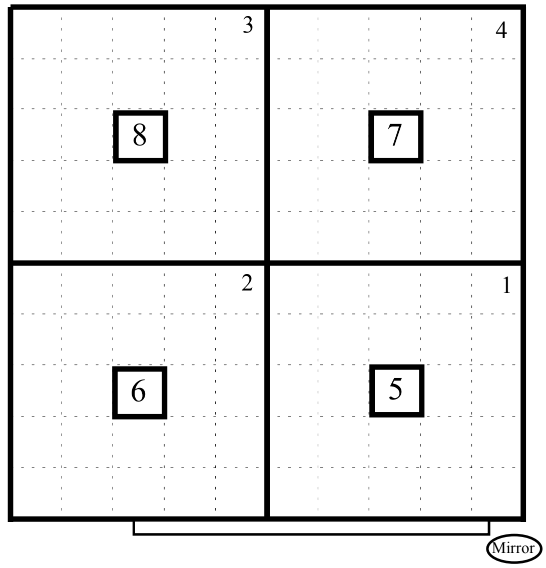
Table 4 - Shape change factor versus psychological category from Satoh et al. ,1983.

Measurements were calculated for the following squares.

- The entire 10 by 10 foot grid
- Each quadrant of the 10 by 10 foot grid (5 by 5 foot areas)
- The center square in each quadrant (1 by 1 foot areas)

Measurements were only recorded if all of the square was visible.

Squares were assigned the following numbers.



Square Number	**Area (ft^2)**
1	5 x 5 = 25
2	5 x 5 = 25
3	5 x 5 = 25
4	5 x 5 = 25
5	1 x 1 = 1
6	1 x 1 = 1
7	1 x 1 = 1
8	1 x 1 = 1
9	10 x 10 = 100

Figure 7 - Square numbering scheme. Square 9 is the whole 10 by 10 grid.

Visual Angle Measurements

The visual angle is the angle subtended by an object at the drivers' eye. The visual angle has some relationship to the minification. Each is reduced with distance with increasing distance from the viewer to the object. However, the minification is not related to the size of the object. It expresses the amount of size reduction from the 'real' image to the 'projected' image. On the other hand, the visual angle of an object increases with the size of the object. The visual angle will tell you how large the image will be at the observer's eye and in effect the visibility of the object.

In this study the visual angle for square 5 was calculated for each of the mirrors. The size of the image on the cross-view mirror as measured in the photographs, and the visual angle calculated by using the trigonometric relationship of the image size and the distance to the driver's eye position to calculate the subtended angle. Satoh et al., 1983, have developed a psychological scale relating the visual angle to the image visibility. This scale is shown in the following table.

Level	**Degree of image form**	**Degree of image size**	**Visual Angle (min)**
1	Excellent	No image small	51+
2	Good	Small, but no problem	21-50
3	Fair	Small, but possible to judge	11-20
4	Poor	Small and hinders judgment	5-10
5	Very Poor	Impossible to judge	>5

Table 5 - Subtended visual angle versus psychological category, from Satoh, et al., 1983

Results

The result of this study are divided in the following categories:

- Field of View Measurements
- Minification Measurements
- Distortion Measurements
- Visual Angle Measurements

Field of View Results

As described above, FOV measurements were made for each of the mirror and adjustment combinations. The field of view results are shown below in several ways. First, the percentage of the 10 by 10 foot grid that was visible is reported. Second, a graphical view is provided that shows which of the 100 squares in the 10 by 10 foot grid were visible. Third, the three-dimensional field of view is shown graphically by displaying the amount each of the 3 foot high child-like objects that was visible.

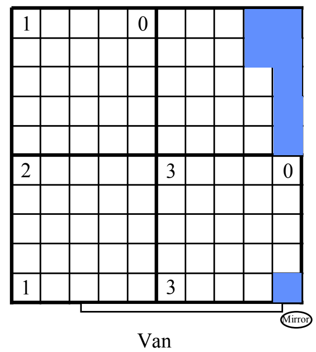
Table 6 summarizes the FOV findings for each of the eleven mirror/adjustment/truck size combination that were evaluated.

Mirror	Adjustment	Size	ROC	Truck Size	Percent Grid Visible
Sure Plus #390	Bumper	10"	13"	Large	92
Sure Plus #390	Center	10"	13"	Large	83
Velvac #713406	Bumper	10"	7"	Large	100
Velvac #713406	Center	10"	7"	Large	100
Velvac #713406	Bumper	10"	7"	Small	100
Velvac #713406	Center	10"	7"	Small	100
Sure Plus #570	Bumper	8"	11"	Small	47
Sure Plus #570	Center	8"	11"	Small	40
Velvac #713120	Bumper	8"	5.5"	Small	100
Velvac #713120	Center	8"	5.5"	Small	100
Mirror Lite Tailwatcher	Bumper	8"x12"	5"-8"	Small	98

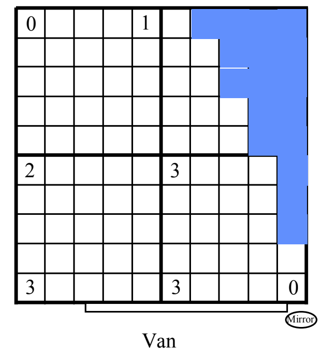
Table 6 : Field of view measurements

In the diagrams below the shaded squares show the squares of the 10 by 10 foot grid that are NOT visible. The white cells represent the FOV of the particular mirror/van combination. Superimposed on each grid are 9 numbers. These numbers represent how much of the 3 foot high child-size objects was visible at this position in the grid. The numbers were limited to 0 feet, 1 foot, 2 feet or 3 feet. The three foot high objects were marked off into one foot segments, and the number reported below is the highest mark on the object that could be seen from analysis of the photographs.

Mirror: Sure Plus #390
Adjustment: Bumper
Size: 10"
ROC: 13"
Truck Size: Large

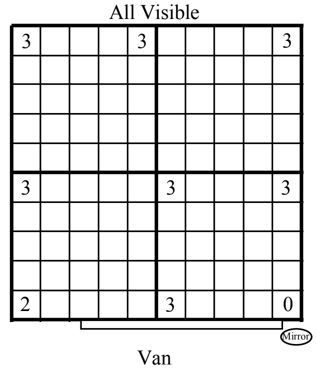


Mirror: Sure Plus #390
Adjustment: Center
Size: 10"
ROC: 13"
Truck Size: Large



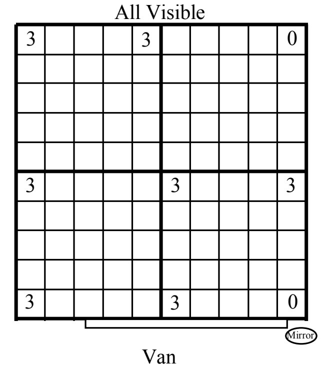
Mirror: Velvac #713406
Adjustment: Bumper
Size: 10"
ROC: 7"
Truck Size: Large

All Visible



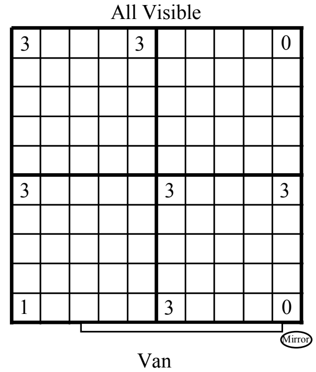
Mirror: Velvac #713406
Adjustment: Center
Size: 10"
ROC: 7"
Truck Size: Large

All Visible



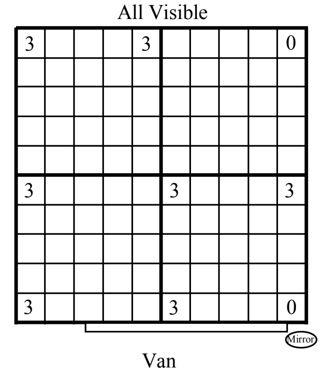
Mirror: Velvac #713406
Adjustment: Bumper
Size: 10"
ROC: 7"
Truck Size: Small

All Visible

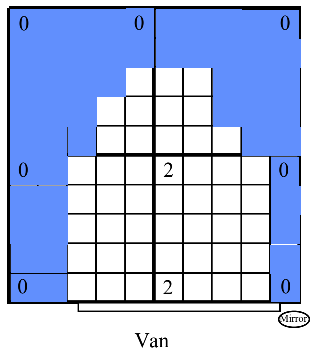


Mirror: Velvac #713406
Adjustment: Bumper
Size: 10"
ROC: 7"
Truck Size: Small

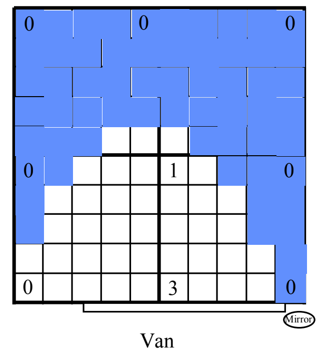
All Visible



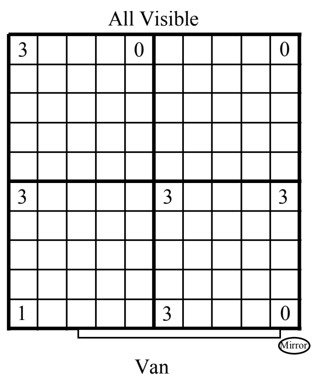
Mirror: Sure Plus #570
Adjustment: Bumper
Size: 8"
ROC: 11"
Truck Size: Small



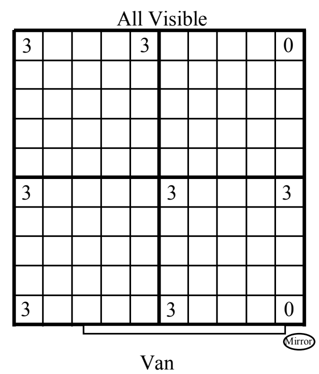
Mirror: Sure Plus #570
Adjustment: Center
Size: 8"
ROC: 11"
Truck Size: Small



Mirror: Velvac #713120
Adjustment: Bumper
Size: 8"
ROC: 5.5"
Truck Size: Small



Mirror: Velvac #713120
Adjustment: Center
Size: 8"
ROC: 5.5"
Truck Size: Small



Mirror: Mirror Lite Tailwatcher
Adjustment: Bumper
Size: 8"x12"
ROC: 5"-8"
Truck Size: Small

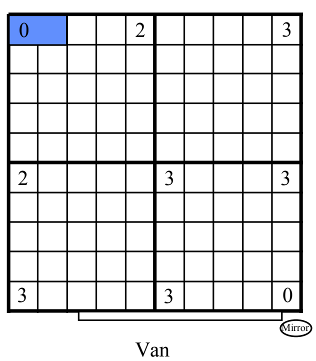


Figure 8 - FOV at ground level shown as white squares, non-visible shown as shaded squares. Numbers represent the amount of the 3 foot high object that was visible.

Distortion Results

The tables below show the results of the distortion measurements for each of the mirrors. The square definitions are as shown in figure 7.

The table below shows the distortion measure (ε) and the psychological rating of distortion for each of the mirrors on the large van. The code NV stands for NOT VISIBLE.

Manufacturer	Mirror Size	ROC	Van Type	Alignment	Square	ε	Rating
Sure Plus	10"	13'	Large	Center	1	NV	NV
					2	1.74	Excellent
					3	1.74	Excellent
					4	NV	NV
					5	2.52	Good
					6	1.77	Excellent
					7	NV	NV
					8	4.38	Fair
					9	NV	NV
Sure Plus	10"	13"	Large	Bumper	1	NV	NV
					2	1.81	Excellent
					3	3.59	Good
					4	NV	NV
					5	2.47	Good
					6	1.86	Excellent
					7	8.00	Very Poor
					8	6.25	Poor
					9	NV	NV
Velvac	10"	7"	Large	Center	1	3.02	Good
					2	1.88	Excellent
					3	3.51	Good
					4	3.05	Good
					5	2.59	Good
					6	1.97	Excellent
					7	6.44	Poor
					8	3.30	Good
					9	3.09	Good
Velvac	10"	7"	Large	Bumper	1	2.65	Good
					2	2.07	Good
					3	3.88	Good
					4	6.41	Poor
					5	2.54	Good
					6	1.87	Excellent
					7	5.94	Fair
					8	3.26	Good
					9	3.26	Good

Table 7 - Distortion ratings for mirrors on the large van.

The table below shows the psychological rating of distortion for each of the mirrors on the small van. The code NV stands for NOT VISIBLE.

Manufacturer	Mirror Size	ROC	Van Type	Alignment	Square	ε	Rating
Velvac	10"	7"	Small	Bumper	1	2.53	Good
					2	1.85	Excellent
					3	3.47	Good
					4	7.77	Poor
					5	2.83	Good
					6	1.67	Excellent
					7	8.86	Very Poor
					8	3.56	Good
					9	3.24	Good
Velvac	10"	7"	Small	Center	1	1.86	Excellent
					2	1.10	Excellent
					3	3.67	Good
					4	7.85	Poor
					5	2.82	Good
					6	1.69	Excellent
					7	7.94	Poor
					8	3.50	Good
					9	3.24	Good
Sure Plus	8"	11"	Small	Bumper	1	NV	NV
					2	NV	NV
					3	NV	NV
					4	NV	NV
					5	2.67	Good
					6	1.79	Excellent
					7	NV	NV
					8	NV	NV
					9	NV	NV
Sure Plus	8"	11"	Small	Center	1	NV	NV
					2	NV	NV
					3	NV	NV
					4	NV	NV
					5	2.82	Good
					6	1.55	Excellent
					7	NV	NV
					8	NV	NV
					9	NV	NV
Velvac	8"	5.5"	Small	Bumper	1	2.75	Good
					2	1.85	Excellent
					3	4.63	Fair
					4	7.41	Poor
					5	2.81	Good
					6	1.71	Excellent
					7	8.94	Very Poor
					8	NV	NV
					9	2.41	Good
Velvac	8"	5.5"	Small	Center	1	2.79	Good
					2	NV	NV
					3	3.97	Good

					4	8.29	Very Poor
					5	2.91	Good
					6	1.72	Excellent
					7	11.15	Very Poor
					8	5.23	Fair
					9	3.30	Good
Mirror Lite	12"-8"	5"- 8"	Small	Bumper	1	2.41	Good
					2	1.74	Excellent
					3	NV	NV
					4	6.61	Poor
					5	2.49	Good
					6	1.62	Excellent
					7	7.70	Poor
					8	3.80	Good
					9	NV	NV

Table 8 - Distortion rating for mirrors on the small van.

Minification Results

The following table displays the minification ratio for each of the mirrors on the large van type. The minification ratio is the ratio of the actual size of a square on the grid to the size of the image on the side view mirror. The linear ratio is the square root of the area minification ratio. NV stands for NOT VISIBLE.

Mirror	Size	ROC	Van	Align	Square	Area	Area ratio	Linear Ratio
Sure Plus	10"	13 "	Large	Center	1	25	NV	NV
					2	25	0.00083	0.02894
					3	25	0.00101	0.03178
					4	25	NV	NV
					5	1	0.00168	0.04107
					6	1	0.00078	0.02799
					7	1	NV	NV
					8	1	0.00041	0.02031
					9	100	NV	NV
Sure Plus	10"	13 "	Large	Bumper	1	25	NV	NV
					2	25	0.00079	0.02818
					3	25	0.00048	0.02192
					4	25	NV	NV
					5	1	0.00165	0.04069
					6	1	0.00076	0.02759
					7	1	0.00057	0.02403
					8	1	0.00026	0.01619
					9	100	NV	NV
Velvac	10"	7 "	Large	Center	1	25	0.00031	0.01757
					2	25	0.00029	0.01699
					3	25	0.00020	0.01425
					4	25	0.00043	0.02065
					5	1	0.00065	0.02540
					6	1	0.00027	0.01645
					7	1	0.00034	0.01849
					8	1	0.00022	0.01470
					9	100	0.00032	0.01785
Velvac	10"	7 "	Large	Bumper	1	25	0.00048	0.02199
					2	25	0.00025	0.01594
					3	25	0.00018	0.01339
					4	25	0.00027	0.01640
					5	1	0.00051	0.02258
					6	1	0.00028	0.01659
					7	1	0.00032	0.01776
					8	1	0.00019	0.01389
					9	100	0.00028	0.01665

Table 9 - Minification ratios for mirrors on large vans.

The following table displays the minification ratio for each of the mirrors on the small van type. NV stands for NOT VISIBLE.

Mirror	Size	ROC	Van	Align	Square	Area	Area Ratio	Linear Ratio
Velvac	10"	7"	Small	Bumper	1	25	0.00166	0.04074
					2	25	0.00056	0.02375
					3	25	0.00041	0.02023
					4	25	0.00070	0.02653
					5	1	0.00177	0.04207
					6	1	0.00056	0.02363
					7	1	0.00065	0.02542
					8	1	0.00034	0.01842
					9	100	0.00075	0.02736
Velvac	10"	7"	Small	Center	1	25	0.00241	0.04910
					2	25	0.00100	0.03158
					3	25	0.00400	0.01987
					4	25	0.00073	0.02700
					5	1	0.00203	0.04506
					6	1	0.00064	0.02536
					7	1	0.00085	0.02923
					8	1	0.00042	0.02054
					9	100	0.00078	0.02789
Sure Plus	8"	11"	Small	Bumper	1	25	NV	NV
					2	25	NV	NV
					3	25	NV	NV
					4	25	NV	NV
					5	1	0.00413	0.06429
					6	1	0.00180	0.04238
					7	1	NV	NV
					8	1	NV	NV
					9	100	NV	NV
Sure Plus	8"	11"	Small	Center	1	25	NV	NV
					2	25	NV	NV
					3	25	NV	NV
					4	25	NV	NV
					5	1	0.00410	0.06402
					6	1	0.00176	0.04197
					7	1	NV	NV
					8	1	NV	NV
					9	100	NV	NV
Velvac	8"	5.5"	Small	Bumper	1	25	0.00088	0.02971
					2	25	0.00036	0.01909
					3	25	0.00032	0.01780
					4	25	0.00041	0.02032
					5	1	0.00102	0.03195
					6	1	0.00035	0.01859
					7	1	0.00038	0.01940
					8	1	NV	NV
					9	100	0.00060	0.02439
Velvac	8"	5.5"	Small	Center	1	25	0.00093	0.03047
					2	25	0.00038	0.01955
					3	25	0.00023	0.01519

					4	25	0.00039	0.01986
					5	1	0.00106	0.03255
					6	1	0.00037	0.01916
					7	1	0.00031	0.01761
					8	1	0.00015	0.01206
					9	100	0.00045	0.02131
Mirror Lite	12"-8"	5"-8"	Small	Bumper	1	25	0.00108	0.03289
					2	25	0.00051	0.02260
					3	25	NV	NV
					4	25	0.00045	0.02231
					5	1	0.00115	0.03393
					6	1	0.00054	0.02325
					7	1	0.00051	0.02251
					8	1	0.00025	0.01581
					9	100	NV	NV

Table 10 - Minification ratios for mirrors on small vans.

Visual Angle Results

To permit comparison of these results to those of other related studies, the visual angle subtended by one of the squares was computed for each of the mirror/adjustment combinations. The square selected was square number 5 from the tables above. This is the closest small square to the driver and represents a best case visual angle.

The table below shows the visual angle (VA) measurements for the mirror in the current study. All ratings were either fair or poor based on the subject scale developed by Satoh, et. al, 1983, as described in the methods section.

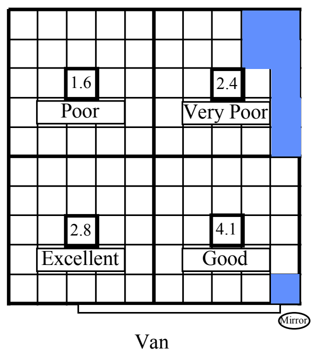
Mirror	**Size**	**ROC**	**Van**	**Align**	**VA (min)**	**Rating**
Sure Plus	10"	13 "	Large	Center	12.28	Fair
Sure Plus	10"	13 "	Large	Bumper	12.12	Fair
Velvac	10"	7 "	Large	Center	7.64	Poor
Velvac	10"	7 "	Large	Bumper	6.77	Poor
Velvac	10"	7"	Small	Center	12.35	Fair
Velvac	10"	7"	Small	Bumper	11.54	Fair
Sure Plus	8"	11"	Small	Center	17.53	Fair
Sure Plus	8"	11"	Small	Bumper	17.39	Fair
Velvac	8"	5.5"	Small	Bumper	8.74	Poor
Velvac	8"	5.5"	Small	Center	8.99	Poor
Mirror Lite	12"-8"	5"-8"	Small	Bumper	9.04	Poor

Table 11 - Subtended visual angle for each mirror/adjustment combination for square 5.

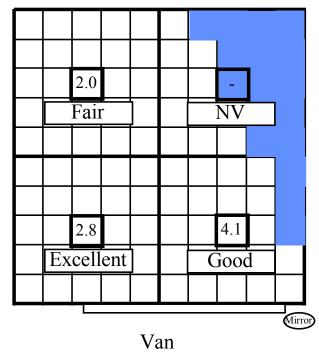
Summary

The figure shows the three types of information for each of the mirror/adjustment combinations. The ground-level FOV is shown by the shaded squares (shaded squares are not visible.) The linear minification is shown by the number in each square as the percent of normal (ex. 2.4 means the image is 2.4% the size of the original image.) Finally, the distortion psychological rating for four of the squares is shown. Rating values are excellent, good, fair, poor, and very poor.

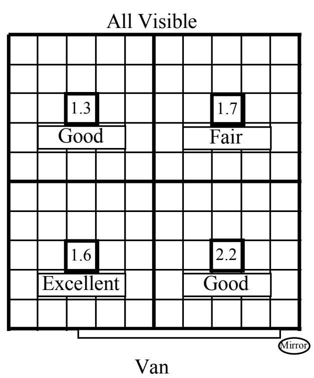
Mirror: Sure Plus #390
Adjustment: Bumper
Size: 10"
ROC: 13"
Truck Size: Large



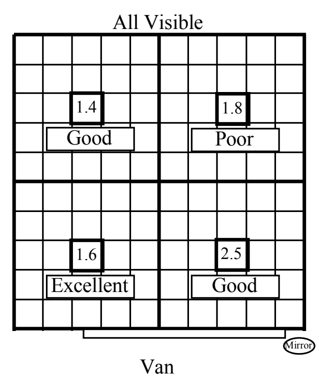
Mirror: Sure Plus #390
Adjustment: Center
Size: 10"
ROC: 13"
Truck Size: Large



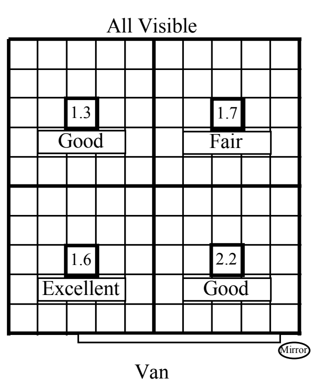
Mirror: Velvac #713406
Adjustment: Bumper
Size: 10"
ROC: 7"
Truck Size: Large



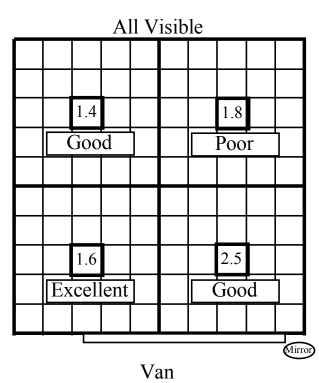
Mirror: Velvac #713406
Adjustment: Center
Size: 10"
ROC: 7"
Truck Size: Large



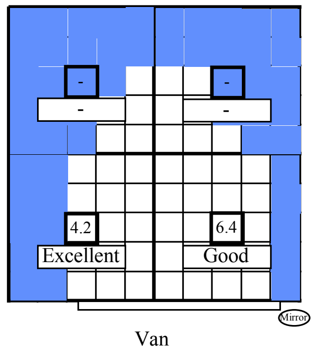
Mirror: Velvac #713406
Adjustment: Bumper
Size: 10"
ROC: 7"
Truck Size: Large



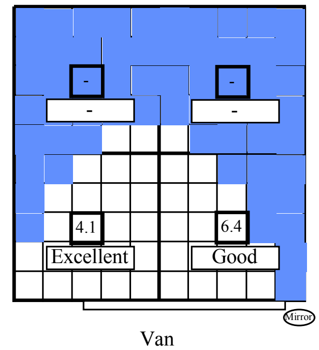
Mirror: Velvac #713406
Adjustment: Center
Size: 10"
ROC: 7"
Truck Size: Large



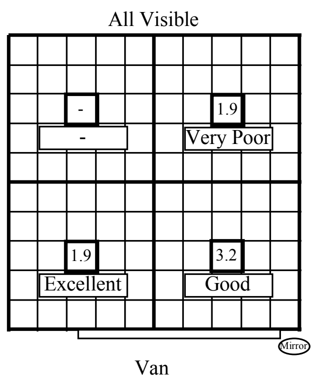
Mirror: Sure Plue #570
Adjustment: Bumper
Size: 8"
ROC: 11"
Truck Size: Small



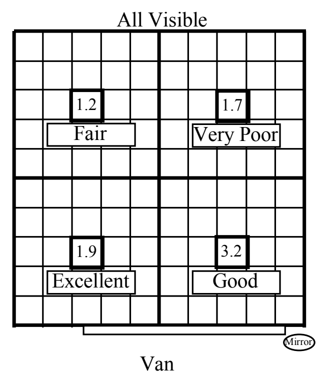
Mirror: Sure Plue #570
Adjustment: Center
Size: 8"
ROC: 11"
Truck Size: Small



Mirror: Velvac #713120
Adjustment: Bumper
Size: 8"
ROC: 5.5"
Truck Size: Small



Mirror: Velvac #713120
Adjustment: Center
Size: 8"
ROC: 5.5"
Truck Size: Small



Mirror: Mirror Lite
Tailwatcher
Adjustment: Bumper
Size: 8"x12"
ROC: 5"-8"
Truck Size: Small

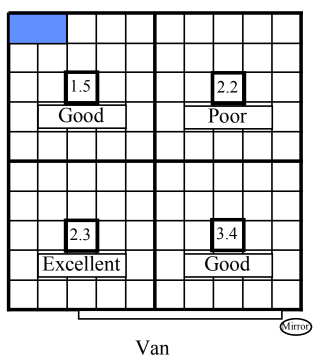


Figure 9: Minification, distortion and FOV summary.

The above figure reveals several insights for the current rear cross-view mirrors.

- The distortion generally does not vary greatly from mirror to mirror.
- The squares that are closest to the van have a good or excellent rating for distortion and the squares furthest from the van tend to have poor or fair rating for distortion.
- The FOV and the level of minification were inversely related. Mirrors that provided a large FOV had a more minification while mirrors with a small FOV had less minification.
- While the method of adjusting the mirror influenced the FOV for some conditions, there were generally not pronounced differences for distortion or minification.

Acknowledgments

WESTAT would like to thank the mirror manufacturers that gave us mirror and mounting hardware samples for this study. These companies included: Mirror Lite, Sure Plus, Roscoe, and Velvac.

References

Satoh, H., Yamanaka, A., Kondoh, T., Yamashita, M., Matsuzaki, M., and Akizuki, K., "Development of a Periscope Mirror System", JSAE Review, November, 1983.