GENERAL DYNAMICS
Advanced Information Systems

Engineering and Evaluation Report
for an
Enhanced Driver Visibility Safety System
for the
Petroleum Technology Alliance Canada

Prepared by:

Jeremy E. Burns
Lead Systems Engineer
Automotive and Transportation Center

Introduction

The night driving system has two main components, the camera and the display. The camera records an image, and the display presents that image. Each of these components has a direct bearing on what the driver sees and how it is seen. The following is an in-depth analysis of the system's configuration, and the engineering details that drive its limitations. An evaluation method for determining the system's effectiveness over the course of the Operational Test (and its likely future effectiveness) is also discussed.

IR Camera:

The IR camera presents an image with an 11 degree horizontal field-of-view, and a 4 degree vertical field-of-view. It is General Dynamics' experience that the vertical field-of-view should be adequate for the task of displaying wildlife, even in hilly terrain. The horizontal field-of-view may present certain geometric limitations to detecting animals in a worst-case scenario.

The scenario in question relates to driver responses from the initial Human Factors Engineering Task Analysis Questionnaire in Phase I, where it was noted that sometimes deer come running out from nowhere and actually hit the side of the vehicle. This particular type of accident, where a deer runs at full speed perpendicular to the travel path of the truck, represents a limiting situation whereby the deer may never be in the camera's field-of-view until the last moment and yet could still be hit by the truck.

We can fix the speed of the deer at its maximum value, in order to get a worst-case scenario. An average deer (or elk, moose, etc.) has a top speed of around 35 miles per hour (56 km/h, or 15.64 m/s). So, picturing a right triangle as shown in Figure 1, where the vertical line is the truck's velocity, the horizontal line is the deer's velocity, and the angle at the bottom represents half of the camera's horizontal field-of-view (i.e., 5.5 degrees), we can now solve for the truck's speed.

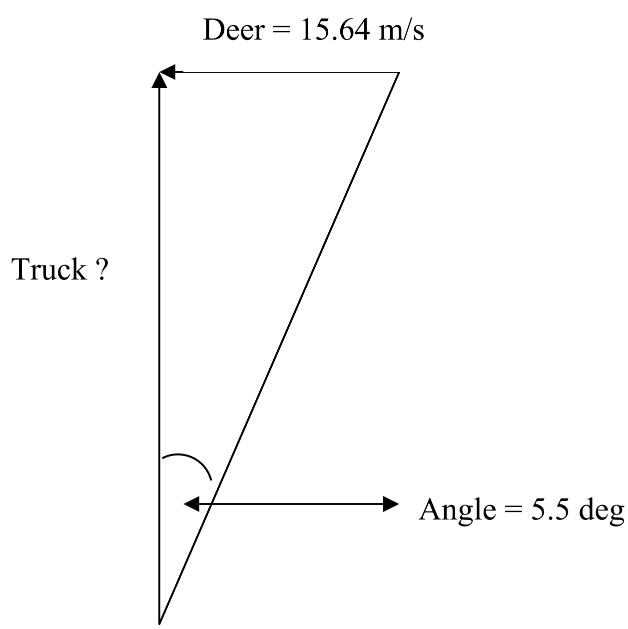

Figure 1: Truck and Deer Closing Velocities

Using the tangent: Truck = Deer / tan(5.5) = ~ 162 m/s or 584 km/h!!

In other words, the truck would have to be traveling at greater than 584 km/h in order to avoid such a collision. Clearly, this demonstrates that a deer running in from the side has the potential to hit a moving truck without ever entering the camera's view (since the angle does not change as the deer and truck approach the collision point), no matter what the truck's speed is. In fact, even if the truck is moving at 60 miles per hour (100 km/h), a deer could theoretically be traveling at a mere 6 miles per hour (10 km/h) and still hit the truck without entering the camera's view.

Arctan(10 / 100) = ~ 5.5 degrees

Of course, such a situation is very unlikely to occur. What this really demonstrates in practical terms is the importance of slowing way down in the vicinity of an animal as soon as it is spotted along the side of the road, because even when it leaves the camera's view it is still a potential threat to the truck if it starts running. We can use this information to direct driver behavior once an animal is spotted ahead.

For instance, Table 1 shows the full width of the viewable area and the corresponding distance away from the camera at which that width can be seen. These chosen widths also roughly correspond to the visible lane and clear-cut shoulder areas of different types of roads noted in the Phase I study, before the shoulder becomes choked with brush. Assuming a deer is standing on the edge of the beam width (just visible), and so is at both the distance away from the truck and off the side of the road listed, we can present a situation similar to Figure 1 and compare both the time it will take the truck to reach the deer ("Time to Distance"), and the time it will take the deer to move (at full speed) in front of the truck ("Deer to Truck Path"). During this entire "Time to Distance" the deer and its movements will no longer be visible to the camera!

Table 1: Camera Geometry

Beam Width	5 m	15 m	25 m	50 m	86 m
Distance Away	26 m	78 m	130 m	260 m	450 m
Deer Dist. Off Road	2.5 m	7.5 m	12.5 m	25 m	43 m
Road Type	1 lane dirt, two-track	2 lane, narrow dirt	wide dirt, paved	near fields, highways	max range, wide-open
Typ. Speed	30 km/h	45 km/h	60 km/h	80 km/h	120 km/h
Time to Distance	3 s	6 s	8 s	12 s	13.5 s
Deer to Truck Path	0.2 s	0.5 s	0.8 s	1.6 s	2.75 s

The most important points to note from this table are the long amounts of closing time during which the deer will no longer be visible, and the very short amounts of time it takes a sprinting deer to become a threat. This combination illustrates how even after a deer is initially spotted, it can remain dangerous within 200 or so meters of that location for many seconds later. This reinforces the fact that drivers must slow down significantly in the area where an animal is spotted, no matter how far off the road or how far away it is initially. The camera will not protect the area immediately around the truck when it is in a potential danger zone, it will only give advance warning of an impending situation. Therefore, drivers will need to be overly cautious when entering an area that is known to have deer nearby. Remember that a deer can move up to 15 m/s, so even at the longest ranges and fastest truck speeds, a deer that is within the viewing area at the time it is spotted is never more than a couple seconds away from causing an accident.

Display:

Placement of the display in the cab, be it LCD screen or HUD combiner, is critical for several reasons. The display must be close enough to the driver's normal field of view so that it can be easily seen in peripheral vision. It must not obscure the driver's view of the road and surrounding area, traffic signs and signals, or dash mounted instruments and other vehicle accessories. It must encroach as little as possible on the tools and communications equipment normally mounted in the cab. It must also be mounted securely and safely. General Dynamics addressed each of these requirements during the test system installation.

After a careful analysis of pickup truck cabs, manufacturers suggested locations, human factors considerations, and the many vehicle and terrain photographs we obtained in Phase I of this program, the logical position for mounting the display became very clear. General Dynamics has recommended that the location should be high on the windshield, just to the left of the rearview mirror. There are many tradeoffs to be considered when coming to this conclusion.

First, let us consider one of the primary performance goals of the system. The display should be easily seen in a driver's peripheral vision, so that any animals present have a chance of being quickly noticed during regular driving situations.

The human eye contains two kinds of photoreceptor cells; rods and cones. Roughly 125 million of them are intermingled non-uniformly over the retina. The ensemble of rods (approximately 120 million in number) in some respects has the characteristics of a high-speed, black and white film. It is exceedingly sensitive, performing in light too dim for the cones to respond to, yet it is unable to distinguish color, and the images it relays are not well defined. These are the cells most responsible for motion detection.

In contrast, the ensemble of 6 or 7 million cones can be imagined as a separate, but overlapping, low-speed color film. It performs in bright light, giving detailed colored views, but is fairly insensitive at low light levels. Figure 2 shows the distribution of rods and cones across the eye's visual field of view.

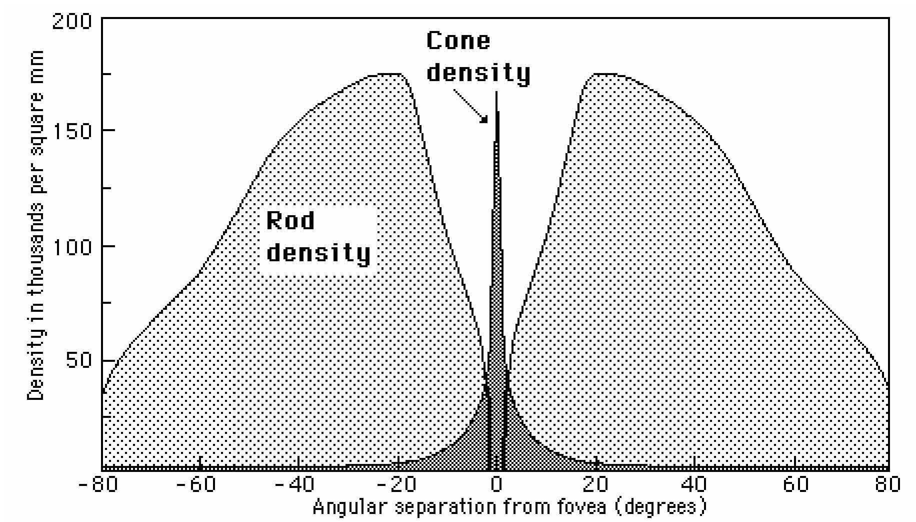

Figure 2: Cone and Rod Density Graph

To form high resolution images the light must fall on the fovea, which is a small depression in the retina (in the center of vision) containing most of the cones. That limits the acute vision angle to about 15 degrees. In order to gain the absolute most acute night vision, the eyes should be shifted slightly—about 4 to 12 degrees off of the centerline of vision—in order to let light fall on both the high-resolution cones and also some low-resolution rods.

However, to achieve the fastest perception of movement, the subject (in this case the display) should be offset by 20 to 40 degrees from the centerline of sight. This places it directly in the eye's highest density region of rods. As stated before, the rods are extremely sensitive to changes in light, which is ideal for noticing movement in the black-and-white displays of the IR night driving system. Well-defined images are unnecessary at this early stage of detection. Once the movement is detected in peripheral vision on the display, the driver can glance directly at the screen to determine what the object is and decide on the best course of action.

The potential caveat to this assertion is the "blind spot" each eye has as a result of the optic nerve. A relatively small point in the eye's peripheral vision (approximately 20 degrees to the right of the centerline of vision) is incapable of detecting images. This spot is depicted in Figure 3. The blind spot goes largely unnoticed in everyday life for three reasons.

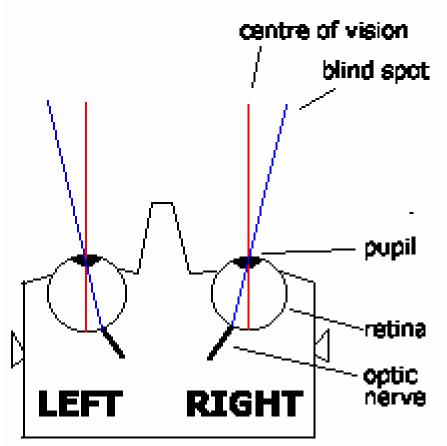

Figure 3: Blind Spot

First, the eyes are constantly moving, which shifts the blind spot around and makes it far less noticeable. Second, the left eye can see into the blind spot of the right eye, and vice versa. The brain compensates by using information from both eyes to create a complete picture without missing areas. This applies to both of the previous reasons.

Third, the blind spot itself is image-compensated in real time by the brain. It will automatically fill in the area in the blind spot with the same color seen around it in the background. It will also manipulate lines drawn through the blind spot. For instance, if portions of a straight line through the blind spot can be seen on both sides, the eye will automatically complete the line through the area of the blind spot. If the line enters the blind spot from one side and stops somewhere in the middle, the eye will truncate the line at the point where it enters the blind spot, no matter how far into the spot it actually extends. If that same line (say, for instance, a pencil) is slid further through the blind spot until it can finally be seen on the other side, the brain suddenly adds the completed line through the blind spot. In this way, the brain is automatically "touching up" the image seen with a best guess assumption, making it very difficult to notice the blind spot at all. However, under certain circumstances (such as staring ahead), this spot has the potential to affect the view of the display. Therefore, its presence should be considered when choosing the location of the display.

To determine the angle of the center of the display, relative to a driver's eye centerline when looking straight ahead down the road, some geometry and vector composition must be performed. This will in turn generate a compound angle from center, and help answer the question "Will the blind spot area be covering the display when a driver is looking straight ahead?"

The distance from the driver's eyes to a line extending sideways from the plane of the display screen (or combiner) and intersecting the centerline of vision was measured to be about 23 inches (59 cm). The actual center of the display screen was approximately 7 inches (18 cm) to the right of this point, and 4 inches (10 cm) upwards.

Geometrically, this gives a horizontal angle to the right of:

$\alpha = \arctan(18 / 59) = \sim 17$ degrees.

The vertical angle upwards is:

$\beta = \arctan(10 / 59) = \sim 10$ degrees.

The final compound angle is:

$\theta = \mathrm{sqrt}(\alpha^2 + \beta^2) = \mathrm{sqrt}(289 + 100) = \mathrm{sqrt}(389) = \sim 20$ degrees.

In a scenario where a driver is "zoning out" late at night, staring straight ahead, it is possible that a display mounted around 20 degrees directly to the right of the driver's centerline of vision may have an occluded area from the blind spot, such that seeing any animal movement in that area would be more difficult. However, this blind spot is relatively small (covering no more than a few degrees in any direction from its center) and it is very close to the horizontal plane through a driver's centerline of vision. In other words, by moving the display both 17 degrees to the right *and 10 degrees upwards*, the view is still in a region of high rod density (at a final compound angle of 20 degrees from centerline of view), and it is also well above and out of the way of the eye's blind spot.

The display must not obscure the driver's view and driving tasks. This applies equally to roadways, traffic signals, and surrounding area, as well as the interior of the vehicle.

There were no locations on or around the dash area in which to mount the display screen. For the HUD, there would be too much of an angle between the projector and the combiner, or a serious compromise in positioning and display quality. The LCD screen has more freedom of mounting locations, but it is larger and more obtrusive than the HUD combiner. On top of the dash, virtually anywhere along it, the LCD blocked too much of the roadway and surrounding areas. There were no suitable mounting locations in front of the dash due to climate and radio controls, gauges, airbags, driver communications equipment, and access to other vehicle functional items. There was potentially some space near the floor, but this would present far too oblique of a viewing angle to be practical for peripheral vision. It also subjects the display unit to more abuse.

The area just left of the rearview mirror presents the best combination of visibility and usability. During the day, the HUD combiner is see-through and the LCD can be folded up and out of the way. At night, both displays were tested in city and rural areas, and were found to hardly ever block traffic lights or signs, and even then it would only do so when very close to certain overhanging signals. In all cases, these signals were seen and noted well before they had a chance of being blocked. This display location also did not occlude the important areas of visibility, although a slightly lower driver's seat elevation helps with this when using the LCD screen.

The display mounting location was also designed not to encroach on existing communications equipment. Most of this equipment was mounted in the center console area, in front of the dash between the driver and passenger seats. A representative picture is shown in Figure 4. By comparison, the headliner and windshield areas of the vehicles were virtually clear. See Figure 5.

Figure 4: Typical Dash

Figure 5: Overhead and Windshield

The display must be mounted securely and safely. This is to minimize the risk of system components in the cab becoming dangerous to the occupants in the event of an accident.

For the HUD, the combiner is very light and if properly applied will hold tenaciously. The projector unit is mounted offset to the right of the driver's head and above it. If it were to somehow be struck in an accident, it is designed to break away from the mounting plate and thus will cushion a strong blow.

The LCD screen is also mounted offset to the right of the driver. This will minimize the chance of an impact with the screen during an accident. General Dynamics has also determined that, properly mounted, the LCD screen should not be able to break away from its mounting in the event of an accident.

The LCD and bracket weigh a combined 2 pounds (0.91 kg). In an accident, G-forces of up to 30 times higher than normal can be generated, which will effectively turn the LCD assembly a 60 pound (27 kg) object. The three sheet metal screws included are a #8 (0.164 inch, or 4.17 mm) self-piercing 'type A' with 15 threads per inch (5.9 threads per cm). In our mounting diagram, these are being driven into the 22 gauge (0.0299 inch, or 0.76 mm) sheet metal 'header' between the headliner and the roof of the vehicle. A 7/64 inch (2.78 mm) drill bit is used to create a pilot hole for this installation.

This combination of screw and sheet metal is rated to nearly 100 pounds (45 kg) of tensile strength per fastener, and nearly 200 pounds (90 kg) of shear strength per fastener. There are three such screws holding the LCD in place, imposing a potential accident load of 20 pounds (9 kg) per screw, so this should be sufficient to maintain the integrity of the mounting in an accident (where the load forces will actually be distributed between tensile and shear components).

However, type A screws are no longer a recommended fastener design. These should be changed to a type A/B screw with 18 threads per inch (7.1 threads per cm) for additional security and safety factor when the full scale field installations are performed. If even more margin for safety is desired, the assembly can be mounted instead with threaded Rivnuts. These expand behind the header on installation, forming a self-made washer to further distribute the load.

PTAC Evaluation Criteria:

PTAC has decided to determine the effectiveness of the night driving system before committing to a full scale deployment. To that end, PTAC has requested that General Dynamics assist them with this task by proposing a suitable method to use. General Dynamics has weighed the options and determined that a final questionnaire would be the preferred method for doing an evaluation. This questionnaire will be designed and created by General Dynamics, to be administered and results analyzed by the appropriate PTAC staff.

In the search for an effective evaluation method, General Dynamics first turned to a quantitative solution. There are many statistical methods which can be performed with either a large enough sample, or a long enough time frame, in order to numerically address the significance of using such a system. These can encompass many fine details such as changes in animal population, number of truck-miles driven, weather, and accident rates in order to glean a useful measure of effectiveness. However, given the small initial deployment for consideration (four systems) and the relatively short time frame over which to collect data, these statistical methods are rendered nearly useless.

Therefore, the best indicator of performance becomes qualitative rather than quantitative. Driver anecdotal evidence is the most direct route to answer the two most general questions: “Does this system work?” and, by extension, “Is this system worth the cost?”

To allow PTAC to answer these two questions, as well as much more specific ones, General Dynamics has created a comprehensive questionnaire. This is to be completed at the end of the evaluation period by all drivers that have used the system. A questionnaire was chosen over other methods (such as a daily log) for two reasons. First, General Dynamics did not want to create additional work that may distract from or modify a driver's daily tasks. Second, and related to the first point, General Dynamics wanted to ensure that the system was used in the same manner as it would be if it was a commonplace device. This will help ensure that the driver feedback is representative and accurate of the final deployment situation (or as close as possible). Also, given that visibility and weather will be different on a case-by-case basis, the driver must have the ultimate decision on whether or not to use the system.

Of course, drivers should be encouraged to use the system as often as practical, so that they may develop a good feel for the system's effectiveness over a wide range of conditions and situations. Also, the number of drivers using the system must be balanced against the length of time they have to become familiar with it. Having more drivers and more opinions is a benefit, as it will provide a wide base of knowledge from which to draw. However, the drivers must have enough experience with the system so that the Hawthorne (or "newness") effect is minimized as much as possible. This effect describes the changes in behavior people exhibit when they are introduced to a new or different experience, compared to how they ultimately behave later once they get completely used to it. It is a very powerful and significant effect, and should be well considered with respect to how the system is used, especially in the initial stages of the system deployment. By the time the drivers are ready to answer the questionnaire (some two months later) they should be well enough acquainted with the system to help negate the Hawthorne effect.

The questionnaire should do an excellent job of answering the first question, "Does the system work?" The second question "Is this system worth the cost?" will be much more difficult to answer. This is especially true in terms of vehicle costs over time without supporting statistical information about changes in accident rates or severity. But, that is not necessarily the only basis for worth, for if driver safety is considered to have value then it must also be applied to the equation.