

## SEEING THE

# Big Picture

*THE LIGHTING  
COMMUNITY  
MUST THINK  
IN TERMS  
OF 'ROADWAY  
VISIBILITY'  
RATHER THAN  
'ROADWAY  
LIGHTING,'  
WHILE  
TAKING A  
SYSTEMS  
APPROACH TO  
DESIGN*

*By John Van Derlofske*

Driving at night is a necessity of modern society. People and goods must move regardless of the time of day. Lighting and visibility elements enable safe, comfortable roadway travel at night. However, if you ask most lighting professionals to define roadway lighting, they will start discussing fixed pole-based lighting. While this is correct in a traditional sense, it is certainly incomplete from a practical perspective. Functionally, roadway lighting, or more appropriately roadway visibility, is a complex assembly of components made up of many elements such as fixed pole lighting, vehicle lighting, signals, and markings. It is, in fact, these elements working and interacting together that provides visibility and information to the roadway user.

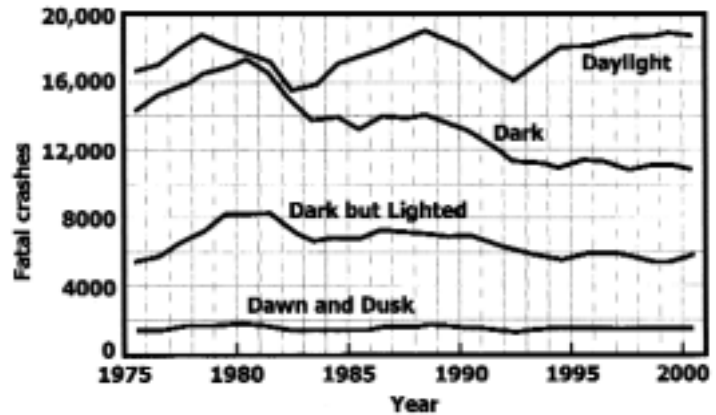
Although these elements act together they are rarely optimized, or even thought as, as a system. Lighting recommendations and standards certainly do not address the system aspects of the roadway. This results in roadway visibility that is not as safe, energy efficient, aesthetically pleasing or light-pollution preventative as it could be. It is as if roadway visibility is a Rube Goldberg invention. Its elements, such as pole-mounted fixtures or vehicle headlamps, are like Rube Goldberg's man slipping on a banana peel or his sleeping dog that gets scared into action. Functionally, each element works well and the assembly of elements may work to some extent, but it is by no means an efficient or an optimized solution.

Currently, we are on the threshold of a new paradigm for roadway lighting and visibility. Discussions are now taking place among roadway stakeholders to develop a systems approach to lighting based on the idea of providing the appropriate visual information to roadway users. However, before this can occur some basic fundamentals need to be established. The roadway visibility system first needs to be defined in terms of its purpose, and which driving behaviors should be addressed through the transfer of visual information. Additionally, its components and stakeholders must also be defined. With this framework in place, research can be developed and communication can occur among all relevant stakeholders that will ultimately result in a safer and a more efficient roadway system.





FIGURE 1. The number of fatal crashes per year as a function of light conditions.



### The Roadway Visibility System

The term, roadway lighting system is a misnomer. A more appropriate term is roadway visibility system. Not all elements in the system are light emitting; retroreflective signs and markers are an important example of critical non-light emitting system elements. Additionally, and more importantly, visibility is the ultimate goal of the system. The objective is to use lighting and visibility components to transfer information to enable safe and efficient roadway use.

**Purpose.** The information provided the driver through visibility is arguably the most important safety factor. At night, when sunlight is no longer available, other measures must be taken to ensure safe vehicle operation. Does roadway lighting make a difference to safety? It is certainly arguable that driving at night is more dangerous. In the U.S., 25 percent of vehicle travel occurs at night. However 55 percent of fatalities happen at night—three times more fatalities at night when weighted per km traveled.[1] Further, there have been studies indicating that lighting works to increase safety:

- Nighttime crashes were reduced

by 45 percent after the addition of roadway lighting to some intersections.[2]

- After roadway lighting was installed, the following reductions in accidents, injuries and fatalities were reported: Finland: 20 percent to 30 percent; Norway: 65 percent (night-time fatalities), 30 percent (injuries); Netherlands: 18 percent to 23 percent.[1]

• Publication CIE 93.1992, *Road Lighting as an Accident Countermeasure*, reports that in 85 percent of the 62 case studies, lighting was beneficial to increased safety.

However, for all of the evidence that lighting can make a difference, it is still apparent that people are getting hurt and killed on today's roads. Except in dark conditions, the number of fatal crashes has not diminished in the last 30 years (see Figure 1).[3] Even though the rate of fatalities has decreased over the years (there are more people on the roadway), the question remains as to why the total number of fatal crashes stays at an unacceptable level.

The answer may lie in the fact that a systems perspective has not been taken to optimize which information should be conveyed through lighting, and how it should be con-

veyed.

But what should be made visible? Should we try to emulate daytime conditions by illuminating everything with electric lighting? Obviously, this solution is impractical for cost and efficiency reasons, not to mention that it might interfere with our enjoyment of the night sky. Therefore, by being selective in what is made visible to the roadway user, care must be taken to use lighting and visibility elements that convey the necessary information as efficiently as possible.

The challenge then comes in determining exactly what information should be conveyed through the visibility system. At a recent Federal Highway Administration (FHWA) roundtable meeting, a model of risk homeostasis was presented as a method that might be used to help answer this question.[4][5] This model states that one's *actual* risk is strongly correlated to one's *perceived* risk, and that behavior changes to match perceived risk.

As an example, people might increase their speed on a well-lit roadway to keep the level of risk constant and, in doing so, cancel out any potential safety benefits from the increased lighting. Perceived risk

# When Headlamps M E E T Roadway Lighting

There are many areas of research and practice where one can consider the interaction of elements in the roadway visibility system. Some of these include: preventing headlamps and pole-mounted fixtures from working to reduce contrast[6]; reducing veiling glare off of retro-reflective signs; using retroreflective and light emitting markers to replace general illumination in areas where only vehicle guidance is necessary; and testing the concept of mesopically enhanced fixed roadway lighting to light the periphery while vehicle lighting illuminates the middle of the roadway.[8]

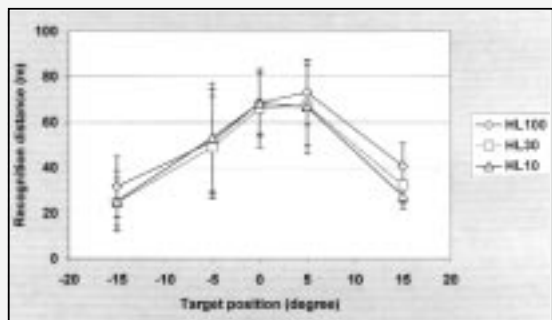
Research has recently been conducted by the National Highway Traffic Safety Administration (NHTSA) in another one of these areas: how much headlamps contribute to visibility in areas of high ambient illumination from fixed roadway lighting.[9] Earlier studies have suggested that when roadway lighting is present (even very poor roadway lighting), headlamps make only a small, and mostly negligible contribution to both on-axis and peripheral visual performance.[10][11] These results suggest that in high ambient illumination areas, headlight beam patterns could be dimmed or redirected without impairing visual performance. This idea fits with new concepts of advanced frontlighting systems (AFS), which proposes a “city beam” to change the headlight beam to reduce glare and better illuminate the sides of the roadway.

To further examine this issue, a study was performed examining the contribution of headlight illumination to target detection distances under various levels of ambient illumination from fixed roadway lighting.[9] In this experiment, 20 cm by 20 cm targets at various angles to the driver’s line of sight were brought towards the subject until they were detected. This was done under three ambient lighting conditions (100 percent, 30 percent, and 10 percent of a design meeting IESNA RP-8 recommendations) for three headlight intensities (100 percent, 30 percent, and 10 percent of typical low beams).

Results of this study are given in Figure 3, which shows the average target recognition distances as a function of target angle for the three headlight light levels tested. In general, the cen-

tral targets (at 0° and ±5°) have longer recognition distances (one can see them at further distances) since they have higher illumination levels and are at, or near, foveal detection areas of the retina. The higher angle targets ((15°) have shorter recognition distances since they have lower illumination levels and are farther from the line of sight. These data also show that, averaged across all of the ambient lighting conditions, there were no significant differences in detection distances for the three headlight intensities examined. In other words, the illumination from the vehicle headlamps did little to affect target detection distance.

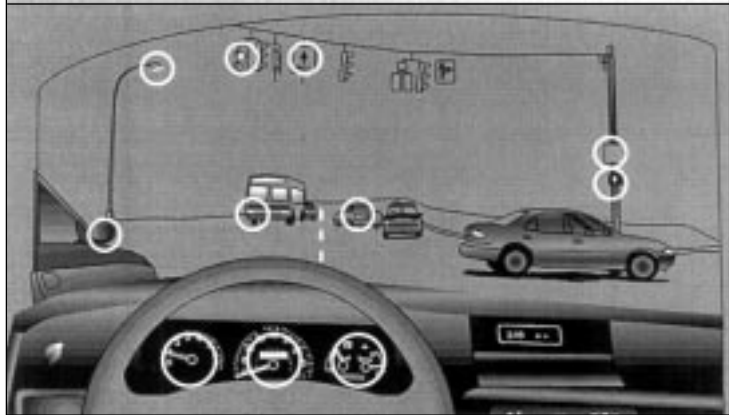
Based on these results, the question then becomes one of efficiency: Why are we using headlamps in these situations to do a job that fixed roadway lighting does better? Headlamps are still needed in these scenarios for vehicle conspicuity so they cannot be shut off completely. However, current sensor and actuator technology allows automatic detection of ambient illumination and automatic vehicle lighting adjustment. Therefore, the idea of dimming headlamps to reduce glare to oncoming drivers or changing the beam pattern to better illuminate the sides of the roadway becomes feasible and attractive.



**FIGURE 3.** Average target recognition distance under ambient illumination from fixed roadway lights for various target angles from the line of sight. Note that there is no significant difference in recognition distance between the three headlight intensities tested (HL100, HL30, HL10 signify 100%, 30% and 10% of nominal light output, respectively).



**FIGURE 2.** Some of the lighting elements that make up the roadway visibility system.



per hour is constant and independent of technology designed to improve safety. However, if perceived risk is poorly correlated with actual risk, accidents may increase and/or traffic flow may be reduced.[5] Thus, the fundamental goal for engineering is not to improve visibility per se, but rather to increase the correlation between actual and perceived risk. If perceived risk is closer to actual risk, then driver behavior will be more

imaginary inventions function, roadway visibility uses many elements to reach the final goal of providing information to the user. In fact, one issue that has prevented a systems approach to roadway visibility in the past is this focus on individual elements. Answers to visibility issues have been typically product driven and not solution driven.

Specific roadway visibility elements include: fixed roadway lighting fixtures, roadway markings and

many lighting and visibility components, these elements can also conflict with each other. Currently, each element is typically designed and specified in relative isolation to each other. For example, the Illuminating Engineering Society of North America (IESNA) recommends lighting practices for roadway lighting without taking into account vehicle forward lighting. Similarly, the Society of Automotive Engineers (SAE) develops standards for automotive forward lighting without considering fixed roadway lighting. These two systems obviously interact with each other. This interaction has the potential to create redundancy or even worse, to decrease visibility.[6]

**Stakeholders.** There are a large variety of stakeholders in the roadway system concerned with many issues, ranging from safety to security to economic development.[7] This raises an important issue. Any change in the way roadway visibility is approached will result in the perception of some stakeholders being winners and some being losers. Since, of course, nobody wants to lose (or be perceived as having lost), proposed changes in thinking can fall victim to inertia. Nobody is

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appropriate for the situation and the goals of greater safety and increased traffic flow will have been met. The real goal, therefore, is to engineer the information provided, not to just enhance visibility.

**Components.** A large variety of lighting, signaling, signage and marking elements are available to provide visual information to the driver. Just as Rube Goldberg used many components to make his

signs (traffic signals, traffic and informational signs, roadway markers, lane delineators, crosswalks), and vehicle lighting (headlamps, brake lights, taillights, interior displays, back-up lights, fog lights and turn indicators). **Figure 2** illustrates some of these elements. **Figure 2** also illustrates how many elements there can be and how visually noisy the scene can become.

Aside from possibly having too

## Double VISION

upset so let's not change anything. This is a barrier that must be overcome in order to start focusing on solutions based on a systems approach to roadway visibility.

Broadly, the stakeholders can be broken out into those who use the roadway and those who build, maintain or supply the roadways. The first group includes drivers, pedestrians, cyclists and residents. The second group includes communities, departments of transportation (DOTs), retailers, utilities, automotive manufacturers and lighting fixture manufacturers.

Different stakeholders can manipulate different aspects of roadway visibility in order to achieve their objectives. For example, agencies primarily concerned with safety aspects of visibility may be very interested in specification of appropriate light levels and spatial distributions of lighting (e.g., for uniformity) in order to optimize safety. Local communities might be very interested in the spectral (color) aspects of fixed roadway lighting in order to ensure high color rendering and attractive appearance of people and objects along a downtown shopping area. Utilities may be interested in the timing and duration of the lighting to address efficiency and cost issues.

### Next Steps

A new paradigm for outdoor lighting is being developed that is based, not simply on lighting, but on engineering the roadway visibility system to provide information that leads to appropriate action. As a start to this process, roadway system stakeholders are being brought together for dialogs and the development of new research agendas. However, shifts in thinking on this scale are large tasks, and it will take input and open-mindedness from all of the stakeholders to achieve safer

The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is currently working on two research projects for the U. S. Department of Transportation dealing with the roadway visibility system and interactions among system components.

For the Federal Highway Administration (FHWA) the LRC is developing a research roadmap to help guide FHWA's research activities for the next five to 10 years. The LRC is developing this research agenda in cooperation with lighting experts, manufacturers, standards-setting organizations, regulators and other stakeholders of the roadway visibility system. The LRC is exploring and defining the roadway visibility system by:

- Holding a meeting of interested stakeholders to identify priorities and avenues for collaboration and develop a working research framework that will lead to roadway visibility systems approach.
- Reviewing the state of the art regarding the roadway visibility system, specifically focusing on interactions among the various components of this system.
- Using the input from the first two steps to develop a research agenda and identify potential research partners, co-funding organizations and facilities, to explore the roadway visibility system.

In a second project, for the National Highway Traffic Safety Administration (NHTSA), the LRC is examining roadway glare from a systems perspective. This extensive research project is made up of four components. The first is a study of driver re-adaptation and the effects that changing lighting conditions has on visibility. The second effort continues the examination of how headlamps and roadway lighting interact to affect visibility and glare, particularly focusing on the role vehicle advanced frontlighting systems (AFS) might play in the future. A headlamp aim survey is also being conducted to determine the role that aiming (or not aiming) of headlamps plays in roadway glare. Finally, the LRC is examining glare and driver behavior in a naturalistic driving study. In this study 100 cars are being equipped with sensors and video cameras and data is being collected over a year period on driver behavior and roadway conditions, including the amount of glare illuminance at the eye. The goal of this effort is to determine what glare conditions drivers on today's roadways are experiencing and what behaviors, if any, are being exhibited in reaction to glare. Overall, by studying how vehicle forward lighting causes glare, alone and in interaction with fixed roadway lighting, the LRC is aiding NHTSA in developing regulations to make the roadways safer.

and more efficient roadway visibility systems that are modeled more after efficient automated assembly lines than after Rube Goldberg inventions.

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