

# IMPROVING THE ROADWAY VISIBILITY SYSTEM

## A Scoping Study



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## EXECUTIVE SUMMARY

The present report outlines activities undertaken to assist the Federal Highway Administration (FHWA) in identifying priorities for research in the area of visibility and visual information. Through a focused review of the literature and through a roundtable meeting of roadway stakeholders, the project team identified areas of promise that are outlined within.

The literature review identified several areas where future investigations will likely be fruitful:

- impacts of visual information on actual driving behavior: do drivers and other users adjust behavior to maintain a criterion level of risk?
- characterizing the relationship between visibility and efficient traffic flow
- understanding the interactions among different components of the visibility system
- consideration of peripheral vision and visibility along the roadway
- characterization of roadway user populations and their visual requirements
- understanding the ability of roadway users to process visual information in increasing quantities
- identifying the proper metrics that can be used to estimate safety or traffic flow impacts

A roundtable of roadway visibility system stakeholders including individuals from government agencies, research institutions, and manufacturers also identified a number of recommendations for needed research activities:

- providing the proper information load to drivers, pedestrians and other users
- weather
- warning drivers about what is ahead using vehicle-based systems as well as information physically located in and along the roadway
- systems to break through driver "shell"
- ensuring consistency of information design

These findings and recommendations can be integrated into research activities that take advantage of their areas of overlap and build on the significant base of existing knowledge about visibility for the roadway system. Common threads among the findings of the literature review and roundtable meeting include:

- interactions among various components of the roadway visibility system
  - combination of headlamps and fixed roadway lighting
  - impact of lighting on pavement marking visibility
  - the role of peripheral vision
- degree of information required in various applications and by various populations
  - understanding where and what type of information is needed - on the roadway and in the periphery

- interaction between infrastructure and in-vehicle information systems
- avoiding over-complexity around intersections and work zones
- understanding the impact of aging and other characteristics of information processing
- understanding and minimizing the impact of adverse weather on visual information

It is important to note that with these common threads, several of the highest priority activities identified could be combined in subsequent research activities. For example, basic studies of roadway user responses could be envisioned with specific modules incorporated to explore the impact of specific scenarios or lighting and visibility conditions.

## 1. INTRODUCTION

In order to assist the Federal Highway Administration (FHWA) in developing future priorities for visual information based research, the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is working with FHWA, other researchers, and with roadway system stakeholders to identify areas of study that will provide beneficial results to the roadway user. The visibility elements being considered in this project, such as fixed roadway lighting, vehicular headlights, traffic signals, signs, pavement markings and other components, together compose the *roadway visibility system*. Their purpose is to provide visual information. This visual information includes systems such as lighting, which makes objects and individuals in and along the roadway more easily and rapidly detected, as well as systems such as signs, in-vehicle messages, which do not directly aid vision but rather provide information to set or modify expectations about what can be found in and along the roadway environment.

Stakeholders in the roadway system include drivers, pedestrians, communities, and electric utilities, each of whom has different goals. These goals include safety, traffic flow, economic development, and environmental considerations such as energy efficiency and light pollution (Van Derlofske et al., 2001). Much of the research conducted on various components of the roadway system (e.g., such as summarized by Boyce, 2003) has focused on visual performance: being able to see, and therefore respond to, obstacles and adverse conditions along the roadway. It is argued for the purposes of this project that a look at the entire roadway visibility system in terms of providing a broader set of visual information for maintaining efficient traffic flow can result in approaches to research and hypothesis testing that will provide measurable benefits to FHWA and the driving public.

### Scope of this Report

The present report summarizes the activities undertaken to provide FHWA with information about research needs pertaining to optimizing the roadway visibility system.

Through a focused review of the relevant recent literature, and through a working group meeting of researchers and stakeholders about the roadway visibility system held on August 19, 2003, the LRC obtained input from these stakeholders about the potential benefits of visibility components. That input, as well as additional input from stakeholders will help to provide FHWA with useful and valuable information about promising research avenues in the future. The findings of the literature review and of the roundtable meeting are in subsequent sections of this report.

The findings herein do not outline specific recommended project activities, but rather discuss areas of research that have been identified as likely to provide FHWA with useful information upon which to base future visibility-related activities and recommendations. These areas include, for example, understanding the interactions among various components of the roadway visibility system, understanding the degree

of information required in various applications and by various populations, and understanding and minimizing the impact of adverse weather on visual information.

Visual information to drivers, pedestrians and other roadway users comes from signs, roadway markings and other informational elements during the daytime as well as the nighttime. A good deal of the focus of this report, however, is on nighttime visibility, when systems such as lighting are also of potential benefit. This focus reflects the greater proportion of crashes that occurs at night compared to the daytime as a function of driven-miles (Boyce, 2003) but should be considered alongside the continued need for many visual information systems (e.g., traffic control devices) to function during daylight hours.

Because the focus of this project was to understand requirements for providing visual information in and along the roadway, the areas of consideration that are outlined in this report include not only infrastructure-related issues but also those pertaining to roadway users and vehicles. While some of these issues lie outside the purview of the FHWA, they are considered within the scope of this report nonetheless and it is envisioned that not only the FHWA but other organizations will consider the approaches in this report for identifying priorities in visibility-related research activities.

## 2. FOCUSED LITERATURE REVIEW

This chapter summarizes some of the published literature pertaining to the visibility system and traffic safety is summarized. This review is not meant to be an exhaustive, comprehensive summary of the literature relating visual perception and information with safety. Rather, key points from several sources such as textbooks and edited compilations are discussed with respect to their conclusions regarding gaps in current knowledge and recommendations for future research activities.

Appendix 1 provides an annotated bibliography providing examples of recent research and applications.

### **Safety and Traffic Flow**

Without a doubt, issues such as increased traffic congestion and reduced traffic flow are becoming more and more critical in the development of the nation's roadway network. Since 1980, traffic has increased by more than 75% in terms of vehicle miles driven, while available lane miles have increased only by about 3% (Wachs, 2002). Indeed, roadways around urban centers make up only about 6% of lane miles but carry almost half of the nation's traffic (Canby, 2002). Traffic flow and congestion have important economic and environmental implications in their own right: the Texas Transportation Institute estimated a cost of \$78 billion annually due to inefficient traffic flow in terms of time and wasted fuel, nearly 7 billion gallons of gasoline (Canby, 2002).

Importantly too, traffic flow most likely has significant implications for safety. Even when considering that more fatal crashes occur on rural roads than urban roads - about 21,000 in rural areas compared to about 14,000 in urban areas (NHTSA, 2001) - the increased volume of traffic near urban centers means that each physical urban lane mile is more than *ten times as likely* as each physical rural lane mile to be the site of a fatal crash, using the breakdown of urban and rural roads estimated by Canby (2002). For example, a single, very busy urban interchange might experience as much traffic as a 100-mile stretch of rural roadway yet the cost to provide lighting or markings for the urban interchange would almost certainly be less than for the 100-mile-long rural roadway.

It might thus appear that approaches targeted exclusively to urban areas would offer the greatest benefit per unit cost, but such an approach must be weighed against other factors. The urban location is more likely to already have lighting or improved markings, for example, with additional improvements only incrementally improving visibility or traffic flow. The same treatments on an unlighted, unmarked rural roadway might be expected to have a relatively larger impact. The concept of equity requires public improvements to be distributed among different types of locations rather than concentrating them within a single type. Thus, social concerns can play an important role in helping to determine the value of visibility-related improvements in the roadway infrastructure.

## **Using Target Risk to Formulate and Test Hypotheses**

It has been argued by some in the transportation safety arena (e.g., Smiley, 2001) that many systems for driving to increase safety have been an unfulfilled promise. Seatbelts, air bags, vision enhancement systems and other approaches have not necessarily resulted in significantly increased safety along the nation's roadways. Indeed the idea that drivers have a level of "target risk" (Wilde, 1994) that they are willing to tolerate while driving suggests that drivers might compensate for increased visibility by increasing driving speed or the frequency of "unsafe" maneuvers, with the overall result of no net change in safety.

The target risk concept, while not fully tested in the driving safety context, presents a challenge to current thinking by suggesting that approaches other than focusing exclusively on visual performance might provide opportunities for breakthroughs in driving safety. In this context, a focus on providing visual information to improve efficient traffic flow, which is certainly related to target risk in terms of driving speeds and other behaviors, is suggested as one potential framework for testing hypotheses about the roadway systems. Hypotheses regarding visual information can be developed and tested on real roadways by examining changes in traffic flow whereas it would be socially irresponsible to test similar hypotheses by examining changes in crash data. Further, as described above, focusing on efficient traffic flow is probably not mutually exclusive with increased safety, given the fact that some locations will experience a higher frequency of crashes per physical lane mile relative to others. Still, this approach must be considered against the equity concept, which requires that the requirements of other types of locations (e.g., those with relatively low traffic flow) be considered.

## **Interactions Among System Components**

Importantly, research and development activities pertaining to each of the various components of the roadway visibility system, including fixed illumination systems, vehicular lighting, traffic signs, traffic signals and pavement markings, occur largely independently of each other (Boyce, 2003). For example, Forbes (1972) points out that many recommendations for visibility and legibility of traffic signs have not taken in to account the variety of ambient and glare conditions under which signs are seen, including different weather conditions. In the keynote lecture for the Vision in Vehicles VII conference, Breen (1999) emphasizes the need to use a systems-based approach for addressing vehicle safety and visibility. Mace (1996) studied nighttime crash rates along roadway locations and showed there was little relationship between crashes and any lighting parameters, but Keck (2001) showed that a metric of target visibility that incorporated contributions from headlamps could be correlated, albeit weakly, with crash rates. With respect to highway informational signs, Carlson and Hawkins (2003) developed minimum recommendations for retroreflectivity taking into account typical parameters of vehicle headlamp systems.



## **Importance of Peripheral Vision**

The significance of peripheral vision and visibility to roadway users cannot be underestimated but is not well understood, relative to foveal or on-axis vision. Allen et al. (2000) point out that most vision testing performed for licensing on drivers relates to foveal rather than peripheral vision, despite its importance. Similarly, Barfield and Dingus (1998) describe the significance of peripheral vision not only for detection of potential roadway hazards but also for the design of in-vehicle information systems that provide additional cues about the visual environment to a vehicle user. Peripheral vision is especially relevant to conditions where the adaptation level is in the mesopic region (Boyce, 2003) where both rod and cone photoreceptors contribute to vision, since most lighting systems along the roadway provide light levels in this region at night (Lewin et al., 2003), and since the retina contains no rods in the fovea.

## **Visual Needs of Different Roadway User Populations**

The aging population and the desire to make the roadway system accessible to all users means a significant proportion of the roadway-using population will differ from a "standard" user with defined characteristics. Schreuder (1998) emphasizes the need to better understand the characteristics and responses of these populations, as do Barfield and Dingus (1998). While the visual responses of many drivers and pedestrians can never be equal to those of young, healthy adults, the configuration of lighting and visual information systems is not yet optimized for many.

## **Processing of Visual Information**

Undoubtedly, most information about the roadway system is provided to users through vision. Lighting of potential hazards as well as signage for information, and in-vehicle systems provide useful information about these hazards and roadway conditions, but also lead to the potential for information overload. Relatively little is understood about the capacity of roadway users to process and respond appropriately to visual information of increasing volume and throughput (Wiener and Nagel, 1988). Understanding the limits to this capacity will be essential in order to effectively deploy visual information. Lerner et al. (2003) investigated driver information overload in the context of highway informational signs and developed a model to predict information overload.

## **Characterizing the Relationship Between Visibility and Safety**

Finally, few would argue that improved lighting and visual information systems would improve visibility along the roadway. Sivak (1996) presents an interesting discussion pertaining to numerous statements that information needed for driving is "90% visual," concluding that there is no data-founded basis for this percentage but that the spirit of such statements (that driving depends primarily upon vision) is undoubtedly true. Interactions between vision and other senses are less well understood (Sivak, 1996), for example, as are the precise types of visual information that are most effective in driving;

these issues are probably of greater value than determining with precision the actual percentage of the driving tasks that depend upon vision.

However, the precise relationship between improvements in visibility and either safety (in terms of reduced crashes) or traffic flow (in terms of vehicle and pedestrian volume) are not well understood. Indeed, a large body of evidence (IESNA, 1989; CIE, 1992; Schreuder, 1998) evidence indicates that installation of lighting where previously none existed can result in a measurable reduction in crashes. However, further increases in lighting might well have no impact, or worse, perhaps even an apparent negative impact compared to lower light levels (Box, 1971), possibly by increasing visual clutter or glare, or even by reducing perceived risk undeservedly. This complex and non-monotonic relationship will need to be understood better than it is currently for the visibility system to have its full impact on roadway users.

## Summary

The literature reviewed above indicates that a number of opportunities exist for better understanding the impact of the roadway visibility system on both user safety and efficiency of the roadway system in terms of traffic flow. The authors of the publications reviewed underscore the importance of considering roadway visibility as a system, with gaps in knowledge identified in the following areas:

- impacts of visual information on actual driving behavior: do drivers and other users adjust behavior to maintain a criterion level of risk?
- characterizing the relationship between visibility and efficient traffic flow
- consideration of peripheral vision and visibility along the roadway
- characterization of roadway user populations and their visual requirements
- understanding the ability of roadway users to process visual information in increasing quantities

Of course, all of these areas hinge upon an assumed relationship between improved visual information and actual safety. While this relationship seems very likely based on evidence gathered to date (e.g., IESNA, 1989; CIE, 1992), a concrete framework relating lighting and visibility systems to fundamental factors such as crash frequency or efficient traffic flow is not yet available.

### 3. ROUNDTABLE MEETING SUMMARY

The agenda for the roundtable meeting that was hosted by the Federal Highway Administration on August 19, 2003 is attached in Appendix 2. A list of attendees is provided in Appendix 3, a more detailed narrative of the roundtable meeting discussion is provided in Appendix 4, and the overhead slides developed by the Lighting Research Center to facilitate discussion at the start of the roundtable meeting is provided in Appendix 5.

After a welcome by J. Van Derlofske of the Lighting Research Center (LRC), C. Andersen introduced M. Trentacoste, Director of Traffic Safety and Development, Federal Highway Administration (FHWA), who opened with a few words describing the goals of FHWA. J. Van Derlofske then gave a presentation outlining an approach to thinking about the roadway visibility system, and welcomed participants' comments, as well as C. Andersen's additional comments regarding the purpose of the meeting.

The meeting began with a presentation outlining an approach to thinking about the roadway visibility system, followed by a presentation describing the use of the *risk homeostasis* concept as a tool for understanding safety and traffic flow, with select areas of emphasis; participants commented. Discussion continued with the concept of safety and traffic flow as complementary, rather than competing objectives for the roadway visibility system (Appendix 5). Discussion afterward touched on issues including impact on crime rates and economic development, as well as traffic flow. Following this discussion, an example of a critical roadway environment (pedestrian rich environments; see Appendix 5) was discussed. Participants were asked to consider some specific questions, e.g. *incremental* versus *radical change*, and defining *measures of success*. Among the comments were a suggestion that some study of spectrum on pavement marking color in the Netherlands had been undertaken.

Participants then discussed what appeared to be missing from the examples and what visibility systems in these situations were supposed to accomplish.

Ultimately, the objective of participants was discussed, to help FHWA develop a research agenda, and the question was asked: what is the best way to productively sort through the possibilities? Consensus developed that breakout groups would focus on the FHWA goals for safety and traffic flow and congestion, with groups focusing on specific goals. Participants broke into five groups based on several of the areas within the Vital Few Goals of FHWA for safety and congestion mitigation:

1. Intersection Fatalities
2. Pedestrian Fatalities
3. Roadway Departures
4. Traffic Congestion
5. Work Zone Traffic

After meeting in groups, a spokesperson from each group reported their findings and recommendations to the meeting. The information presented during the breakout groups had several common threads, including *provision of proper information load to drivers and pedestrians, warning drivers about what is ahead, and consistency of information design.*

Participants were also invited to provide additional specific ideas not touched upon during the roundtable for FHWA consideration and participants were encouraged to contact the project team with them. The team would also solicit further comments from individuals involved with organizations such as the Institute of Transportation Engineers, Illuminating Engineering Society of North America and others involved in preparing recommendations and standards for practice. Comments received as of October 2003 can be seen in Appendix 5.

To conclude, it was reiterated that the project team would prioritize the comments and input from the roundtable and from additional comments, and compile a report to FHWA describing possible approaches for FHWA research relating to visibility. The report might be published as a circular through the Transportation Research Board. The information will be distilled into a framework and thereby provide opportunity to address issues discussed in the roundtable.

## 4. EVALUATION OF PROPOSED CONCEPTS

### Background

On August 19, 2003, the Federal Highway Administration (FHWA) hosted and the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute moderated a roundtable meeting on research needed to optimize the roadway visibility system. Participants discussed what research needs existed, focusing on reductions in five areas that correspond to several of FHWA's Vital Few Goals for safety and congestion mitigation:

- intersection fatalities
- pedestrian fatalities
- roadway departures
- traffic congestion
- work zone crashes

Working in breakout groups corresponding to these areas, participants suggested research activities that could be undertaken with the objective of aiding FHWA in achieving its goals.

### Ranking Methodology

In order to prioritize these potential research activities, LRC project staff performed an initial ranking, using the following four criteria:

- Is the proposed research cross-cutting (across multiple elements of the visibility system)?
- Will the proposed research generate new information (as opposed to building incrementally on existing information)?
- Can the proposed research be conducted with reasonable cost and efficiency?
- Will state transportation agency stakeholders be interested in the results of the proposed research?

All rankings were performed individually by three members of the LRC project staff (J. Van Derlofske, J. Bullough and P. Rizzo). Initial rankings were made using a three-point scale (1=high/good; 2=medium/average; 3=low/far-poor) with all criteria weighted equally. The objective of this activity was to identify a small (three to four) number of potential research activities within each of the five areas.

With the next list (Table 1), project staff re-ranked the smaller list using the same criteria, but with different weights associated with each criterion. These weights were selected in order to bias rankings toward cross-cutting activities that would likely generate new information. The weights for each criterion used were:

- cross-cutting (weight=0.4)
- new information (weight=0.3)
- cost/efficiency (weight=0.2)
- stakeholder interest (weight=0.1)

Table 1 lists the mean rankings in each criterion for each proposed research activity, as well as the resulting weighted average score (again, lower numerical scores correspond to higher priority). Average scores shown in bold were the ones with the highest priority rankings.

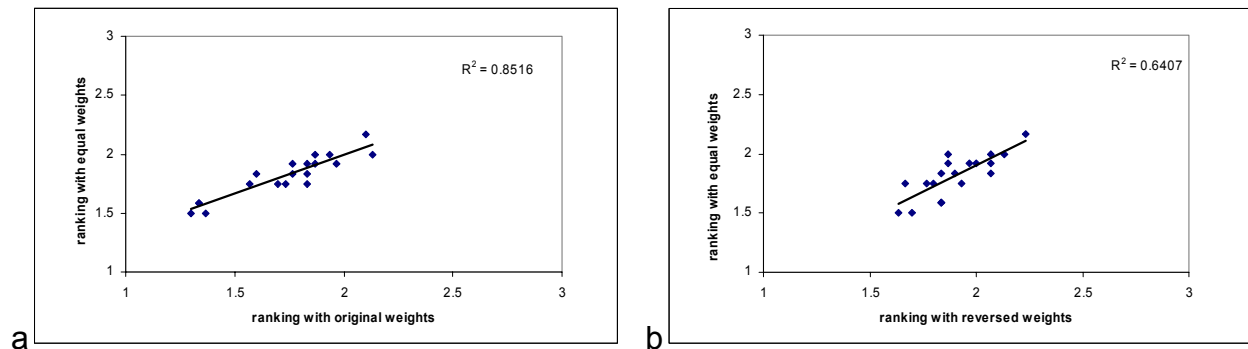
### **Sensitivity Analysis**

As a sensitivity analysis, the rankings in Table 1 were re-calculated with different weights for the four criteria listed above. In one case, all criteria were given equal weights of 0.25; in the other case, the weights were reversed (with cross-cutting receiving a weight of 0.1 and stakeholder interest receiving a weight of 0.4). The final rankings of each research activity were plotted against each other in order to determine if large deviations were found. Figures 1a and 1b show the equal-weight rankings plotted against the original and reversed-weight rankings. In general there is good agreement among the rankings, indicating that the weighting system described above did not greatly skew the individual results.

**Table 1.** Weighted average ranking of the prioritized research activities.

Study	Mean Score
(lower = better)	
<b>Proposed In Two or More Categories</b>	
Lighting interaction (headlamps and streetlights, and other)	1.30
In vehicle warning/information	1.57
<b>Intersection Fatalities Group</b>	
Brain loading studies	1.33
Transition in and out of intersection	1.87
<b>Pedestrian Fatalities Group</b>	
Fixed overhead lighting methods for non-designated crosswalks	1.73
Special lighting requirements for designated crosswalks	
Directional lighting in the crosswalk area	
New and special distributions for headlamps	1.77
Adaptive forward headlighting systems	
Correlation of visibility to nighttime accident rate	2.10
Proper target for visibility research	1.83
<b>Roadway Departures Group</b>	
Using HSIS/NHTSA/state data	1.87
Determining proper methods of evaluation	1.83
Define problem types	1.77
Task analysis for each problem type	1.93
<b>Traffic Congestion Group</b>	
Standardizing message/text/terminology	2.13
In-vehicle information	1.60
Increasing capacity by mitigating weather and night impacts	1.37
<b>Work Zone Traffic Group</b>	
Does audio information work	1.57
Barrels/cones versus continuous delineation/pipes/rope	1.83
Changes in work zones/equipment visibility/overcomplexity	1.70
Temporary pavement markings	1.97

**Figure 1.** Sensitivity analysis using different weighting schemes.



## 5. CONCLUSIONS AND RECOMMENDATIONS

The review of literature and the findings of the roundtable provided a number of common threads regarding recommendations for future research activities pertaining to the roadway visibility system:

- interactions among various components of the roadway visibility system
  - combination of headlamps and fixed roadway lighting
  - impact of lighting on pavement marking visibility
  - the role of peripheral vision
- degree of information required in various applications and by various populations
  - understanding where and what type of information is needed - on the roadway and in the periphery
  - interaction between infrastructure and in-vehicle information systems
  - avoiding over-complexity around intersections and work zones
  - understanding the impact of aging and other characteristics of information processing
- understanding and minimizing the impact of adverse weather on visual information

### Comparing Proposed Activities

The literature review and roundtable meeting formed the basis of the ranking exercise in Chapter 4 of this report, "Evaluation of Proposed Concepts." However, the methodology used in developing rankings might be too extensive to be of significant practical use by FHWA and other organizations undertaking visibility-related research activities. Nonetheless, the criteria used to prioritize concepts in that chapter are useful measures by which to evaluate them. This section offers guidance with which this evaluations might be carried out informally in a way that is consistent with the findings of the project. It is based on the relative weightings of the four criteria outlined in Chapter 4:

- cross-cutting (CC)
- new information (NI)
- cost/efficiency (CE)
- stakeholder interest (SI)

The following simple questions can be answered quite rapidly in order to provide an estimate of its priority (the questions are provided in random order). Answers to the questions are given using a four-point scale (1=no/never, 2=probably not/not often, 3=probably/often, 4=yes/always):



Question	Score
Will the proposed activity be completed in a short enough time frame to be useful? (CE)	
Does the proposed activity address more than one mode of visual information? (CC)	
Are pedestrians and bicyclists considered in the proposed activity? (CC)	
Is the proposed activity different from previous activities that have been or are being conducted? (NI)	
Can the proposed activity address more than one of the Vital Few Goals of the FHWA? (CC)	
Can the proposed activity lead to significant improvements in safety or traffic flow? (NI)	
Does the proposed activity address vehicle systems as well as infrastructure? (CC)	
Does the cost of the proposed activity limit ability to conduct activities in other areas? (CE)	
Might the proposed activity identify new unused approaches for implementing visual information? (NI)	
Can states and localities implement the results of the proposed activity? (SI)	

The questions pertain to each of the four priorities listed above, with the number of questions related to each criterion proportional to the weight of that criterion as outlined in Chapter 4. Thus, proposed activities can be compared quickly by comparing the scores (the sum of the answers for all questions) among them. This approach also has the flexibility of accommodating changing priorities of FHWA by replacing questions.

### Examples

For example, the potential study of roadway lighting spectral power distributions on peripheral visibility and on the perception of sign and pavement marking colors described above might be evaluated as follows:

<b>Question</b>	<b>Score</b>
Will the proposed activity be completed in a short enough time frame to be useful? (CE)	4
Does the proposed activity address more than one mode of visual information? (CC)	4
Are pedestrians and bicyclists considered in the proposed activity? (CC)	3
Is the proposed activity different from previous activities that have been or are being conducted? (NI)	4
Can the proposed activity address more than one of the Vital Few Goals of the FHWA? (CC)	3
Can the proposed activity lead to significant improvements in safety or traffic flow? (NI)	3
Does the proposed activity address vehicle systems as well as infrastructure? (CC)	4
Does the cost of the proposed activity allow the ability to conduct activities in other areas? (CE)	3
Might the proposed activity identify new unused approaches for implementing visual information? (NI)	4
Can states and localities implement the results of the proposed activity? (SI)	4
<b>Total</b>	<b>36</b>

As another example, consider a proposed activity to provide visual information where pedestrian crosswalks are likely to be unexpected through increased illuminances in these locations. Such an activity might be evaluated as follows:

<b>Question</b>	<b>Score</b>
Will the proposed activity be completed in a short enough time frame to be useful? (CE)	3
Does the proposed activity address more than one mode of visual information? (CC)	3
Are pedestrians and bicyclists considered in the proposed activity? (CC)	4
Is the proposed activity different from previous activities that have been or are being conducted? (NI)	2
Can the proposed activity address more than one of the Vital Few Goals of the FHWA? (CC)	3
Can the proposed activity lead to significant improvements in safety or traffic flow? (NI)	3
Does the proposed activity address vehicle systems as well as infrastructure? (CC)	2
Does the cost of the proposed activity allow the ability to conduct activities in other areas? (CE)	3
Might the proposed activity identify new unused approaches for implementing visual information? (NI)	3
Can states and localities implement the results of the proposed activity? (SI)	4
<b>Total</b>	<b>30</b>

Both activities result in scores that are relatively high, but the higher score of the former activity relative to the latter one could assist FHWA in developing priorities, all other factors pertaining to the activities (such as actual cost to complete, time frame) being equal.

### **Common Approaches**

It is important to note that with the common threads identified during the course of this study, several of the highest priority activities identified above could be combined in specific research activities. For example, a basic study of cognitive loading to understand roadway users' ability to process and respond to visual information both in the central field of view and in the visual periphery could be conducted, with specific modules incorporated to explore the impact of ambient lighting and weather conditions, specific responses in work zones or other scenarios, and the responses of older drivers.

Similarly, many of the areas described above could be studied using the spectral power distribution (color) of lighting and visual information as a parameter. Interactions among light source spectrum and the color perception of traffic sign and pavement marking materials could be studied in parallel with the impacts on peripheral vision under mesopic light levels. Spectrum in turn could affect visual discomfort. Further, there are interactions between spectrum and visual processing for many populations, including, for example, older roadway users and persons with color vision deficiencies.

Using the areas identified above as a framework for planning future research activities will assist FHWA in developing priorities for allocating resources and program planning. These areas have been found to be ones that by consensus among authors of the published literature and among roadway visibility system stakeholders are needed to optimize the roadway visibility system for all users of the roadway.

## APPENDIX 1: SELECTED ANNOTATIONS

**Akashi Y. and Rea M. S. 2002. Peripheral detection while driving under a mesopic light level. *Journal of the Illuminating Engineering Society* 31(1): 85-94.**

- the spectral power distribution of fixed-pole lighting impacted peripheral detection more than one's own headlights

**Allen M. J. (ed.). 2000. *Forensic Aspects of Vision and Highway Safety*. Tucson, AZ: Lawyers and Judges Publishing Company.**

- despite the importance of peripheral vision in driving, most jurisdictions include only on-axis vision testing for licensing

**Anonymous. 2001. Roundabouts' improve safety, reduce delays. *Consumers' Research Magazine* 83(9; September): 27-29.**

- roundabouts slow traffic yet increase throughput and decreased accidents

**Bacon K. 2001. To be seen, or not to be seen? *Occupational Hazards* 63(7; July): 55-57.**

- high conspicuity visibility elements in work zones are often overlooked

**Bahaj P. and Kher S. 1999. Smart control of headlight intensity of automobiles for improved night vision. *SICE '99 Proceedings*, July 28-30, Morioka, Japan, pp. 1187-1192.**

- this study proposed a control method to dim headlights using a fuzzy algorithm that decides proper headlight intensity based on driving speed, distance from other vehicles, driver action, weather condition, and road geometry
- the main objective of this AFS is to reduce glare to oncoming driver; no human factors investigations were reported

**Barfield W. and Dingus T. A. 1997. *Human Factors in Intelligent Transportation Systems*. Mahwah, NJ: Lawrence Erlbaum Associates.**

- the visual requirements of older drivers are not often considered in the design of systems for increasing roadway safety
- peripheral vision is an important design consideration for in-vehicle display information systems since these are often first seen through the visual periphery

**Birch B. 2001. Adaptive front lighting. *Automotive Eng.* (December): 39-42.**

- the Variable Intelligent Lighting System (VARILIS) program was introduced
- the program addressed direct lighting of the area immediately in front of the car, which is desirable when the road surface is dry but can dazzle oncoming traffic when wet, while light emitted above the cutoff line in fog can dazzle the driver
- five principal conditions are defined as follows:
  - town light: areas of high intensity within the light distribution are unnecessary.

- country light: recognition of course of the road and objects in the vicinity of the road; guidance of the driver's attention to relevant areas of the road; and low level of dazzle to other road users
- motorway type light: a symmetrical beam pattern with a sharp cutoff and very small forward rake angle is the best approach; dazzling the traffic in front should be as little as possible
- adverse weather light: reflection on the wet road causes dazzle to oncoming drivers. Because of the high proportion of light reflected forward, the driver becomes aware of a reduction in illuminance in front of his or her vehicle. So, the level of illumination in the immediate frontal zone—up to about 20 m in front of the vehicle should be reduced to an acceptable level to oncoming traffic
- bending light: for both static and dynamic bending light, a cutoff prevents dazzle to oncoming traffic

**Blanco M. et al. 2001. Detection and recognition on non-motorists and objects using new technologies to enhance night vision. *ITS America: ITS Connecting the Americas*. Miami Beach, FL.**

- statistical analysis of all types of fatal auto accidents, involving all types of individuals, under all different conditions determined there is a higher fatality rate for all types of crashes at night
- fatality rate for pedestrians at night is double than during daytime regardless of driver or road condition
- further discusses 12 night vision enhancement systems that compensate for varied road conditions, such as weather, as well as various human factor elements
- vision enhancement systems will be comprised of 5 technologies: 1) halogen headlamps; 2) HID headlamps; 3) three levels of UV-A (low, middle and high); 4) infrared thermal imaging systems; and 5) high output halogen

**Box P. C. 1971. Relationship between illumination and freeway accidents. *Illum. Eng.* 66(5): 365-393.**

- lighted roadway areas had reduced night/day accident ratios compared to unlighted areas
- reductions in the night/day accident ratios were greatest for illuminances of about 5 lx on the roadway surface
- the night/day accident ratio increased slightly for illuminances above 5 lx on the roadway, but it was difficult to generalize why

**Boyce P. R. 2003. *Human Factors in Lighting*. New York: Taylor & Francis (pp. 337-394).**

- "...components of the lighting systems designed to help the driver have been developed piece-meal, without regard to the variety of conditions that the driver may experience. This is most marked for road lighting and vehicle forward lighting. Vehicle forward lighting primarily lights the vertical surfaces of objects on the road while road lighting primarily lights the horizontal road surface. The combined effect can be to eliminate the contrast of the object against the road, yet only rarely is the

combined effect of vehicle lighting and road lighting considered. The physics of what is required to make an object on or near the road visible is well understood. What appears to be missing is the will to consider all components involved in making an object visible to the driver in all conditions.”

- Turner et al. established that ultraviolet headlights that supplement conventional vehicle headlights combined with fluorescent materials in road markings increases pedestrian visibility dramatically while decreasing glare to other drivers
- introduction of road lighting to previous unlit roadways decreases night-time fatalities by 65%
- road lighting luminaires can produce disability glare that “produces a measurable change in visibility because light scattered in the eye reduces the luminance contrasts in the retinal image”
- in assessing roadway and vehicle lighting, many small target visibility studies have been conducted but they only account for one aspect of the visual task of driving – driving is a multi-faceted visual and perceptual undertaking

**Breen J. 1999. An international perspective on vision in vehicles. *Vision in Vehicles VII* (Gale A., ed.). New York, NY: Elsevier.**

- a systems-based approach to understanding visibility as it relates to driving safety is encouraged

**Canby A. P. 2002. Managing the urban transportation system: the need for a new operating paradigm. *ITE Journal* 72(8; August): 50-51.**

- in the 1990s, vehicle miles increased by 22% while lane miles increased only 1%

**Carlson P. and Hawkins H. G. 2003. *Minimum Retroreflectivity Levels for Overhead Guide Signs and Street-Name Signs*, FHWA-RD-03-082. Washington, DC: Federal Highway Administration.**

- based on driver visual needs, recommendations for sign retroreflectivity are provided
- interactions with headlamp systems on vehicles are considered

**Commission Internationale de l'Éclairage. 1992. *Road Lighting as an Accident Countermeasure*, Pub. No. 93. Vienna, Austria: Commission Internationale de l'Éclairage.**

- a series of studies involving installation or changing of lighting systems along roadways are summarized and analyzed
- when statistically significant results were found these generally favored the role of lighting in reducing accidents 13% to 75%
- a curvilinear, diminishing relationship between light level and accident reduction seemed likely
- increases in uniformity seemed to mitigate the impact of light level on accident reductions

**Forbes T. W. (ed.). 1972. *Human Factors in Highway Traffic Safety Research*. New York, NY: Wiley.**

- notes that recommendations for highway sign visibility are generally made without consideration to glare conditions under which they are often viewed

**Gallagher V. P. and Janoff M. S. 1972. *Interaction Between Fixed and Vehicular Illumination Systems*, FHWA-RD-72-51. Washington, DC: Federal Highway Administration.**

- the effects of oncoming glare (headlamps at a distance of 100 feet from subjects) on reaction time were investigated but no significant effects were found

**Hamm M. and Rosenhahn E. 2001. System strategies and technology for improved safety and comfort with adaptive headlamps. *SAE World Congress*, Detroit, MI, pp. 9-16**

- photometric measurements to rate glare effects during curve road driving for different headlamp algorithms are carried out; these investigations show that adaptive curve lights can reduce glare by using suitable curve light parameters
- by using an experimental headlamp prototype with freely programmable parameters, this study compared glare illuminance levels for a car driver who drives a left hand curve (or a right hand curve) when three headlamp control algorithms are adopted—a conventional headlamp system, a steering wheel controlled curve light, and a predicting curve light system; the results suggested that predicting curve light system and steering wheel controlled curve light system are better than conventional system regarding glare

**Hasson P. and Lutkevich P. 2002. Roadway lighting revisited. *Public Roads* 65(6).**

- discusses the value of nighttime roadway lighting in economic terms due to the prevention of human fatalities
- cites a number of examples in Austin, TX, Milwaukee, WI and Finland where turning off freeway lighting (in an attempt to save money) led to increased accident rates
- discusses “European Scanning Tour” – where U.S. representatives visited Europe to identify “cutting-edge” roadway lighting design practices
- describes in detail Swiss practice of lighting pedestrian crosswalks vertically and how that has reduced fatalities by 67%; this method is being tested at two sites in the United States

**Illuminating Engineering Society of North America. 1989. *Value of Public Lighting*, IES-CP-31-1989. New York, NY: Illuminating Engineering Society of North America.**

- a series of studies are summarized that describe, generally, reductions in accidents with installation or improvement of lighting along roadways
- sometimes little benefit was found with lighting, confounds within studies are common

**Kalze F.-J. 1999. Static bending light: A new light function for modern headlamp systems. *SAE World Congress, Detroit, MI, pp. 131-134.***

- the side area close to a car up to a distance of 20-30 m, called “no man’s land” was considered; this area reinforces peripheral vision while turning to the right or left
- computer software, called the Light Distribution Editor (LDE) was used for the simulation
- this paper mentioned that cutoff-line to avoid glare to oncoming traffic was also considered but no data were shown for the cutoff-line

**Kalze F.-J. 2001. Situation adapted light distributions for AFS-headlamps. *PAL Symposium, Darmstadt, Germany, pp. 474-484.***

- Hella’s AFS concept was summarized, composed of a basic light module (left and right headlamp), high beam, and static bending light and provides a compromise between visibility distance, reduced glare for oncoming traffic, and comfortable spread of homogeneity
- in town light mode, the basic light modules have symmetrical cutoff line geometry; depending on speed, the modules are swiveled
- in night rain situation, the left basic light module generates a horizontal cutoff line and is forced into divergent mode with an angle of 15 degrees; the right module generates the motorway cutoff line with divergent mode of 5 degrees; this beam pattern can reduce reflex glare to the oncoming traffic
- it is not reported how the cutoff lines were determined

**Keck M. E. 2001. A new visibility criteria for roadway lighting. *J. Illum. Eng. Soc. 30(1): 84-89.***

- a re-analysis of the data from Mace (1996) demonstrated that a photometry-based visibility metric involving both roadway lighting and vehicle headlamps could be correlated, weakly, with night/day crash rates

**Kobayashi S. and Hayami T. 1999. Development of the phase-1 AFS front lighting system. *PAL Symposium, Darmstadt, Germany, pp. 449-464.***

- an advanced front lighting system was proposed composed of basic beams (motorway beam, country beam, and town beam) and an additional function beams (adverse weather beam, bending beam, overhead sign beam, and dipping and dimming beam)

**Lehnert P. 2001. Disability and discomfort glare under dynamic conditions: The effect of glare stimuli on the human vision. *PAL Symposium, Darmstadt, Germany, pp. 582-592.***

- an equation for dynamic discomfort glare was proposed



**Lerner N., Llanera R., McGee H., Taori S. and Alexander G. 2003. *Additional Investigations on Driver Information Overload*, NCHRP Report 488. Washington, DC: National Cooperative Highway Research Program.**

- a series of investigations to study information overload from highway signs is presented
- a predictive model of information overload is developed

**Lestina D. C. et al. 1999. Benefits and costs of ultraviolet lighting. *43<sup>rd</sup> Annual Proceedings of the Association for the Advancement of Automotive Medicine*. Barcelona, Spain, pp. 45-56.**

- this paper attempts to prove that the combination of fluorescent roadway delineation and auxiliary ultraviolet headlights reduces crashes, fatalities and saves money by increasing nighttime visibility
- field study comparisons with and without UVA headlamps were conducted and then compared to actual fatality data and analyzed
- the authors assert that the above system will reduce pedestrian accidents 19% and all accidents 5.5% and those figures will compensate for any additional costs of implementing fluorescent roadway delineation and installing UVA headlamps

**Lewin I., Box P., Stark R. E. 2003. *Roadway Lighting: An Investigation and Evaluation of Three Different Light Sources*, Report 522. Phoenix, AZ: Arizona Department of Transportation.**

- most roadway lighting systems result in mesopic (rod and cone) visual adaptation
- light sources with differing spectral power distributions can have differing impacts on visibility at these light levels
- research on visibility under mesopic conditions is summarized

**Mace D. 1996. *Safety Benefits of Roadway Lighting Using Small Target Visibility*, FHWA Report. Washington, DC: Federal Highway Administration.**

- no correlations between photometric measurements and night/day crash ratios were identified

**Minerd J. 2000. Fighting traffic with technology. *Futurist* 34(5; September/October): 26-30.**

- variable message signs provide information but can contribute to increased complexity in driving

**National Highway Traffic Safety Administration. 2001. *Traffic Safety Facts 2001*. Washington, DC: NHTSA.**

- in 2001, there were 21,000 fatal crashes in rural areas and 14,000 in urban areas
- estimated cost of traffic accidents in U.S. is \$231 billion

**Opiela K. S., Andersen C. K. and Schertz G. 2003. Driving after dark. *Public Roads*.**

- FHWA is investing in various roadway projects to increase night visibility including: retroreflective materials in traffic signs and pavement markings, fixed roadway lighting crosswalk lighting and AFS
- based upon European designs, crosswalks should be lit vertically – not horizontally so that pedestrians may appear brightly against a dark background
- high-mast lighting systems at highway interchanges reduce accident risks by providing uniform illuminance over entire area
- the “Smart Road” has a variable lighting section “...with special three-pronged light poles that are spaced to enable duplication of almost any roadway lighting designed in the United States”

**Pohl W. 2001. Enhancing visibility by reducing glare of street luminaries. *PAL Symposium, Darmstadt, Germany*, pp. 759-768.**

- author argues that glare from street lamps drastically reduces the visibility that the luminaires are in fact supposed to provide
- author advocates the use of both new headlamp and streetlamp systems designed with “spot-decomposition” – lamps made up of small specially shaped reflector facets

**Roelfsema A. et al. 1999. European side-markers effect on traffic safety. *SAE World Congress, Detroit, MI*, pp. 141-147.**

- side markers improve vehicle conspicuity and can thus enable crash avoidance, especially when the driver approaches a complex light environment; the side markers discussed are the ones utilized by Europeans and are amber in color

**Rumar K. 2001. Night traffic and the zero vision. *PAL Symposium, Darmstadt, Germany*, pp. 849-858.**

- chronicles Sweden’s efforts to reduce traffic accidents and fatalities to zero percent
- Sweden considers traffic fatalities a public health problem – since almost 5% of the population dies from traffic fatalities
- the 5% is a larger percentage than other forms of transportation and all other forms utilize a “zero fatality vision”
- the “zero fatality vision” is defined as follows: “*This vision of the future road safety situation in Sweden states that nobody (zero) should be killed or permanently disabled in road traffic accidents*”
- the author believes roadway planners should adapt a “vision strategy” — where numerous staff and actors work together towards one very well-defined common goal without too much micromanagement or administration; an example of this is NASA’s effort to get a man on the moon
- the final analysis of the total roadway system concludes that vehicle low-beams are the most serious problem in enhancing driver visibility

- the author believes the most effective and technologically feasible solutions to date are to improve target contrast and visibility by means of efficient retroreflective materials
- in approximately ten years electronic vision may be a solution for the more difficult visibility issues

**Sato T., Kojima S. and Matsuzaki M. 2001. The smart headlamp system with variable low beam pattern. *SAE World Congress, Detroit, MI, pp. 215-218.***

- an AFS called the “Smart Headlamp System (SHS)” was evaluated in terms of visibility and discomfort glare; discomfort glare evaluation used Schmidt-Clausen’s formula
- oncoming glare of the SHS is slightly higher than conventional headlamp system but still within acceptable range
- an adaptation level of 1.0 cd/m<sup>2</sup> was used based on a previous study

**Schnell T. et al. 2001. Pedestrian visibility under automobile lowbeam headlight illumination, with and without headlight covers. *TRB 80th Annual Meeting, Washington, DC.***

- study regarding the use of headlamp covers at night
- only function is to enhance appearance of vehicle, and most consumers of headlamp covers are young drivers
- two very definitive conclusions from study – 1) nighttime pedestrians should wear white or retroreflective clothing, not dark colors; and 2) motorists should not drive with dark headlamp covers at night

**Schreuder D. A. [1974-1975]. Vehicle Lighting Within Built-Up Areas. *Woorburg, Netherlands: Institute for Roadway Safety Research SWOV.***

- a “city beam” pattern was discussed based on reviewing literature from 1950s to 1974
- the optimum light for the front of motor vehicles to be used on lit roads should have an intensity that is lower than present low beam headlights, but higher than present sidelights; it is suggested that the minimum luminous intensity should be at least 20 cd, and the maximum not more than about 100 cd
- when road lighting is present (even very poor road lighting), low beam headlights can make only a small, and mostly negligible contribution to illumination and thus to the visibility of objects
- glare from the low beam headlights of oncoming traffic disturbs perception in all normal nighttime situations
- moveable headlamps were considered as a future technique
- the upper limit of the luminous intensity, 100 cd, of the “city beam” was considered based on the level of admissible glare; relevant research results are given by: Adrian (1969, 1964, 1969); Allen (1970); Bindels (1973); De Boer & Morass (1956); Fisher (1974); Fisher & Christie (1965); Hartmann (1963); Hartmann & Moser (1968); Hemion (1968); Johansson et al. (1963); Vos (1963); Webster & Yeatman (1968); Wortman & Webster (1968)

**Schreuder D. A. 1998. *Road Lighting for Safety*. London, UK: Thomas Telford.**

- requirements for older roadway users are not often considered in the design of safety improvements
- despite evidence that lighting can decrease crash frequency in some locations, conflicting evidence sometimes points to little effect or even negative effects

**Shamo D. E. 2002. Smart work zones improve highway safety and traffic flow. *Public Works* 133(11; October): 62-64.**

- 868 people per year are killed and 38,000 injured in work zone accidents

**Sharke P. 2000. Let light be there. *Mechanical Eng.* (June): 70-73.**

- this article reviewed AFS technology and referred to the EUREKA study
- lighting that reduced glare on wet roads helped both the driver and oncoming drivers
- the size of the light source affected the level of discomfort; after sources were normalized to the same luminous intensity, the researchers discovered that small areas of glare were more disturbing than large ones
- NHTSA reported complaints about glare from identify high intensity discharge headlamps and sport utility vehicle headlamps, claiming that both are too bright and the latter are too high

**Sivak M. 1996. The information that drivers use: Is it indeed 90% visual? *Perception* 25: 1081-1090.**

- statements abound in the driving safety literature that information needed for driving is 90% visual
- without arguing that the essence of such statements is incorrect, no evidence for such a quantitative assessment apparently exists

**Sivak M. et al. 2001. Quantitative comparisons of the benefits of applying adaptive headlighting to the current U.S. and European-low-beam patterns. *PAL Symposium, Darmstadt, Germany*, pp. 942-957.**

- glare illuminance levels (illuminance at an eye position) and visibility levels were calculated for left and right curve road conditions, European and the US beam pattern, and with and without bending beams; adaptation level was always 1 cd/m<sup>2</sup>
- this study concluded that glare is unlikely to be a problem with the shifted beams

**Smiley A. 2000. Behavioral adaptation, safety, and intelligent transportation systems. *Transp. Res. Rec.* (1724): 47-51.**

- drivers will adapt behavior in response to changes to decrease risk in potentially hazardous locations
- the influence of safety measures might be misgauged if such adaptation is not considered

**Stam J. S. 2001. Automatic vehicle high-beam headlamp control system. SAE World Congress, Detroit, MI, pp. 49-58.**

- a sensor system detects vehicle tail lamps and oncoming headlamps and switches from high beam to low beam to prevent glare

**Taieb-Maimon M. 2001. Minimum and comfortable driving headways: reality versus perception. *Human Factors* 43(1; Spring): 159-172.**

- 25% of all accidents are rear-end collisions often caused by too-short headway

**Van Bommel W. 2001. Road lighting research: Yesterday, today and tomorrow. PAL Symposium, Darmstadt, Germany, pp. 974-986.**

- the author believes that the older literature should be revisited in the context of today's research – investigation into ever-increasing complex driver overload, larger density after dark and congestion

**Van Derlofske J., Bullough J. D., Lingard R., Rea M. S. 2001. Roadway lighting: A systems approach. IES of Australia and New Zealand Annual Convention, Auckland, New Zealand, April 20-22, pp. 183-189.**

- individual components of the roadway visibility (lighting, signals, marking, signage) system are designed in isolation
- interactions among components of the system are critical to performance

**Volker S. 1999. The effect of discomfort glare on the development of headlamps. PAL Symposium, Darmstadt, Germany, pp. 765-773**

- summarized existing glare studies including Bindels and Schmidt-Clausen (1974), Olsen and Sivak (1984), Alferdinck (1991 and 1996), Sivak (1990), Lachenmeyr (1997)

**Von Hoffmann A. 2001. Analysis of adaptive light distributions with AFSim. PAL Symposium, Darmstadt, Germany, pp. 1018-1029.**

- glare illuminance from oncoming AFS headlights with different cutoff angle was measured; computer software, called AFSim, is also introduced
- this study did not discuss the effects of adaptation levels on glare

**Wachs M. 2002. Fighting traffic congestion with information technology. *Issues in Science and Technology* 19(1; Fall): 43-50.**

- vehicle miles increased 75% since 1980 but road miles only 3%
- 6% of lane miles - around urban centers - carry 47% of traffic

**Wiener E. L. and Nagel D. C. (eds.). 1998. *Human Factors in Aviation*. New York, NY: Academic Press.**

- understanding of individuals' cognitive capacity to deal with increased amounts of visual information is lacking

**Wilde G. J. S. 1994. *Target Risk: Dealing with the Danger of Death, Disease and Damage in Everyday Decisions*. Toronto, ON: PDE Publications.**

- the suggestion that people adjust behavior (by increasing or decreasing risk) to maintain a level of target risk is proposed
- safety measures to decrease risk might be accompanied by increases in risk-taking behaviors

**Wilson B. 2000. Road ready to take intelligence test. *Roads and Bridges* 38(2): 22.**

- discusses the “Smart Road” designed and implemented in the state of Virginia
- twenty research projects being conducted including enhancing night visibility via a combination of ultraviolet headlights, fluorescent pavement markings and sign materials

**Worner B. 1999. Adaptive frontlighting: Experimental system. *PAL Symposium, Darmstadt, Germany*, pp. 844-845.**

- for application in town conditions, characterized by lower speed and public lighting, the conventional light distribution can be dimmed and reduced in the symmetrical part, or, depending on speed and ambient light conditions a very wide illumination only can be chosen which do not interfere with the contrast, provided by the public illumination
- it was found that dimmed lighting for public lit areas was fully sufficient and the conspicuity to other traffic participants was felt quite good

## APPENDIX 2: REVISED ROUNDTABLE AGENDA

**Event:** Federal Highway Administration Roundtable  
**When:** August 19, 2003  
**Where:** Transportation Research Board Office  
500 5th St., NW  
Washington, DC, Room 109  
**Time:** 9:00AM to 4:00PM

### Agenda

- 9:00 Continental Breakfast and Introductions**  
**9:30 Carl Andersen, FHWA Project Intro and Background**
- 9:45 John Van Derlofske, Head of Transportation Lighting, Lighting Research Center, Overall Vision**
- 10:00 Mark Rea, Director, Lighting Research Center**
- 10:30 John Van Derlofske**
- **Laying the Framework**
    - Roadway as a system
  - **Strategy: Diversify our Portfolio**
    - What research investments will have social and economic value?
    - Focus on Traffic Flow
  - **Information Overload**
    - What is a person's capacity to process information? how much? how quickly?
- 11:15 BREAK**
- 11:30 John Van Derlofske**
- **Roadway System "What If"?**
    - Create Scenario: Pedestrian-Rich Environment
    - Develop Hypothesis
    - Determine Breakthrough
    - Group Discussion
- 12:30 LUNCH**
- 1:30 BREAKOUT SESSIONS**
- **Divide into Working Groups Based on FHWA Vital Few Goals**
  - **Work Through Individual Goals for Traffic Safety and Traffic Flow**
  - **Develop Research Agendas Based on Goals, Tasks, Methods of Evaluation and Studies**
- 3:30 REPORT, FEEDBACK, NEXT STEPS**
- **Result: Diversified Research Portfolio**
- 4:00 ADJOURN**

## APPENDIX 3: ROUNDTABLE PARTICIPANTS



Name		Organization
Carl	Andersen	FHWA
Nathaniel	Behura	Transportation & Energy Solutions
Stephen	Brich	Virginia DOT
Linda	Brown	FHWA
John	Bullough	LRC/RPI
Paul	Carlson	TTI
Seth	Chalmers	Chalmers Engineering Services, Inc.
Mike	Flannagan	Univ. Michigan
Mark	Freedman	Westat
Bob	Gent	IDA, Inc.
Ron	Gibbons	VTTI
Mike	Griffith	FHWA
Peter	Hatzi	FHWA
James	Havard	LITES
David	Henderson	AEL
Michael	Janoff	
Frank	Julian	FHWA
David	Keith	Marshall Design
Paul	Lutkevich	Parsons Brinkerhoff
Terry	McGowan	EPRI/LRO
Cameron	Miller	NIST
Joe	Moyer	FHWA
Yoshi	Ohno	NIST
Ken	Opiela	FHWA
Doug	Paulin	Lighting Forensics
Mark	Rea	LRC/RPI
Larry	Rice	Guide Corp.
Patricia	Rizzo	LRC/RPI
Greg	Schertz	FHWA
Tom	Schnell	U of I
Dick	Schwab	consultant
J.F.	Simard	Lumec
Richard	Stark	ERS Engineering
Bart	Terburg	General Electric
Michael	Trentacoste	FHWA
John	Van Derlofske	LRC/RPI

## APPENDIX 4: ROUNDTABLE DISCUSSION NARRATIVE

The list of attendees is attached in Appendix 3. After a welcome by J. Van Derlofske of the Lighting Research Center (LRC), C. Andersen introduced M. Trentacoste, Director of Traffic Safety and Development, Federal Highway Administration (FHWA). M. Trentacoste opened with a few words describing the goals of FHWA, which include:

- Looking at how to improve safety as well as traffic flow
- Visibility is an important and underutilized area
- Developing a roadmap with regard to visibility and lighting
- Focusing on value of accomplishments in terms of highway safety
- FHWA working with American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB)
- Need better emphasis on implications of not having better visibility and lighting products (e.g., signs, pavement markings)
- Research and technology partnership agenda on safety (nationally) in research and technology transfer
- FHWA is look to this meeting to help collectively develop roadmap
- An important step to help identify priorities

C. Andersen provided additional comments about the purpose of the meeting:

- Participants are not just the "usual suspects" in lighting and visibility
- We are at a very interesting time: Changes in technology, metrology, human factors research
- Where should FHWA be in 6 years? And how do we get there?
- Advanced research versus applied research
- All done things from our own perspective
- Prioritize research by basic cost, benefit/cost ratio?
- Overall objective is to improve safety and mobility on American roads

J. Van Derlofske gave a presentation outlining an approach to thinking about the roadway visibility system. Comments from participants included:

- FHWA should investigate mobility as well as safety (R. Schwab)
- Feedback from applications should be incorporated back into strategy (D. Keith)
- The cost of activities in this area need to be considered (T. Schnell)
- Important to provide proper feedback to the roadway users (M. Freedman)
- Developments in Intelligent Transportation Systems (ITS) work should be considered (M. Flannagan)
- Gains in capacity might be eaten up by increased demand (S. Brich)

M. Rea gave his presentation describing the use of the risk homeostasis concept as a tool for understanding safety and traffic flow. His areas of emphasis were:

- Risk homeostasis
- Engineering visual information
- Tight correlation between perceived risk and actual risk
- Then redefine what we do as a community

Comments on the presentation by M. Rea included:

- Seat belts are effective; risk homeostasis does break down. It might be a bad idea to believe strongly in risk homeostasis, but drivers probably use some kind of behavioral compensation. Basically, people are rational decision makers (M. Flannagan).
  - M. Rea responded that he tried to poke holes in Wilde's risk homeostasis theory and that his role was more rhetorical as a way in which to test hypotheses.
- Risk homeostasis could be an important context in which to lay framework, allowing researchers to look at all predictable behaviors (M. Freedman, S. Brich).
- Fog situations are important areas to investigate (R. Schwab).
- Planners might even overcompensate with complex roadways, such as a multi-roundabout in Europe (L. Rice).
- Other distractors affect behavior (coffee, cell phone) (N. Behura).
- Important to understand what the variables are (F. Julian).

J. Van Derlofske continued with a discussion of safety and traffic flow as complementary, rather than competing objectives for the roadway visibility system (Appendix 2). Discussion afterward touched on issues including:

- What are impacts on crime rates and economic development, important reasons lighting is used (M. Janoff)?
- Understand whether increased traffic flow increases or decreases safety (T. Schnell).
- How traffic flow is measured can influence the decisions made in such studies (M. Freedman).
- Important not to mix dependent and independent variables in studying these issues (M. Flannagan).
- Operational definition(s) of traffic flow and safety are needed (M. Rea).
- Semantics about traffic flow and fatalities can increase confusion (S. Brich).
- Smaller headway increases throughput, larger headways are safer (T. Schnell).
- Urban and rural roadways have different requirements and safety issues (M. Trentacoste).
- Is the focus on urban traffic flow (D. Keith)?
- Why do people slow down and why do they feel unsafe (M. Rea)?
- One difference between urban and rural is ambient light levels: the first increment of lighting is often beneficial, further increments often not (M. Janoff).
- The presence (or lack) of signing is another urban/rural difference (R. Schwab).
- Should design be for the familiar or unfamiliar driver (T. Schnell)?

- Drivers do not expect intersections in a rural area (F. Julian).
- Focus on what makes people slow down and pay attention (stop using cell phone, or stop eating) while driving (P. Carlson).
- What aspects cause people to pay attention: is that our goal and how do we engineer changes in behavior (M. Rea)?
- Transportation agencies also need to focus on maintaining present levels of safety but more efficiently and with longer life or reduced cost (S. Chalmers).
- If brake lights appear less frequently, that could be considered success (P. Hatzi).
- Traffic flow concept is more than volume, could consider brake lights, lane excursions (J. Bullough).
- Economic factors are important, difficult to set up roadway lighting, using a street light as a beacon rather than to provide illuminance is probably beneficial and feasible (R. Schwab).
- Driving has inherent risks unrelated to lighting, can lighting make driving as safe as during daytime (J.-F. Simard).
- Rural roadways are important areas in which to focus (G. Schertz).
- Traffic systems are built into the radio sometimes in Europe (B. Gent).
- It is extremely important to provide information for emergency situations, such as deceleration when brake lights are used; light emitting diodes (LEDs) could be easily modulated for this purpose.
- What is known about information overload while driving and how to measure it (T. McGowan)?
- Models are available to predict information overload (R. Gibbons).
- These models consider attention demand and are evolving (S. Brich).
- Driver demographics are changing, and issues like glare from advertising signs where FHWA has no regulatory role are impacting the visibility system (F. Julian).
- Drivers in Netherlands are required to take a difficult test to be licensed for driving (B. Terburg).
- The issue of obtrusive roadway lighting is being discussed by a committee of the Illuminating Engineering Society of North America (IESNA) (D. Paulin).
- The driving task needs to be broken down into components that apply in different situations (P. Lutkevich).
- The driving task can be perceived differently in different situations leading to either information overload or underload (long empty stretches); behavioral compensation is a large problem (J. Moyer).
- Regarding traffic flow and safety, traffic calming can reduce flow significantly (N. Behura).
- It is important to reduce the potential for conflicts and make decisions as easy for the driver as possible (R. Stark).
- Important to know who are drivers at night, compared to during the day, what criteria do they use to make decisions (P. Carlson)
- Distractions are a problem; information should be provided simply (D. Henderson).
- Design of the roadway itself is also important, including surfaces and curvature (T. Schnell).

Following this discussion, J. Van Derlofske continued with an example of a critical roadway environment (pedestrian rich environments; see Appendix 2). He asked participants to consider the following questions:

- Is it an incremental or radical change?
- What are the measures of success?

Among the comments were a suggestion that some study of spectrum on pavement marking color in the Netherlands had been undertaken (B. Terburg).

J. Bullough asked participants what appeared to be missing from the examples and what visibility systems in these situations were supposed to accomplish. Responses included:

- It is important to know enough to maintain an appropriate speed when pedestrians are present, including monitoring the dashboard speedometer and using information outside the vehicle (D. Keith).
- Possible approaches could be to identify the importance of certain information, or even to elevate the perception of risk (risk homeostasis) to a proper level. This could be especially critical where pedestrians are not expected, such as mid-block (S. Brich).
- An important issue too is driver scanning (for pedestrians) and being able to pick up movement. Landscaping sometimes dangerously impairs this behavior (F. Julian).
- The visual task also changes according to weather, location and other factors (J.-F. Simard).
- Not all information must be visual; vibration (rumble strips), sound (honking, beeping) and other types of stimuli can help (D. Henderson).
- Does the use of heads-up display systems necessarily compete with lighting and other visibility-related treatments (markings, etc.) (J.-F. Simard)?
- Important to consider "non-traditional" (for FHWA) methods for improving pedestrian visibility - reflective clothing (L. Rice).
- The visibility system should help drivers distinguish between actual and potential hazards (D. Keith).
- Some communities (e.g., Berkeley, CA) require pedestrians to carry high visibility flags at night (S. Chalmers).

M. Rea reminded participants that ultimately, we need to help FHWA develop a research agenda; what is the best way to productively sort through the possibilities? He made the following suggestions on reaching consensus:

- Do we want a portfolio of successes (some long-term, some near-term)?
- Cost of impact?
- Score a novel suggestion higher?
- Experiments should be hypothesis-driven rather than post hoc.
- There needs to be agreement on what the operational definition of an outcome is.

- Converging operations should be used.
- There must be a clear definition of success and the criteria that are used to judge success.

Responses to these suggestions included:

- Focusing on safety or throughput should not be an either/or situation (S. Brich).
- FHWA has specific "vital few" goals pertaining to safety and traffic flow; safety goals include reducing by 10% by 2008 (G. Schertz, F. Julian):
  - intersection fatalities
  - roadway departure fatalities
  - pedestrian fatalities
- Is there a mechanism to indicate something ahead in the roadway 10 seconds before reaching it (R. Gibbons)?
- Should the discussion include both incremental and radical goals (S. Chalmers)?
- For example, if the "beacon effect" for roadway lighting at intersections is true, couldn't a study to test this hypothesis be conducted in the field (M. Rea)?
- Few roadway lighting applications provide measurable data that can be used to refine potential solutions (S. Chalmers).
- Discussion should include traffic flow goals of FHWA as well as safety goals (T. Schnell).
- Discussion should also address what proxies for effectiveness are valid - it is not always ethical or practical to wait for crashes to pile up to test whether a particular proposed solution works (D. Keith).
- Measures of effectiveness should be considered only after an understanding of the goals (such as FHWA's "vital few" goals), and the driver and pedestrian tasks involved (P. Carlson); then, potential studies to gauge effectiveness could be proposed (D. Henderson).

Consensus developed that breakout groups would focus on the FHWA goals for safety and traffic flow and congestion, with groups focusing on specific goals. Each group would then address in turn the following:

- Tasks involved for drivers and pedestrians (as well as any other users)
- Proper methods of evaluation to ensure that the needs for these tasks are met (which are currently not well understood)
- Details about useful studies that could help answer the question, "does the roadway system provide useful visual information"?

Participants broke into five groups based on the Vital Few Goals of FHWA:

#### *Safety*

- To reduce intersection fatalities
- To reduce pedestrian fatalities
- To reduce roadway departures

### *Traffic Flow/Mobility*

- To reduce the effects of congestion and traffic incident delays
- To reduce work zone delays

After meeting in groups, a spokesperson from each group reported to the meeting their findings and recommendations.

### **Report of the Intersection Fatalities Group** (S. Chalmers, group spokesperson)

#### *Goal*

The group was concerned that focusing on intersection fatalities was too narrow of a goal, that a broader goal of reducing other types of accidents/crashes including:

- Fatalities
- Property damage only
- Injury related

#### *Tasks*

Different for drivers and pedestrians. Pedestrians need to:

- Recognize where the crossing, if any, is located.

Drivers need to:

- Recognize the intersection.
- Evaluate the conditions:
  - Level of control (stop, yield, signal)
  - Traffic
    - Status/speed
    - Cross-traffic
    - Turning
    - Mix of other drivers and pedestrians
    - Physical configurations
- Navigate through the intersection.
  - Select destination/direction
  - Maneuver into proper lane position
  - Turn (if necessary)
  - Understanding of control of vehicle during navigation
- Detect other vehicle behavior
  - Different aspects are important when vehicles are far, in transition or near

### *Measures of effectiveness*

- Tort liability findings
- Intersection crash/fatalities data
- Camera-based measures
  - Brake lights
  - Driver error (lane departures)
- Subjective and reactive responses (in controlled field studies)
- Brain loading

### *Studies*

- Brain loading studies
- Redo or update Commission Internationale de l'Eclairage report on traffic signals into a U.S. document
- Effectiveness of color differences versus luminance contrast
  - Sign and signal visibility optimization study (off axis/on axis)
    - Placement
    - Luminance
    - Color
- Impact of "additive luminance" (e.g., roadway lighting and headlights)
  - Road lighting
  - Headlights
  - Retroreflective materials
- Transition in and out of intersection
  - Lighting (on axis/off axis)
- In depth legal case study of intersection
- Intersection lighting needs analysis
  - Match level/criteria to environment presented by intersection

### **Report of the Pedestrian Fatalities Group** (R. Gibbons, group spokesperson)

#### *Goal*

To reduce the pedestrian fatalities by 10% by 2007.

#### *Tasks*

Tasks to be performed by the drivers include:

- The driver must detect and identify a low contrast pedestrian at night with enough time to avoid striking
  - Low beam headlamps only work up to 40 mph
  - There are 2800 pedestrian fatalities due to darkness per year



- Pedestrian crashes are four times more likely in the dark than in the light; this is very speed dependent – at low speeds, two times, at high speeds, eight times

Pedestrian-performed tasks include:

- The pedestrian must be aware of and avoid potential conflict areas in the roadway
  - The expectation of a pedestrian has a great impact on the visibility of the pedestrian
  - Pedestrians in much lower contrast (dark) clothing are more vulnerable than in light clothing

### *Measures of effectiveness*

- Reduced number of pedestrians killed or injured
- Increased detection distance for pedestrians
- Decreased pedestrian exposure (potential pedestrian – vehicle conflicts)

### *Studies*

- Studies of methods for changing pedestrian behavior
  - Compare eastern U.S. behavior versus western U.S. behavior
  - Change pedestrian clothing requirements
    - Consumer Product Safety Commission (CPSC)
  - Implement retroreflectorization requirements (CPSC)
- Infrastructure methods
  - Fixed overhead lighting methodologies for non-designated crosswalks (e.g., identifying trouble spots)
  - Special lighting requirements for designated crosswalks
  - Directional lighting in the crosswalk area
  - Interaction of vehicle and infrastructure lighting
- Vehicle methods
  - New and special distributions for headlamps
  - AFS – adaptive forward headlighting systems
  - Enhanced vision systems (infrared systems)
  - Headlamp polarization
  - Low mass headlamps/less aggressive front ends
  - On-board collision warning systems
- Fundamental issues
  - How do we prevent low contrast conditions?
  - What is the correlation of visibility to the nighttime accident rate?
- Methodological issues
  - What is the proper target for visibility research?

## **Report of the Roadway Departures Group (M. Freedman, Group Spokesperson)**

### *Goal*

The goal of FHWA is to reduce road departure fatalities by 10% from 1998 – 2008, including:

- Runoff road crashes – crash occurs off edge of road
- Head-on crashes
- Intentional (passing)
- Unintentional
- Opposite direction sideswipe

### *Tasks*

Relevant details of the driver's visual tasks include:

- Detect road surface condition
- Maintain lane position
  - Lane markings/delineation
  - Rumble strips
- Detect hazardous roadside objects
  - Poles, culverts, ditches, fixed objects
- Detect hazardous roadway objects and situations (edge dropoff)
  - Reaction time problems
- Detect
  - Curve markings
  - Lane markings
  - Slower vehicles

Other issues pertaining to driver error include:

- Design driver (who is making the errors)
- Design vehicle: depends on what the objective is
- Design scenario: weather/surface/geometry

Means of obtaining data to help answer these questions include:

- HSIS/NHTSA/State data
  - Who is the road user and what are road scenarios
  - Inventory of drivers across time of day, functional class, region, etc.
  - Who is the design driver for each problematic scenario – need to experience all to decide who is the priority
  - What are the problem situations (crash data sources)
  - How do problems divide into driver, vehicle, road systems task analysis

- What are potential visual information countermeasures

A brief list of potential hazards and the factors that affect their importance includes:

- Head on – passing (intentional)
  - Clear sight lines
  - Effective no passing zone markings and warnings: conventional or in-vehicle display
  - Conspicuity of passing and approaching vehicle
  - Displays and warnings in vehicle
  - Displays on roadway to warn of dangerous situation
  - Improved means for driver to determine gap and time to collision
- Head-on driver failure (unintentional and crossing)
- Opposite directional sideswipes – intentional
  - Warning of crossing markings and delineation (traditional) or advanced in-vehicle systems
  - Distraction causes
- Opposite direction sideswipes – unintentional
- Wrong way entry onto ramps and freeway
- Run off road (communicating changes in alignment)
- Road surface problems
- Lane keeping – keeping within lane limits
- Perceptual issues – providing positive guidance
  - Appropriate speed – speed warning, speed advisory
  - Anticipation and preparation
  - Detect roadside objects
    - Trees, poles, posts – improved edgeline
    - Ditches, culverts
    - Animals

#### *Measures of effectiveness*

- Fatal/injury/towaway crash counts; exposure measures
- Near misses/conflicts – measured by manual observation or advanced measurement
- Need renewed conflict relationship to crashes – relative risk
- Speed, headways, closing rates
- Driver response to onset of event
- Response time – other behaviors via video in moving vehicles
- Eye marker – vehicle dynamic responses – driver control responses
- Photometric measures (road surface, road edge, road background, delineation markings, signs, other advanced devices)

## *Studies*

- Determine methods of evaluation
- Define problem types
- Task analyses for each problem type

## **Report of the Traffic Congestion Group** (N. Behura, group spokesperson)

### *Goals*

Highway system capacity varies during the day due to:

- Demand variations
- Weather
- Day/night conditions

Issues pertaining to congestion are as follows:

- Congestion occurs when capacity is exceeded by demand
- It is often time related
- Familiarity of the roadway network can help one's success in driving during congestion
- Slow and steady flow can increase the throughput of the bottleneck
- Rerouting excess traffic capacity is important

### *Tasks*

The tasks of visibility elements on roadways should be to:

- Forewarn drivers to reduce excess speed
- Maintain design capacity
- Discipline users to optimize use

### *Methods of evaluation*

- Vehicles/lane/hour (higher is better)
- Average speed (higher is better)
  - Standard deviation of speed (lower is better)
- Brake light incidents (fewer are better)
- Define other incidents
  - Reduce incidents
  - Reduce duration of incidents
- Travel time delay measurement (less is better)

## *Studies*

- Forewarn driver to re-route and eliminate excess demand
  - Variable message signs (in-road) location standards
  - Standardize message/text/word and abbreviation choice
  - Standardize visual aspects – pixel size, stroke width, color, intensity
  - In-vehicle information (info already exists – dissemination)
- Increase capacity by mitigating weather and night unfavorable impacts
  - Better lighting
  - In-road pavement markers (lighted)
  - Advise speed ahead – color change
  - Weather conditions – solar power
    - Discipline user to maximize throughput at the bottleneck
  - Pacing devices
  - Median glare/visual distraction screens
  - Markings w/ “optical illusions”
    - Arterial
  - Signal timing coordination
  - Speed information
    - Freeway
  - Congestion pricing
  - Toll booth traffic flow and management
  - High occupancy vehicle lanes
    - Pedestrian
  - Innovative methods for infrequent pedestrian crossing
  - Lighted pavement marker (flashing)
  - Lighting (flood) at pedestrian crossing
  - Use detector for signs to warn drivers

## **Report of the Work Zone Traffic Group** (T. Schnell, Group Spokesperson)

### *Goal*

Improve traffic flow through work zones.

### *Tasks*

- Identify the work zone
  - Provide information to the driver that there is one
  - Is the work zone moving (painting) or fixed (road repairs)?
- Decisions
  - Based on type of work zone
  - Speed adjust
  - Lane shift
- Execute

- Speed
- Lane shift
- Car following
- Lane keeping
- Maintain situation awareness
- Interpret cues
  - Danger signs - such as workers, power shovels
- Prioritize cues

### *Measures of effectiveness*

#### **Objective**

- Speed (nominal is best)
- Throughput (higher is better)
- Number of crashes (lower is better)
- Type of crash (category)
- Speed differential (lower is better)
- Headway – optimum
- Number of last-minute lane shifts (lower is better)

#### **Subjective**

- Worker perceived safety (see September *Readers Digest*)

#### **Driver measures**

- Workload (physiological measures)
- Steering and brake inputs
- Statistical analysis of lane errors
- Visual complexity

### *Studies*

- Non-visibility/lighting elements such as Audio Travel Info System (ATIS) over radio - does it work?
- Barrels and cones versus continuous delineation
  - Lane shifting
  - Barrier mounted delineators
  - Light emitting diode (LED) edge delineators; Europe uses red LEDs for highway delineation
- Light guidance pipes
- Rope lights
- Work zones change
  - Visibility of construction equipment
  - Too many flashers increase complexity
- Driving tasks
  - In work zone

- Approaching work zone
- Work zone lighting
  - Must meet OSHA
  - Spill light control
- Approaching the work zone
  - Diagrammatic guide signs (overhead)
- Moving work zones
- Visibility issues related to color or markings on pavement)
- Crash attenuator visibility
- Marking on equipment
- Worker visibility
- Robo-flagger
- Work zone signs
  - Orientation not always ideal (S. Brich)
  - LED enhanced signs (Border)
- Sign and equipment handling (portable friendly)
  - Quality control standards
  - Engineer for fool-proofing
- Cone and Jersey barrier spacing to properly manipulate speed
- Arrow panels
- CMS overload
- Temporary pavement markings
- Study novel guidance concepts
- Spatial temporal color
- Radar speed sign

## **Roundtable Summary**

The information presented during the breakout groups had several common threads:

- Providing the proper information load to drivers, pedestrians and other users
- Interactions
- Weather
- Warn driver about what is ahead using vehicle-based systems as well as information physically located in and along the roadway
- Systems to break through driver "shell"
- Consistency of information design

J. Van Derlofske invited participants to provide additional specific ideas not touched upon during the roundtable for FHWA consideration and participants were encouraged to contact J. Van Derlofske with them. The LRC will also solicit further comments from organizations such as the Institute of Transportation Engineers, Illuminating Engineering Society of North America and others involved in preparing recommendations and standards for practice.

Comments received as of October 9, 2003 include:

- What traffic signal luminances are required at night? (S. Chalmers)
- Task-by-task study of spectral effects at mesopic light levels (S. Chalmers)
- Color rendering needs for fixed and vehicle lighting (S. Chalmers)
- How should signs be lighted in light of new retroreflective materials? (S. Chalmers)
- What is value of raised retroreflective pavement markers? (S. Chalmers)
- Include roadway and sign lighting in MUTCD? (S. Chalmers)
- What is best metric (illuminance, luminance, small target visibility) for roadway lighting? (S. Chalmers)
- What are the impacts of light trespass? (S. Chalmers)
- Determining the optimum spacing of roadside delineators (S. Chalmers)
- What are appropriate service levels for retroreflectors? (S. Chalmers)
- How to provide the present level of service less expensively/more efficiently (S. Chalmers)
- Minimum luminance/contrast requirements for signs (S. Brich)
- Sequencing embedded LEDs to help guide speed in fog (S. Brich)
- Re-education program for license renewal (D. Paulin)

C. Andersen reiterated that LRC would prioritize the comments and input from the roundtable and from additional comments, and compile a report to FHWA describing possible approaches for FHWA research relating to visibility. The report might be published as a circular through the Transportation Research Board. The information will be distilled into a framework and thereby provide opportunity to address issues discussed in the roundtable.



## APPENDIX 5: ROUNDTABLE PRESENTATION OVERHEADS

Project for the Federal Highway Administration

## Roundtable Meeting

# Redefining the Roadway Visibility System

Transportation Lighting Group  
Lighting Research Center  
Rensselaer Polytechnic Institute



Project for the Federal Highway Administration

## Roundtable Meeting Agenda August 19<sup>th</sup>, 2003

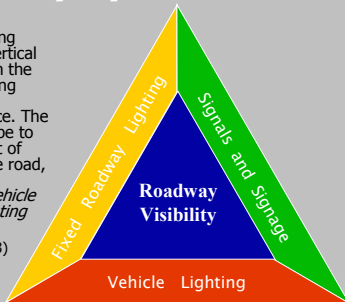
- 9:00 Breakfast and Introductions All
- 9:30 Project Introduction C. Andersen
- 9:45 Overall Vision J. Van Derlofske
- 10:00 Lighting for Information M. Rea
- 10:30 Framework for Discussion J. Van Derlofske
- 11:15 Break
- 11:30 Roadway System "What If?" J. Van Derlofske
- 12:30 Lunch
- 1:30 Breakout Sessions All
- 3:30 Report, Feedback, Next Steps
- 4:00 Adjourn



## Defining the Roadway Visibility System

Vehicle forward lighting primarily lights the vertical surfaces of objects on the road while road lighting primarily lights the horizontal road surface. The combined effect can be to eliminate the contrast of the object against the road, yet only rarely is the combined effect of vehicle lighting and road lighting considered.

(Boyce, P.R. 2003)



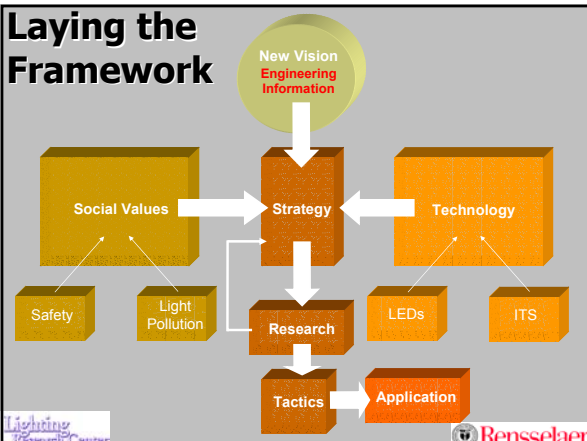
## Why Use Lighting and Visibility Elements?



Provide Information!

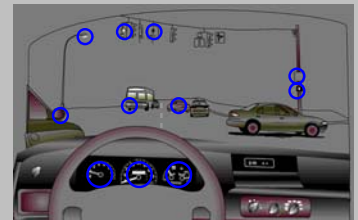


## Laying the Framework



## What Visibility Elements Provide this Information?

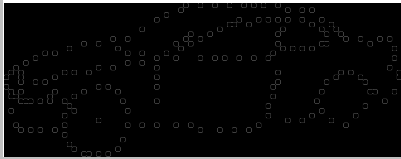
- Roadway lighting
- Road markings
- Signs
- Vehicle lighting
- Traffic signals
- Vehicle displays
- Others?



The Roadway Visibility System



Roadway System Research  
Connecting the Dots...



- Research information is dots on the page
  - New dots help to identify the overall picture
  - More dots in one area provide greater precision

## Incremental vs. Radical Change

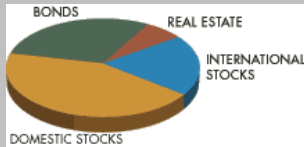
- Brake light before CHMSL



- Brake light after CHMSL



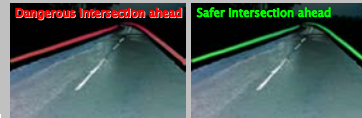
## Strategy: Diversify Our Research Portfolio



- Perform both:
  - Steady growth research
  - High risk/high yield research

## Meeting Goals

- Identify strategic research projects with large potential impact
  - Be data driven (FARS)
  - Determine incremental vs. radical
  - Optimize the cost/benefit ratio
    - Focus on "bang for buck" areas



## What is the Roadway Visibility System for?

- Safety
- Traffic flow
- Economic development

## Why Use Visibility Elements?

- Improve safety



## Why Use Visibility Elements?

- Improve traffic flow



## Why Use Visibility Elements?

- Foster economic development



## What is Our Vision?

- Research and develop the roadway visibility system to supply the necessary information to the driver
  - Efficient traffic flow
  - Improved safety



## Key on Traffic Flow

- Traffic flow is an increasing problem:
  - Traffic volume has increased by 76% since 1980
  - Lane miles have increased only by 3% since 1980 (Wachs, 2002)
- Greater volume of traffic occurs in urban areas:
  - Urban roadways make up only 6% of lane miles in U.S.
  - These same roadways carry almost half of all traffic (Canby, 2002)

## Key on Traffic Flow

- Traffic flow is important economically
  - Annual cost of traffic congestion is \$78 billion
  - Almost 7 billion gallons of gasoline are wasted (Canby, 2002)
- Improved traffic flow probably has direct safety implications:
  - Even though more fatal crashes occur on rural roads than urban roads (21,000 versus 14,000) each urban lane mile is more than *ten times as likely* as each rural lane mile to be the site of a fatal crash (NHTSA, 2001; Canby 2002)

## The Punchline:

- Engineer visual information
  - Illuminance *and* luminance
- Focus on urban traffic flow issues
  - Use traffic flow as a measure to test hypotheses
  - Safety should correlate
  - Bonus: economic and environmental impacts

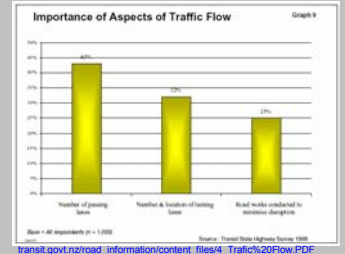
## The Challenge

- How can driving behavior be affected by the visibility system to improve traffic flow?



## What Do We Need?

- What visual information is needed for efficient (and safe) traffic flow?
- How is it provided
  - Cost efficiently
  - Energy efficiently
  - Unambiguously



## What Do We Need?

- Optical flow information
- Speed guidance
- Headway information
- Information about surrounding environment



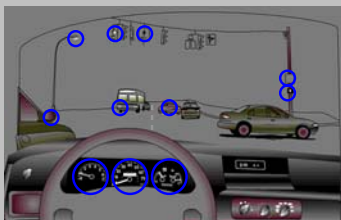
## What Visual Tasks are Involved in Basic Driving?

- Lane keeping
- Maintaining appropriate speed
- Judging relative position
- Understanding location of decision points (exits, turns, etc.)
  - Important for older and inexperienced drivers
- Avoiding unexpected obstacles

Note: Tasks also depend on driver behavior

## How is this Information Provided?

- Roadway lighting
- Road markings
- Signs
- Vehicle lighting
- Traffic signals
- In-vehicle systems



*The Roadway Visibility System*

## Lane Keeping

- Conventional marking systems adequate(?)



## Maintaining Appropriate Speed

- At sensitive locations markers could warn drivers of potentially hazardous road conditions
- Spacing between lane markers could be altered to encourage drivers to slow down or speed up
- Pace setting lighting



## Judging Relative Position

- "Blue dot" taillights – colors "merge" beyond certain distances



## Understanding Location of Decision Points

- Using color of markings or pavement itself to provide a message about upcoming decision points (exit ramps, pedestrian crossings, etc.)



## Avoiding Unexpected Obstacles

- "Tuning" light sources and illuminate the visual periphery to provide higher "mesopic" efficiency



## Information Overload

- We can provide information via Variable Message Signs (VMS)
  - A lot for driver to absorb
  - Cause confusion
- Or simple in ground signals
  - Blue road studs



## What Do McDonald's and Transportation Have in Common?



Provides a signal that is recognizable, unambiguous, and easy to comprehend

## An Example: Pedestrian Rich Environments

- Improving traffic flow through high-pedestrian locations by engineering visual information



## Convention

- Crosswalks
- Pedestrian signals
- Signage



## What Visual Tasks Are Involved?

- *Lane keeping*
- Maintaining appropriate speed
- *Judging relative position*
- Understanding location of decision points
- Avoiding unexpected obstacles

## Questions

- What visual information is needed by the driver?
  - The roadway system
  - Socially and environmentally responsible
- How is it being provided?
- How is it quantified and measured?
- Is this an incremental or a radical change?

## Potentially Beneficial Visibility Elements

For maintaining appropriate speed:

- In-ground lights



## Potentially Beneficial Visibility Elements

For understanding the location of decision points:

- Colored pavement treatments



## Potentially Beneficial Visibility Elements

For avoiding unexpected obstacles:

- Higher vertical illuminances
- "Town" driving beam
- Peripheral illumination (mesopically tuned)



## Potential Interactions

- Glare from wider "town" beam and vertical illumination?
- Could higher ambient levels reduce effectiveness of in-ground flashing lights?
- Impact of spectral content of lighting with pavement markings?



## What Approaches to These Questions Could Work for:

- Work zones
- Heavy rain/snow
- Bottleneck situations:
  - Tunnels
  - Toll plazas
  - Bridge approach
- Intersections

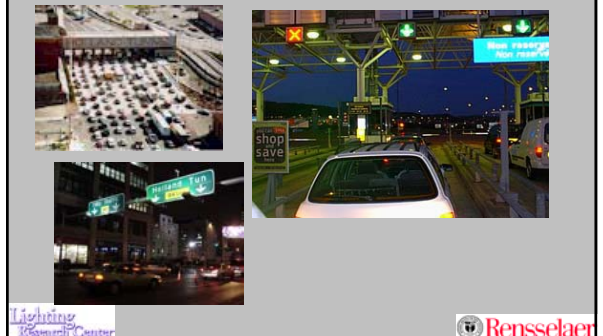
## Work Zones



## Heavy Rain/Snow

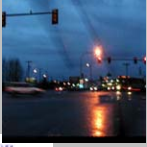
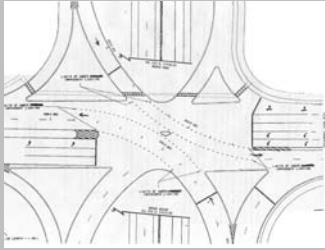


## Bottleneck Situations





## Intersections



## Working Examples

### Questions

- ☐ What visual information is needed by the driver?
- ☐ How is it being provided?
  - The roadway system
  - Socially and environmentally responsible
- ☐ How is it quantified and measured?
- ☐ Is this an incremental or a radical change?