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Roadway Lighting Revisited

by Patrick Hasson and Paul Lutkevich

The cost of nighttime crashes is high. Even though only 25 percent of the vehicle-miles traveled occur at night, nearly 50 percent of fatalities occur during those hours. The nighttime fatality rate is three times the daytime rate. If we could get the nighttime rate to approach that of the daytime, we could save as many as 14,000 lives per year. Calculating the value of life as $3 million, the cost to society of those 14,000 fatalities is $42 billion per year, based on the U.S. Department of Transportation's *Revised Department Guidance, Treatment of Value of Life and Injuries in Preparing Economic Evaluations,* 2002.

Clearly, any efforts we can initiate to reduce nighttime fatalities are worthy of attention. It is no wonder that we are examining minimum maintained levels of sign and pavement markings for nighttime visibility (retroreflectivity), advanced Intelligent Transportation System technologies, and other options with the potential to increase the safety of nighttime driving. One traditional technology, namely roadway lighting, can make a substantial difference.

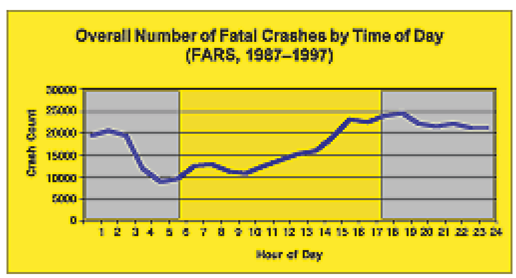

Figure 1. Overall Number of Fatal Crashes by Time of Day. This graph shows that the number of fatal crashes from 1987 to 1997 rose from a low of 10,000 to 5 a.m. to a high of 25, 000 at 7 p.m.

Roadway lighting serves several purposes. It provides improved visibility for users of roadways and associated facilities. It reduces crashes by helping drivers obtain sufficient (visual) information. Finally, it supplements vehicle headlights, when warranted. Side benefits that often are overlooked include civic beautification and the reduction of crime.

Various studies have examined the safety and cost effectiveness of lighting. A Federal Highway Administration (FHWA) 1996 report showed that installing lighting has the highest benefit-cost ratio of all safety improvements. Specifically, for each dollar spent, $26.80 was saved in reducing fatalities and injuries in vehicle crashes from 1974_1995. This figure should not be misconstrued to say that lighting is effective for every mile of roadway in the United States. Rather, it simply illustrates that when lighting is chosen as the preferred countermeasure, it is likely to be cost effective.

For crashes, injuries, and fatalities, lighting has been shown time and again as a true winner. Some of the more notable examples have occurred because of energy-saving measures. In 1973, Austin, TX, turned off approximately 50 percent of the lights on 7 miles (11.3 kilometers) of southbound lanes (except for ramps and frontage roads) on one roadway. Analysis by the Texas Transportation Institute (TTI) in 1981 showed that for the 2 years that the lights were off, the crash frequency was down 22 percent overall, but on the unlighted side, the crash frequency was up 22 percent. The crash rate increased from 1.51 to 1.91 crashes per million vehicle miles. The rate of injury crashes rose 96 percent, and the rates of specific crash types (sideswipes, single vehicle, rear end, and pedestrian crashes) all rose substantially. TTI showed that annual energy savings ran $25,250, but crash costs increased by about $17,000. In other words, positive gains in energy conservation were made at the expense of a measurable decrease in motorist safety. It should not be surprising that the lights were turned back on after a little over 2 years.

According to the National Lighting Bureau, a similar example occurred in Milwaukee, WI. On October 1, 1980, all of Milwaukee's freeway lighting was turned off (with the exception of seven interchanges) to save money. A public outcry occurred and, 20 days later, the lights were turned back on. Later analysis using data from the previous 3 years for comparison showed that the total number of nighttime crashes increased 6 percent, reportable night crashes were up 14 percent, injury crashes rose 5 percent, and the number of people injured was up 50 percent. Once again, the safety costs associated with removing lighting were too high to bear.

Lighting Scan Tour

On the international scale, similar experiences were revealed during a European lighting scan tour in 2000. Because the American Association of State Highway Transportation Officials (AASHTO) was updating its *Informational Guide for Roadway Lighting*, it recognized the need to gather information from transportation ministries and lighting professionals across the world through an international technology scan. Many countries reported research results that indicated a 20 to 30 percent reduction in the number of crashes when roadway lighting was installed. In an experiment in southern Finland, road lighting was cut in half and resulted in an increase of 13 percent in the crash rate. Total elimination of lighting resulted in a 25 percent increase.

The U.S. transportation community is interested in identifying cutting-edge research and technology in highway engineering and operations from whatever source is available, including our international peers. To this end, a coalition of organizations formed the International Technology Scanning Program in 1990 to link U.S. highway experts with their counterparts around the world to learn about the newest approaches to transportation policy and highway operations, planning, design, construction, and maintenance. The goal is to see if any approaches from other countries have application in the United States.

Master lighting plans serve road safety, personal security , and community beautification needs as shown in this bridge in Zurich, Switzerland.

The program is a joint effort of AASHTO and the Federal Highway Administration (FHWA), in collaboration with the Transportation Research Board's National Cooperative Highway Research Program. The organizations work together to identify priorities, organize scanning studies, and help implement key findings.

The information gathered during the European scan on roadway lighting is now providing a basis to update the guide and a better tool for State and local authorities that design, install, operate, and maintain public lighting systems.

The team members brought a variety of professional perspectives to the study. Participants included representatives of the States of Alabama, Pennsylvania, Texas, and Wisconsin; FHWA; and the Illuminating Engineering Society of North America. The study team met with lighting experts in Belgium, Finland, France, the Netherlands, and Switzerland.

Information was collected in the following 11 primary areas of interest:

1. *Visibility Design Technique.* Designing lighting using what is known as the "visibility design technique" is growing in interest in the United States and is a topic of much heated debate. During the scan, the team found that none of the countries that were visited use visibility design techniques. Visibility research with three-dimensional targets is, however, being conducted in France and Belgium. This European research suggests that the visibility design technique may provide a more complete approach to lighting design, although more experience is needed. *The panel recommended more research using this approach on active roadways.*

2. *Dynamic Road Lighting*. In the Netherlands, highway engineers installed a dynamic roadway lighting system that can be operated at three levels of brightness, depending on the amount of traffic and weather conditions. The high level is about twice the level normally found on roads in the United States. (As a general rule, the scan tour's participants found that European roads are much more brightly lit than U.S. roads.) Research using this system revealed that no significant change in crash rates occurs when roads are lit at levels higher than those used in the United States. As well, when lighting was reduced for environmental reasons to levels that were about one-fifth the levels normally used here, the crash rate at low traffic volumes was acceptable. A similar road lighting system currently is being installed in Finland.

Other items of interest included studies by the French on retrore-flectivity and active luminous devices. Similarly, the Netherlands is conducting research on the acceptability of different types of guidance systems, especially in conjunction with extremely reduced or eliminated lighting. At the time of the visit, the Dutch were experimenting with a variety of light-emitting diodes (LEDs) and fiber-optic devices that could provide positive guidance to roadway users in the absence of road lighting.

As an approach to more dynamic management of roadway lighting, the panel recommended investigating the application of dimmable lighting systems, systems that turn the lighting off, and alternative guidance systems.

3. *Pavement Reflection Factors*. One parameter in lighting design is a Pavement Reflection Factor. Standard factors for various pavements are included in the R-tables used by designers. The team learned that some countries noted problems with the standard R-tables in that the values

measured in the field vary from those predicted by design calculations that employ the standard R-tables. To address this issue, the French are researching the photometric properties of various new road surfaces, such as "quiet" or "waterdraining" pavements, very thin asphaltic concretes, and surface dressings. The evolution of road surface technology and the use of bright and colored road surfaces have necessitated this research. The French also are examining the possibility of using a virtual reflectometer for field measurements. In Belgium, a new laboratory device for examining pavement reflectance was presented to the group. *Because pavement reflectance is an important element of lighting design, the panel recommended that more research, including field measurements, be conducted in order to overcome the acknowledged inadequacy of the R-tables for pavements.*

4. *Master Lighting Plan*. Throughout the scan, the panel noted that a number of cities have developed formal master lighting plans. The plans take into account economic and cultural changes, a city's public image, and technological developments. The benefits of such a plan are that it coordinates the various municipal lighting functions, proactively plans lighting for the different areas of a city, and schedules expenditures and implementation. The plans are based on the concept of providing safety, beautification, and security for goods and people. In this context, urban lighting is viewed as a key component of city management. *The panel encouraged the development of master lighting plans to improve the coordination of roadway and urban lighting in such matters as lighting levels and styles for safety, security, and beautification.*

5. *Roundabout Lighting*. Many more roundabouts are in operation in Europe than there are in the United States. In France alone, an estimated 1,000 roundabouts are built each year. Because of the growing interest in roundabouts in the United States, the team was interested in finding out as much as possible concerning lighting this type of intersection. Each of the countries visited has specific recommendations for roundabout lighting. All cited the importance of ensuring that roundabout light levels are higher than the levels on approach roads and streets. The European philosophy of roundabout lighting sees the goal as providing a total view of the roundabout geometry from three levels: long distance, nearby from 109 yards (100 meters), and at the entrance to the roundabout. *The panel recommended that the European experience in roundabout lighting be synthesized and consolidated for U.S. application.*

The lighting shown here in Belgium is functional and serves to memorialize events at this site in World War II.

6. *Crosswalk and Pedestrian-Area Lighting.* One item that drew high interest among the team members is a lighting method for pedestrian crosswalks being used in Switzerland. This lighting design technique, coupled with a new pedestrian right-of-way law, has been credited with a two-thirds reduction in pedestrian fatalities. This method uses a vertical illuminance criterion to help define how much light must be placed on pedestrians to make them visible. (See "Lighting for Pedestrian Safety.") *The panel recommended the consideration of vertical illuminance as*

a design approach to improve safety in crosswalks and other pedestrian areas.

7. *Energy-Absorbing Poles.* A roadside safety feature that was observed in Finland was energy-absorbing poles, which flatten upon impact and wrap around a car. Energy-absorbing poles may be of particular interest in places where breakaway poles are not desirable—in an urban area, for example, where collateral damage caused by a falling pole could be very high. *The panel recommended investigating the use of energy-absorbing poles as an option for selected applications.*

8. *Experimentation.* Throughout the trip, the team encountered a number of instances in which the Europeans gained knowledge and experience by conducting practical experiments on active roadways. This approach permits more rapid implementation of new ideas. *The panel encourages more innovative experimentation on active roadways and test tracks.*

9. *Crashes and Lighting.* The police in Zurich, Switzerland, described an extensive accident-reporting process. The police analyze the cause of automobile accidents in the Zurich area and make recommendations for lighting applications. *The panel recommended the development of reporting systems that consider the lighting conditions at crash scenes.*

10. *Equipment Quality Level and Maintenance.* European lighting equipment generally appeared to be of a high quality, and few roadway lighting outages were observed. For the most part, the lighting systems were relamped on a group basis, typically on a 3- to 5-year cycle. Maintenance of tunnel lighting systems usually is conducted on a shorter cycle coinciding with the schedule for washing. The tunnels on the Periferique (beltway) in Paris are cleaned every month. Overall, maintenance is performed in a more regular and comprehensive manner than is normally the case in the United States. But Europeans still suffer from poor training of maintenance personnel, as is the case in the United States, detracting from a high level of maintenance. The panel recommended that, when possible, higher quality lighting materials be considered to ensure improved maintenance and durability for the life of the lighting systems. In addition, maintenance personnel should be thoroughly trained to ensure the integrity of lighting systems.

11. *Signs*. Not unlike some places in the United States, several European countries are eliminating sign lighting and using microprismatic (i.e., highly retroreflective) sheeting material on signs in its place. France is moving away from fixed sign lighting but continuing to use engineering-grade retroreflective sheeting material. The panel recommended the use of micro-prismatic materials for unlighted overhead and left-shoulder-mounted signs.

Lighting for Pedestrian Safety

All of the panel's recommendations have been acted on in one way or another. For instance, AASHTO's revised *Informational Guide for Roadway Lighting* addresses nearly every item. States that participated in the scan have implemented specific findings. Further research and evaluation is taking place as well. In particular, roadway lighting for pedestrian safety is receiving close attention.

In 2000, according to the National Highway Traffic Safety Administration, 4,739 pedestrians died and 78,000 were injured in traffic crashes in the United States. Most pedestrian fatalities occur in urban areas (71 percent) and at night (64 percent). In addition, a recent FHWA report entitled *Pedestrian Facilities Users Guide* identifies roadway lighting as the only countermeasure that can address all types of pedestrian crashes. Although a number of studies have investigated various aspects of crosswalk lighting, widely used recommendations for these installations are limited or nonexistent.

Computer modeling of a site in Madison, WI, showed that adjusting luminaire placement from the before situation (left) could make pedestrians in the crosswalk more visible. Note on the right that the overhead warning sign and pedestrians approching the crosswalk are also more visible.

Knowing this, the team was especially interested in the Swiss method for lighting pedestrian crosswalks. On returning from the scan, a team composed of the Wisconsin and Alabama State departments of transportation, FHWA, and Parsons Brinckerhoff (a major U.S. engineering firm) initiated a project to evaluate that approach. The National Cooperative Highway Research Program, Parsons Brinckerhoff, and FHWA provided funding for the research. The ultimate goal is to develop an approach that can serve as a national standard for crosswalks. For this reason, the team is closely allied with the Illumination Engineering Society of North America.

The Swiss method recommends that for roads with illumination of less than 2 candela (luminous intensity) per square meter (2 cd/m^2), poles be placed on the approach sides of the crosswalk and produce 40 vertical lux (a unit of illumination) in the crosswalk. With proper placement, typical street lighting equipment can easily provide this level of illumination.

Two sites in Madison, WI, on Johnson Avenue and University Avenue, were selected for the initial portion of the study. The sites are located in the university section of the city and are mid-block crosswalks with heavy pedestrian traffic. The existing lighting system provided less than 2 candela per square meter (2 cd/m^2) on the roadway, and the vertical levels in the crosswalk were between 8 and 11 lux. An additional light pole was placed on the approach side of the crosswalks in order to produce 39 to 40 lux of vertical illumination at the crosswalk, as recommended by the Swiss.

The visibility testing was conducted with a subject seated in a minivan parked in the left traffic lane 250 feet (76 meters) from the crosswalk. The vehicle was equipped with a manually operated shade that could be raised and lowered to limit the subject's exposure to the testing scenario. The subject was told to get ready, and the shade was raised for 2 seconds, allowing the subject to view the crosswalk scene ahead. After the shade was lowered, the subject told the experimenter how many pedestrian cutouts were visible in the crosswalk. Each subject was tested individually on both of the lighting conditions (i.e., Swiss method versus U.S. system). A total of 30 subjects were tested. They ranged in age from 16 to 70 years old with a mean age of 46.5. There were 7 females and 23 males. Most of the subjects tested were Wisconsin Department of Transportation employees, their dependents, and FHWA Division Office employees.

The testing measured a number of variables that could indicate both the level of visibility of the objects in the crosswalk and the number of objects. During this real-world testing of the Swiss method, it performed better than the traditional U.S. system. At Johnson Avenue, for instance, the mean percentage of the cutouts identified was only 72 percent under the U.S. lighting condition but increased to 94 percent under the Swiss lighting method. Much smaller increases were observed at University Avenue. At both sites, the subjects more often saw the correct number of cutouts in the crosswalk with the Swiss method than they did with the U.S. system.

The initial results confirm that a simple adjustment to the placement of light fixtures can make pedestrians more visible to drivers from a greater distance. This adjustment should result in increased recognition distances and improved yielding behavior by drivers and therefore increased pedestrian safety. The lighting also provides better illumination of crosswalk warning signs and pedestrians approaching the crosswalk. Both of these features, though untested, are expected to provide safety benefits.

This research will continue with further testing planned in the spring of 2002 at the FHWA Turner-Fairbank Highway Research Center. The lighting and background variables will be further controlled and altered in order to test specific benefits or drawbacks to the Swiss method of crosswalk lighting. Ultimately, the research should lead to a national standard.

Roadway lighting is a proven countermeasure for a variety of road safety problems. It has the potential to help lessen the severe toll of lives and injuries on our roads every year. But we have not finished our work. More research and evaluation that targets specific safety problems is needed so that we can take full advantage of roadway lighting.

Patrick Hasson is the Safety and Operations team leader in FHWA's Midwestern Resource Center. In this position, he is involved in regional, national, and international projects in the areas of geometric design, Intelligent Transportation Systems, and safety engineering, education, and enforcement. Hasson and his team provide extensive training, technical assistance, and expert advice to State departments of transportation, local officials, national organizations, and others. He is the national coordinator for the FHWA Stop Red Light Running Program, is actively involved in the intersection safety programs, is chairman of an international Expert Group focused on Safety and Technology, and participates in a variety of panels and committees for the National Cooperative Highway Research Program (NCHRP), Transportation Research Board (TRB), and Institute for Transportation Engineers. He spent 2 years in the Road Transport Research Program at the Organization for Economic Cooperation and Development. Prior to these assignments, Hasson worked on a variety of transport projects and programs with FHWA, including extensive activities associated with the transportation impacts of the North American Free Trade Agreement. He holds a B.S. in engineering from the University of Maryland and an M.S. in engineering from Cornell University.

Paul Lutkevich is a senior supervising engineer for Parsons Brincker-hoff in Boston, MA. Over the last 18 years, he has been involved in the design of more than $200 million of lighting systems for roads and tunnels throughout North America. This includes Boston's Central Artery/ Tunnel Project, which consists of 161 lane miles of roadway, half of which is in tunnels. Lutkevich has received awards for his work, including an International Illuminating Design Award for the lighting modernization of Boston's Callahan Tunnel. The lighting system, the first of its kind, is the world's largest light guide installation. He is a graduate of the University of Massachusetts and holds a B.S. in electrical engineering technology. He is a licensed professional engineer in several U.S. states. He is currently the chair of the Illuminating Engineering Society's Tunnel Lighting Subcommittee, as well as the incoming chair for the Roadway Lighting Committee. He is also an active member of the Commission Internationale De L'Eclairage (International Committee on Illumination).

The full scan report can be found on the FHWA website at http://international.fhwa.dot.gov/.

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