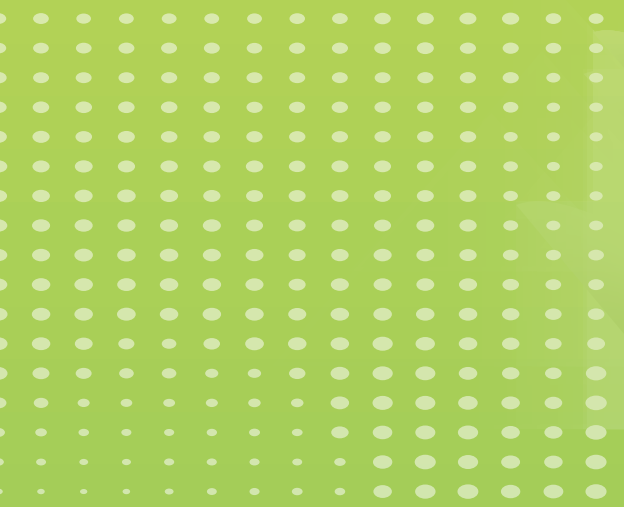




Roadway Lighting Design Guide

Seventh Edition ★ October 2018



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CHAPTER 1

INTRODUCTION



1.1 OVERVIEW

This is the seventh edition of the AASHTO *Roadway Lighting Design Guide*, with the sixth edition having been published in October 2005. This seventh edition has been revised to reflect current practices in roadway lighting and ultimately replaces the 1984 publication entitled *An Informational Guide for Roadway Lighting*. This guide provides a general overview of lighting systems from the point-of-view of state transportation departments and recommends minimum design parameters.

This guide may be used by agencies to warrant and design roadway lighting systems within their jurisdiction. Additionally, agencies can incorporate this information into their own roadway lighting policies. Agency-specific policy may also include types of lighting equipment and technologies, lighting calculation preferences, or maintenance issues.

Significant changes in the seventh edition of this guide include the following:

- ♦ additional information on roadway lighting safety research,
- ♦ commentary on emerging technologies,
- ♦ Revised goals of master lighting plans,
- ♦ additional information on coordination with the Federal Aviation Administration,
- ♦ additional information about pedestrians at intersections,
- ♦ new criteria and methods for determining the need for overhead sign lighting, and
- ♦ new information on sky glow and light trespass.

Please note, however, that one of the key components of the sixth edition of the AASHTO *Roadway Lighting Design Guide*, i.e., the Illuminance and Luminance Design Value tables in Chapter 3, has not changed significantly. No reduced lighting levels are recommended regardless of the color temperature of the luminaire.

Beyond the information included in the seventh edition of this guide, various guidelines of national and international lighting engineering and architectural groups may be consulted for reasonable limits and strategies to optimize lighting designs while limiting any negative effects. Table 1-1 lists some of these groups.

Table 1-1. Resources for Lighting Engineering Guidelines

Organization	Internet Address
The Illuminating Engineering Society (IES)	http://www.ies.org
The International Commission on Illumination (CIE)	http://www.cie.co.at
The European Committee for Standardization (CEN)	http://www.cenorm.be
The Transportation Association of Canada (TAC)	http://www.tac-atc.ca

1.2 NEED FOR ENGINEERING EXPERTISE

Most states require final design documents to be signed and sealed by a registered professional engineer. Roadway lighting designs, as described in this guide, meet the criteria for requirement of an engineering seal. An engineer's seal is necessary primarily because the public's interest is at stake. In addition, roadway lighting designs often integrate other aspects of transportation engineering that cannot be overlooked by the designer.

These other aspects may include support structures, breakaway devices, pavement designs, electrical standards, traffic operations and traffic engineering, or safety factors. Engineering economics must also be utilized when determining various aspects of the facility, including the consideration of construction costs, maintenance programs and life-cycle analysis.

The engineering expertise necessary for developing quality roadway lighting designs includes, but is not limited to the following:

- light source types and characteristics, including depreciation factors and efficacy;
- ballast types and characteristics;
- luminaire mechanical characteristics;
- lens types;
- photometric performance of luminaires and factors impacting such performance;
- luminaire mounting types;
- pole mechanical and electrical characteristics;
- breakaway device options and when appropriate to use;
- clear zone criteria;
- overhead utility clearance factors;
- pole types, luminaire mounting options, and loading considerations;
- foundation and support details;
- road surface classification;
- luminaire mounting height and spacing options;
- light trespass and sky glow issues including local laws and ordinances;
- lighting quality measures, such as illuminance, luminance, veiling luminance, visibility, and color spectrum;
- lighting technology options (such as LED);
- maintenance considerations for individual components and the lighting system as a whole;
- electrical distribution and wiring systems;
- energy and life-cycle costs;
- coordination with master lighting plans; and
- right-of-way considerations and public involvement.

Lighting system design should be performed in an engineering manner. This includes exercising engineering judgment when balancing all of the above characteristics.

Many of the current problems in roadway lighting are due to poor lighting designs. Excessive glare, poor uniformity, visual clutter, sky glow, and light trespass are all noticeable disadvantages of poor designs. Excessive maintenance and energy costs are just two of the hidden expenses resulting from less-than-optimal roadway lighting systems. The use of improper depreciation factors and inaccurate photometric distributions may magnify these issues. A relatively new issue arises when some agencies convert to LED lighting based solely on energy cost saving criteria, with no consideration of the resulting light levels, uniformity, or glare. Fortunately, the quality of roadway lighting designs can be improved with education and experience.

1.3 SAFETY RESEARCH AND APPLICATION

The *Highway Safety Manual* (HSM) (1) was released by AASHTO in 2010 as a tool to quantitatively predict and evaluate changes in crash rates given the presence or modification of a specific feature for roadway segments and intersections.

A major component of the HSM with regard to quantitative crash prediction involves the use of Crash Modification Factors (CMFs). A CMF is a value which represents the predicted change in number of crashes when a specific treatment is added or removed. This value is then multiplied by existing crash data to achieve the predicted number of crashes at the location.

CMFs involving the installation of roadway lighting are available for roadway segments as well as intersections. According to the HSM, the installation of lighting along roadway segments of all types is predicted to reduce nighttime crashes of all severities by 20 percent. Nighttime injury and non-injury crashes are predicted to decrease by 28 percent and 17 percent, respectively.

The HSM includes CMFs for the installation of roadway lighting at intersections as well; however, the CMFs provided reflect injury crashes only. When lighting is installed at intersections, nighttime injury crashes are predicted to be reduced by 38 percent while nighttime pedestrian injury crashes are predicted to be reduced by 42 percent.

When existing crash data is not available, predicted crashes can be calculated through the use of Safety Performance Functions (SPFs). SPFs are pre-determined equations for roadway segments and intersections used to predict the number of crashes. Coefficients are included as elements within the SPF to reflect the roadway segment or intersection's conditions (turn lanes, lane width, presence of lighting, etc.). CMFs can then be applied to estimate the affect of a change in conditions, such as the installation of roadway lighting. The end result is a predicted number of crashes based on those characteristics.

1.4 RECOMMENDED ROADWAY LIGHTING DESIGN METHODS

AASHTO strongly recommends the luminance or illuminance design methods. Several popular lighting design software packages utilize these methods, allowing many designs to be analyzed in a time-efficient manner.

AASHTO previously supported research for visibility-based methods, but increased benefits have not been adequately demonstrated. Accurate small target visibility (STV) calculations require the input of all light sources, including vehicle headlamps and off-roadway contributions. Such data are not easily obtained on roadways during moderate traffic conditions, let alone high-volume conditions typically characterized by roadways requiring lighting.

Although the STV design method has made significant contributions to roadway lighting, it is generally not recommended by AASHTO as standard practice. However, STV or other visibility factors may be considered during roadway lighting design as a comparative method or as a complement to the primary method.

1.5 MASTER ROADWAY LIGHTING PLANS

AASHTO encourages the use of master roadway lighting plans for implementation by traffic management centers, emergency management agencies, or other central control facilities. Better use of resources (and subsequent energy savings) may be achieved through innovative strategies such as lighting curfews, special event adjustments, weather adaptation, or maintenance automation.

1.6 MODERN ROADWAY LIGHTING CONTROLS

Modern lighting controls (also termed Electrical and Lighting Management Systems) offer significant benefits for master roadway lighting plans that agencies may determine provide enough benefit to warrant the additional expense of modern controls. Lighting control systems that allow agencies to monitor or adjust, or both, lighting systems from a remote location are now available. While maintenance tasks are still necessary, modern roadway lighting controls can inventory assets, observe power usage, compute life-cycle costs, and monitor the performance of individual systems. This provides a more effective means of identifying and diagnosing lighting issues than methods previously used.

1.7 EMERGING ROADWAY LIGHTING TECHNOLOGIES

New roadway lighting technologies have inundated the market and are being promoted as having advantages over traditional lighting sources. Solid-state lighting (SSL)—principally light emitting diodes (LEDs), but also light emitting plasma (LEP), and other technologies—is being promoted as improving safety, conserving natural resources, reducing energy consumption, and reducing life-cycle costs of roadway lighting operations. Until recently, the majority of roadway lighting was comprised of high-intensity discharge (HID) lighting, specifically high-pressure sodium (HPS). There are many differences between SSL and HID beyond the physical equipment differences. Examples include the following:

- ✦ light distribution,
- ✦ lighting output control (dimmability),
- ✦ spectral power distribution (SPD), and
- ✦ efficiency of lighting production suitable for human perception (luminous efficacy).

Research comparing the use of SSL to HID for roadway lighting has established some benefits in terms of energy consumption, luminous efficacy, color rendering, and adaptability.

The NCHRP technical report *Analysis of New Highway Lighting Technologies* (Project No. 20-7/305, published in 2013) (2) documents and presents the results from a study of roadway lighting technologies including the use of LED sources and other light source types. A review of published research and case studies of new lighting technologies, as well as a comparison of roadway luminaire photometric performance, suggests that LED technologies, while still rapidly developing, are viable for specifying energy efficient and visually effective roadway lighting systems. New metrics such as luminaire system application efficacy can allow engineers to make informed decisions about the roadway lighting system configurations (including luminaire selection, spacing, and mounting height) that will lead to the most economical system performance. Research also suggests that a number of other metrics such as mesopic photometry, brightness perception, and spectral sensitivity for discomfort glare could

assist the designer in selecting among new lighting technologies, most of which have greater short-wavelength spectral output than conventional high-pressure sodium lighting. Evaluations of visual performance and visibility coverage areas from roadway lighting may also be of use in identifying appropriate adaptive control strategies for roadway lighting.

When considering any new technology, it is appropriate to carefully evaluate the benefit and potential risk associated with that product. In the case of LED highway lighting, great improvements have been made during the past few years. Manufacturers have developed creative solutions to concerns such as heat dissipation, light output, photometrics, and durability. For roadway lighting, the industry-wide trend appears to be away from HPS and towards LED systems. While light levels and distributions of LED roadway lighting luminaires are now similar or in some cases better than traditional luminaires, some of the unanswered questions include:

- Does the higher color temperature of LED luminaires result in the need for less overall illumination?
- Will LED luminaires last as long in the field as predicted by manufacturers? Does the higher color temperature of LED luminaires create any health concerns related to the effect of melatonin levels on sleep and alertness?
- Does the higher color temperature of LED luminaires create any environmental concerns related to negative impacts on fauna and flora?

National Cooperative Highway Research Project (NCHRP 05-22), *Guidelines for Solid-State Roadway Lighting*, is currently underway, with an expected completion date in 2019. Further updates to this Guide may occur after that report is published. Other research efforts related to health concerns are also underway. Regarding SSL/LED lighting, a list of items that still need research includes the following:

- metrics for assessing the effectiveness of roadway lighting, with and without headlights, to achieve adequate contrast;
- standardization and asset management for SSL replacement to simplify maintenance;
- potential revenue streams from data collection and barriers to their implementation;
- real-time asset management within the context of ITS framework;
- metrics to characterize the environmental and health effects of roadway light spectrum, amount, distribution, and timing;
- metrics for assessing light depreciation and means of determining end of useful life; and
- light and adverse weather.

1.8 REFERENCES

1. AASHTO. *Highway Safety Manual*, First Edition, with 2014 supplement, HSM-1-M. American Association of State Highway and Transportation Officials, Washington, DC, 2010.
2. Bullough, J. D. and L. C. Radetsky. *National Cooperative Highway Research Report 20-7/305: Analysis of New Highway Lighting Technologies*. NCHRP, Transportation Research Board, Washington, DC, 2013.



MASTER LIGHTING PLANS

2.1 OVERVIEW

2.1.1 Introduction

The commitment to lighting roadway facilities is a large responsibility. A master lighting plan can help in the fulfillment of this responsibility by defining the direction and ultimate goal desired. This chapter provides general guidelines for implementing a master lighting plan when local authorities determine that such a plan is desirable for their community.

2.1.2 Definition

A master lighting plan is a formal arrangement between local governments and other entities within a regional area to coordinate and standardize the design, operation, and maintenance of public lighting. Master lighting plans can include lighting curfews and modern electronic monitoring and control systems (described in Sections 2.4 and 2.5, respectively).

2.1.3 Benefits

The basic benefits of lighting include safety, beautification, and security for people and property. Additional benefits derived from a master lighting plan include the following:

- ✦ improving safety through the maximizing of resources;
- ✦ improving traffic flow;
- ✦ improving driver comfort or confidence, or both;
- ✦ identifying the nature of the site (residential versus “restaurant row,” for example);
- ✦ managing energy use;
- ✦ controlling sky glow and light trespass;
- ✦ implementing lighting curfews;
- ✦ increasing public security (other concerns may warrant immediate turning on or off);
- ✦ standardizing design choices;
- ✦ coordinating maintenance; and
- ✦ coordinating maintenance specifications, such as poles, breakaway devices, and luminaires.

2.2 PLAN DEVELOPMENT

2.2.1 Introduction

The master lighting plan development process can proceed as shown in the following table.

Table 2-1. Master Lighting Plan Development Process

Step/Action	More Information
1. Coordinate with other participants to set goals.	See Section 2.2.2 for information on participants. See Section 2.3 for information on goals.
2. Consult with and consider the concerns of various groups having a stake in public lighting.	See Section 2.2.3.
3. Conduct a study to justify and determine the feasibility of the planned strategies. management systems.	See Section 2.4 for details on lighting curfews. See Section 2.5 for details on electrical and lighting See Section 2.6 for details on conducting studies.

2.2.2 Participants

The master lighting plan approach is a regional concept that could involve the following entities and stakeholders:

- ✦ state DOT;
- ✦ municipality;
- ✦ county;
- ✦ transportation agency;
- ✦ police;
- ✦ traffic management centers, emergency management centers, or other central locations;
- ✦ fire, EMS, and other emergency agencies;
- ✦ turnpike and bridge authorities;
- ✦ sea ports;
- ✦ rail-road and bus stations;
- ✦ stadiums and sports complexes that hold major events;
- ✦ tunnel operators;
- ✦ chambers of commerce (event coordination);
- ✦ Federal Aviation Administration (near airports);
- ✦ Coast Guard (near waterways);
- ✦ environmental agencies; and
- ✦ utility companies.

Coordination Needed—Officials of these organizations can coordinate all publicly owned lighting systems by setting joint goals and laying out plans to achieve those goals. A master lighting plan should be seen as a component of agency management.

2.2.3 Groups Having Concerns about Lighting

In addition to the participating entities, other groups may have concerns related to public lighting, and their concerns should be considered. These groups may include the following:

- ✦ citizens and property owners;
- ✦ road users;
- ✦ retailers and other business;
- ✦ users of park-and-ride facilities;
- ✦ universities;
- ✦ astronomers;
- ✦ tourists;
- ✦ resorts;
- ✦ visitors;
- ✦ users of bike and pedestrian trails;
- ✦ users of parks and sports facilities (including spectator sports and participant sports such as driving ranges and softball);
- ✦ “dark sky” advocacy groups; and
- ✦ American Medical Association (AMA).

2.3 GOALS OF A MASTER LIGHTING PLAN

2.3.1 Introduction

A master lighting plan can help maximize available resources and increase management coordination. Maximizing resources means lowering the operating costs of existing and new lighting systems, which may allow the installation and operation of more lighting systems that operate only when needed.

A master lighting plan should address the following major goals:

- ✦ improve roadway safety,
- ✦ increase personal security,
- ✦ provide nighttime aesthetics,
- ✦ consider environmental issues,
- ✦ use energy efficiently, and
- ✦ plan maintenance.

Discussions of each of these goals follow under separate headings.

2.3.2 Improve Roadway Safety

Improved roadway safety is often the primary goal of public lighting. Public lighting affects all road users, including motorists, cyclists, transit users, and pedestrians. Public lighting may be provided for roadways, sidewalks, multi-use paths, and signs. The principal measure of effectiveness for roadway safety is crashes. This goal aims to reduce or minimize the risk and actual number of crashes related to all road users. Roadway safety is not the same as “personal security,” which may be another goal of roadway lighting and is discussed further below.

2.3.3 Increase Personal Security

A goal of public lighting can be to reduce crime within the lighted area and to enhance both the perception and reality of personal security, particularly with respect to pedestrians, cyclists, and transit users. This is sometimes referred to as “safety,” but when used in this sense safety is meant with respect to law enforcement and crime prevention, as opposed to “roadway safety” which was discussed in Section 2.3.2.

2.3.4 Provide Nighttime Aesthetics

Public lighting intended to attract tourists, central business district (CBD) customers, and nighttime activities may include pedestrian, building façade, bridge or structure, landscape, and sign lighting. The intent of this goal is to improve aesthetics and to provide a pleasing and attractive environment for nighttime activities.

2.3.5 Consider Environmental Issues

Environmental considerations include visual comfort, sky glow, light trespass, glare, and visual clutter.

Consideration should be given to the desires of facility owners, public officials, and citizens as expressed in public hearings, local laws and ordinances, and other sources.

All outdoor lighting creates some degree of sky glow and light trespass. Modern controls can implement switching or dimming curfews that may better address the needs and desires of the community. In short, all community and business desires should be respected, and competing concerns should be balanced as much as possible.

A wide variety of alternatives are available for outdoor lighting. Various environmental factors should be subjectively evaluated for different situations. Some factors to consider include the following:

- ✦ purpose of the lighting,
- ✦ source type,
- ✦ degree of light cutoff (degree of up light),
- ✦ light level,
- ✦ mounting height,
- ✦ ambient light levels (other lighting in the area),
- ✦ historical considerations,
- ✦ area land use,
- ✦ roadway classification,
- ✦ pedestrian and cyclist use,
- ✦ transit use,
- ✦ consideration of lighting curfews (see Section 2.4), and
- ✦ effect on wildlife (some studies show that nighttime lighting may affect wildlife).

A review of the following facility types should demonstrate an intuitive weighting and consider:

- ✦ urban freeways,
- ✦ rural freeways,
- ✦ central business district (CBD),
- ✦ arterial roadways,
- ✦ collector roadways,
- ✦ residential streets,

- parklands and campgrounds,
- park-n-ride lots and rest areas, and
- bus stops.

2.3.6 Use Energy Efficiently

Important factors affecting energy use include light levels, lamp type, lamp wattage, ballast type, and quality of the electrical system. Lighting curfews can also help conserve energy.

Newer highway lighting technologies, most prominently light emitting diode (LED) and light emitting plasma (LEP), use less energy than some traditional lighting technologies, such as high-pressure sodium (HPS). However, care should be taken when evaluating new lighting technologies with respect to the expected photometric light pattern, pole spacing, color spectrum, and life-cycle costs.

2.3.7 Plan Maintenance

Ongoing maintenance is a critical part of a successful roadway lighting installation. Maintenance responsibilities should be considered as a part of the master lighting plan. For any given project, maintenance responsibilities may be assigned to one of the following parties: state departments of transportation, counties, municipalities, utility companies, homeowners associations, or commercial entities. Additionally, two or more parties can enter contract agreements that would allow one party to pay the capital construction costs for a lighting installation, another party to maintain the lighting once installed, and potentially a third party could be responsible for the ongoing electrical costs.

The master lighting plan can be used to prioritize maintenance schedules, organize contracts, and determine acceptable light levels. Planned maintenance establishes consistent replacement products, coordinates traffic control setups, enhances the use of electronic monitoring, takes advantage of modern inventory systems, reduces trouble-shooting of problems, and reduces electrical hazards, which can lower overall costs. Larger systems are more likely to have a lighting engineer available to oversee the total process of design, installation, and maintenance, thereby allowing for replacement fixtures with suitable photometric, electrical performance, and aesthetic features. Under a master lighting plan, life-cycle costs, life expectancy, and quality studies are enhanced, and the region may have more buying clout. See Section 2.5 for a discussion of how modern electrical and lighting management systems can help with maintenance.

2.4 LIGHTING CURFEWS

2.4.1 Introduction

Curfews for lighting involve the use of modern controls to turn off or dim selected parts of lighting systems as permitted by reduced traffic flow, favorable weather conditions, and other local conditions. Lighting curfews represent the active “operation” of the system, allowing for energy savings, greater flexibility in resource allocation, and reduction of light-trespass. However, officials implementing such options should be aware of consequences and conduct meaningful studies of costs and benefits.

Generally, studies have shown lighting may be expected to significantly reduce nighttime crashes (see additional information in Section 1.3). The precise mechanism for the reduction of those crashes is not known. Currently it is not possible to translate surrogate measures, driver performance with targets, or other measures directly into a safety change.

The benefits of roadway lighting may be reduced in the later hours of the night. The number of overall crash-es tapers off substantially after midnight on weekdays and after 4:00 a.m. on weekends (however, crash rates are typically higher during these hours). At these late hours, most of the crashes are single vehicle, off-roadway crashes for which lighting may not be likely to help, except possibly at decision-making points such as ramp gores, intersections, and merge areas.

Warrants for lighting are empirically derived and based, among other things, on traffic volume. For lighting that has been installed based on traffic volumes, it may be reasonable to cut back the operation of the lighting system to complete interchange lighting or to partial interchange lighting when traffic volumes subside.

Studies show that crash rates increase where systems are turned off or where every other luminaire is turned off. Alternate luminaire operation results in poor uniformity ratios and should be avoided. The issue of driver needs and safety versus conservation efforts should be closely examined when considering curfews. Poorly conceived conservation efforts may contribute to increases in traffic crashes and operational problems. These problems may actually result in higher overall costs.

2.4.2 Reasons for Curfews

Government entities around the world are considering lighting curfews for the following reasons:

- **Low late-hours traffic volumes**—AASHTO warrants for highway lighting are based, among other things, on traffic volume. When the primary reason that lighting is (or was) installed was due to high traffic volumes and high usage, which drops off in later hours of the night, it is reasonable to turn off or reduce the lighting after such drop-offs.
- **Freeing resources for greater overall safety**—Lowering the operational costs of lighting systems by reducing electrical and maintenance costs through curfews may allow more lighting systems or other crash counter-measures to be installed, thereby reducing the overall nighttime crash rate within the jurisdiction of the master lighting plan.
- **Technology now practical**—Modern control technology now allows control of individual luminaires or systems of luminaires at reasonable costs.
- **Positive study results**—Recent studies show that light dimming and turn-off curfews are viable options for the management of public lighting systems, including roadway lighting. Although past studies showed unfavorable increases in traffic crash rates because of turning off lighting, these studies were performed on systems where the lighting was turned off or partially turned off for the entire nighttime period.
- **Energy savings**—Lighting curfews can reduce the total operating time of a luminaire will reduce energy costs, providing an ongoing expense relief.
- **Extend luminaire service life**—By reducing a luminaire's hours of operation, the luminaire's useful life expectancy should increase.
- **Sky glow**—Lighting curfews can be a means to mitigate sky glow concerns.

2.4.3 Considerations before Implementation

Special events, maintenance or construction activities, weather, and other local considerations should be included in the decision to implement lighting curfews. Implementation of curfews should occur through traffic management centers or other central locations and should be monitored to gain experience as to the best operational procedures.

The following excerpts are from the FHWA report *Reduced Lighting During Periods of Low Traffic Density* (FHWA/RD-86/018)(1). When considering lighting curfews, the complete report should be read, while realizing that it is dated August 1985. Modern crash data should be analyzed.

In part, this report states,

Over 50 percent of all motor vehicle fatalities occur in darkness even though only 25 percent of all travel occurs at night. This over representation has been used as a justification for installing fixed roadway lighting on many highways. However, research that has attempted to determine the effect of such fixed lighting on frequency and severity of night accidents appears to be mixed, such frequencies and severities being dependent on a host of geometric and traffic factors including the volume of traffic utilizing the road, how such volume is related to the road's capacity, and the complexity of the driver's visual search task.

During the past decade, several highway agencies have switched off roadway lighting during periods of energy shortages to reduce maintenance and operating costs. However, quite often such lighting was restored when nighttime accidents increased. One fundamental problem with these light reduction techniques was that lighting was reduced or eliminated during the entire nighttime period, rather than only when traffic volume was low.

By providing full lighting during periods when volumes are high and the roadway operates near capacity and by providing reduced lighting as the traffic decreases, the potential exists for realizing considerable energy savings while still providing the benefits of full lighting at locations (e.g., interchanges) and at times (i.e., high volumes) where driver decision-making is the most critical and the greatest visibility is required.

From a safety standpoint there is a definite reduction in (simulated) hazard detection performance, which theoretically implies some reduction in safety. This implied reduction in safety is statistically significant for "all off" and "one side only" lighting tactics, but not statistically significant for the dimmed tactics and the "every other off" tactic. Unfortunately, it is not possible at this time to quantify the exact decrease in safety in terms of the frequency of nighttime accidents, the night accident rate, or the night-to-day accident ratio. Only an evaluation of long term installations can address this issue (see Section 2.6 for a discussion of further research needs).

Reduced freeway lighting tactics normally should not be implemented before 11:00 p.m. in most urban areas, since traffic density typically remains relatively high until that time. Regularly scheduled sports events and other large traffic generators could change this time to a later hour, while cities with little or no evening activity might allow an earlier light reduction.

A more recent report by the Texas A&M Transportation Institute (FHWA/TX-13/0-6645-1, published in 2013) is *Guidelines for Freeway Lighting Curfews* (3). It examines the possibility of lighting curfews on urban mainline freeways. Part of the conclusion of the report reads: "The key element of these guidelines is that a lighting curfew appears feasible when the traffic volume during the hours of the curfew is 100 vehicles per hour per lane (vphpl) or less. There are numerous constraints associated with implementing a lighting curfew, such as lighting that was installed as safety lighting or as the result of a safety study should not be included in a lighting curfew." The report also recommends against curfews for certain types of roadway segments (such as interchange areas or segments with major changes in geometry), and for certain time periods (such as major special events or unusual weather conditions).

2.5 ELECTRICAL AND LIGHTING MANAGEMENT SYSTEMS

2.5.1 Introduction

Master lighting plans allow for benefits to be derived from modern electronic monitoring and control systems known as electrical and lighting management systems (ELMS). This technology can detect lighting problems more quickly and accurately than traditional methods with ELMS capable of displaying luminaire locations on

Google Maps and provide GPS locations. The maximum benefit is most likely realized when the technology is applied across the entire lighting infrastructure within a local authority's inventory. Remote monitoring technology can modernize the management, operation, and maintenance of the roadway lighting infrastructure.

2.5.2 Cost

The costs of introducing the technology are difficult to estimate without significant evaluation. This has led to concerns over initial investment costs, operating costs, and anticipated payback on investment. It is important that evaluations consider a whole system approach. Remote monitoring can be progressively used and specified for new lighting schemes and for installations requiring additional or extraordinary monitoring and control.

2.5.3 Benefits

The benefits of ELMS are outlined in Table 2-2.

Table 2-2. Benefits of Electrical and Lighting Management Systems (ELMS)

Benefit	Explanation
More efficient contract management	Contracts can be written to pay for maintenance by the month instead of by each part repaired or replaced. Percent of luminaires burning can be verified electronically through ELMS, thus reducing survey costs.
Improved electrical safety and reliability	ELMS provide for ground fault detection and notification of system malfunction.
Energy savings	Energy saving lighting curfews are facilitated through remote or automatic control of lighting systems.
Reduced maintenance costs	ELMS facilitate advance knowledge of problems, parts needed, and types of personnel needed. This results in better overall contractor information and supervision of maintenance work.
Reduced life-cycle costs	ELMS can provide the information and documentation needed to write specifications and modify approved products lists, thus lowering maintenance costs and improving reliability.

Modern technical advances have made new technologies available to organizations that operate and maintain roadway lighting systems. These technologies have the potential to improve service quality, lower maintenance costs, increase productivity, and conserve energy. But the implementation of new technologies also holds risk because of technical and commercial complexities. The key to reducing this risk is to make the new technologies compatible with existing systems and to ensure that the systems of different suppliers are interoperable.

Master lighting plans and ELMS allow coordination, through the traffic management centers, of all interested subjects and parties including municipalities, department of transportation personnel, police, special events, traffic management, state and local ordinances, landscape lighting, landscape installation (especially trees), landscape maintenance, pedestrians, cyclists, and central business district interests.

2.5.4 Benefits of ELMS Standardization

Interoperability and compatibility standards for ELMS results in four significant benefits, as outlined in Table 2-3.

Table 2-3. Benefits of ELMS Standardization

Benefit	Explanation
Reduction in the complexity of integrating systems	This translates into lower risk of implementation delays and fewer resources required for system installation and introduction.
Creation of more open and competitive market	Proprietary technologies tend to lock buyers into single-source supply arrangements. Such arrangements give the incumbent supplier undue leverage in future purchases and make substitution of non-performing suppliers expensive. Standardization discourages this tendency.
Allowance for the mixing of systems from different suppliers	Various systems have their own strengths and weaknesses, given the differing situations in which they are used. If a buyer wishes to implement a system with “best of breed” components, then interoperation and compatibility between these components make that possible.
Evolution through open participation in which all views are considered	Due process through a public forum ensures validation and utility of the underlying technologies.

Interoperability and compatibility standards lead to a more competitive environment for suppliers. However, suppliers benefit from standards as well. In general, buyers are suspicious of single-source market conditions, and therefore simply delay purchases until a competitive environment has evolved. History has shown that the establishment of standards accelerates adoption of new technologies and causes the market to expand more rapidly. Existing standards, such as the National Transportation Communications for Intelligent Transportation System Protocol’s NTCIP 1213 document (2), should be considered when evaluating ELMS compatibility standards.

2.6 CONDUCTING STUDIES

2.6.1 Introduction

Before developing a master lighting plan, a study should be conducted by traffic and lighting engineers. The study is needed for the following reasons:

- ✦ to determine how the various lighting systems can best be optimized and coordinated,
- ✦ to justify the implementation of lighting curfews, and
- ✦ to justify expenditures for technological improvements such as ELMS.

Generally, the study should cover the following items:

- ✦ study area,
- ✦ lighting justification criteria,
- ✦ electrical system,
- ✦ purpose of the lighting system,
- ✦ benefits and effects of curfews and dimming,
- ✦ traffic studies,
- ✦ crash history,
- ✦ surrounding land use and surrounding lighting,
- ✦ security concerns,
- ✦ sky glow and light trespass issues,
- ✦ community goals,
- ✦ coordination with navigation authorities,

- ✦ traffic management interaction,
- ✦ controls,
- ✦ curfew monitoring,
- ✦ ELMS Implementation,
- ✦ coordination with roadway maintenance and construction activities, and
- ✦ budget.

These items are discussed under separate headings here and in subsequent chapters.

2.6.2 Lighting Justification Criteria

The purposes of roadway lighting should be defined, including one or more of the following goals as discussed previously in Sections 2.3.2 through 2.3.4: roadway safety, personal security, and nighttime aesthetics. Specific criteria, potentially differing for each purpose, should be established. Chapter 3 provides additional information related to justification criteria related to roadway safety.

2.6.3 Electrical System

The study should evaluate electrical energy use and potential for savings.

2.6.4 Benefits and Effects of Curfews and Dimming

Dimming should be considered if light levels are higher than those required by AASHTO. In some instances, lighting is installed at levels higher than the minimum required because of safety considerations or work zones. It may be reasonable to dim lighting to only the required level after heavy traffic subsides. The same logic can be applied to dimming as is applied to curfews.

2.6.5 Traffic Studies

Assess the hourly nighttime traffic volumes and crashes. Consider reducing continuous lighting to partial interchange lighting at the point during the nighttime hours when the number of fatal crashes analyzed over a three-year period drops to half of the peak rate. Consideration may be given to the type of crashes occurring and to any study that determines if lighting is a factor in the specific traffic safety problem.

2.6.6 Community Goals

Conduct a survey of community goals for lighting.

2.6.7 Budget

Consider how the master lighting plan relates to the following budgetary factors:

- ✦ How will the plan affect the budget for lighting installation and maintenance?
- ✦ How will the plan affect the budget and methods for other traffic safety devices?
- ✦ What is the budget for installing controls?