Highway Lighting Practices and Policies

Requested by
Jerry Champa, Caltrans Division of Traffic Operations

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Caltrans is seeking current information on national and state highway practices, policies, warrants and standards. Caltrans is particularly interested in large metropolitan areas: how agencies light highways that are large (multilane, urban) and complex (toll lanes, high-occupancy vehicle [HOV] lanes, express lanes, uncommon interchanges), and whether practices are based on traffic levels, crash rates, or both.

Following are the most relevant findings in this Preliminary Investigation. An overview of all findings appears in the **Outline** section that follows.

- The key national document pertaining to Caltrans' inquiry is the 2005 *AASHTO Roadway Lighting Design Guide*. In a 2010 AASHTO survey, 32 of 36 states, or 89 percent, reported making use of this guide. Among the lighting warrants in this publication are those for continuous lighting of freeways in urban areas, which is a practice in a number of states.
- Selected relevant practices and policies are highlighted from the following state DOTs:
    - In **Florida,** all interchanges on the Interstate highway system must be lighted, which is based on a policy issued in 2013; moreover, nearly all six-lane limited-access facilities within large urban boundaries have continuous freeway lighting.
    - **Illinois** DOT will typically add lighting to complex highway scenarios and configurations. Other states have similar policies or guidance for such configurations.
    - Lighting varies throughout **New York State**, with highway lighting more common in urban areas. Few if any sections of the Interstate are lit in the Capital District, and Interstate lighting is not predominant statewide.
    - **New Jersey**'s warrants, based on the AASHTO guide, also provide additional design considerations that address ramps, acceleration lanes, and main line highways. The guidance calls for "accident data … to determine the night-to-day accident ratio. The ratio could dominate the determination if highway lighting is required."

    - In **Pennsylvania**, lighting warrants are analyzed and used in conjunction with the density of the area to determine partial interchange, complete interchange, or continuous lighting. Additionally, lighting may be recommended by a safety review committee for areas with high accident rates.
    - **Texas**' expansion on AASHTO guidance includes an "eligibility requirement" for highway lighting; this is discussed in the interview with Texas DOT's Greg Jones.
- It is noteworthy that new lighting technologies are driving today's transitional period for highway lighting practices.
- In practice, data required for safety policies (such as for the establishment of night-to-day crash ratios) can be difficult to obtain and hard to use. Texas DOT stated that the agency commonly relies on "engineering judgment" where such data are lacking.

Outline

The main sections of this Preliminary Investigation and their contents are outlined below.

National Standards and Guidance

- **AASHTO** references:
  - The 2005 *AASHTO Roadway Lighting Design Guide.*
  - Interview feedback from the chair of the AASHTO Joint Technical Committee on Highway Lighting.
  - A 2010 survey of AASHTO members by this committee.

- Resources from the **United States Department of Transportation** (U.S. DOT):
  - The 2012 *FHWA Lighting Handbook* and correspondence with Ernest Kim of FHWA's Safety Office.
  - U.S. DOT's National Transportation Communications for ITS (Intelligent Transportation Systems) Protocol (NTCIP) Object Definitions for Electrical and Lighting Management Systems (ELMS) and an interview with an NTCIP committee industry representative.
  - FHWA's 2001 International Technology Exchange Program report *European Road Lighting Technologies*.

- **Illuminating Engineering Society (IES)** guidance:
  - IES recommended practice *Roadway Lighting—IES RP-8-00*, published in 2000 and reaffirmed in 2005.
  - The IES *Lighting Handbook: Reference and Application*, published in 2011.
  - IES Roadway Lighting Committee activities and an interview with committee member Andrew Silbiger and his thoughts on these publications.

- The **Transportation Association of Canada** published a *Guide for the Design of Roadway Lighting* (2006).

State Standards, Guidance and Practice

Summaries of correspondence, interviews and documentation for a total of **11 state agencies**: California, Colorado, Florida, Illinois, Minnesota, New Jersey, New York State, Oregon, Pennsylvania, Texas and Washington State.

Research

- Three U.S. **research centers**: Virginia Tech Transportation Institute (including an interview with its director), Rensselaer Polytechnic Institute Lighting Research Center, and Texas A&M Transportation Institute.

- Nine **research publications**, primarily from the past five years: publications from the centers noted above, journal articles, NCHRP research findings, and a handbook.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the individuals listed below:

Government Agencies and National Organizations

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U.S. Department of Transportation
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Chair, U.S. DOT NTCIP 1213 Committee
(Note: Frazer is also Chair of the IES Roadway Lighting Energy Management Subcommittee)
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National Standards and Guidance

National guidance on this topic includes documentation and expert input from AASHTO, U.S. DOT and the Illuminating Engineering Society. We have also included a reference from AASHTO's Canadian counterpart, the Transportation Association of Canada.

AASHTO

AASHTO Roadway Lighting Design Guide, 2005
https://bookstore.transportation.org/item_details.aspx?id=320
From the description: "The guide provides a general overview of lighting systems from the point of view of the transportation departments and recommends minimum levels of quality. The guide incorporates the illuminance and luminance design methods, but does not include the small target visibility (STV) method."

The AASHTO survey (see citation below) and state DOT interviews suggest that this guide is the primary source for highway lighting policy and warranting used by state DOTs. The individual state guidance documents that we reviewed typically called out this guide, or earlier versions of it, and in some cases noted where state policy or practice differ from AASHTO guidance.

Warranting conditions are detailed for Continuous Highway Lighting (page 18), Complete Interchange Lighting (page 19), and Partial Interchange Lighting (page 19). Criteria include average daily traffic levels, geometry of interchanges, proximity of developments, and night-to-day crash ratios.

Additional design considerations appear on page 20, with suggested placement of luminaires based on highway geometry.

AASHTO Joint Technical Committee on Highway Lighting
http://design.transportation.org/Pages/HighwayLighting.aspx
This AASHTO committee is responsible for updating the AASHTO *Roadway Lighting Design Guide*. It is a joint committee of the Highway Subcommittee on Traffic Engineering and the Highway Subcommittee on Design.

Interviews
We interviewed some of the state DOT committee members during the course of this investigation: Mark Luszcz, Delaware DOT (committee chair); Norm Schips, New York State DOT; and Susan Zarling, Minnesota DOT.

- Luszcz stated in email correspondence that "the AASHTO group is working on revisions to the AASHTO Lighting Guide, but at this time we have not suggested any significant changes to the warranting section. We are spending a lot of time discussing LED and new technology lighting, color spectrum, etc."
- Additional comments from Schips and Zarling appear in the **State Standards, Guidance and Practice** section of this report.

AASHTO Joint Technical Committee on Roadway Lighting—Survey of AASHTO Members, December 2010
http://scote.transportation.org/Documents/JTC%C2%A0on%C2%A0Roadway%C2%A0Lighting%C2%A0-%C2%A0survey%C2%A0results-April%C2%A02011.pdf
Thirty-two states and one Canadian province responded to this AASHTO survey and answered a series of questions related to highway lighting. (Note that for three states there were two survey respondents,

bringing the total response count to 36). A list of participants, including names, phone numbers and emails, appears on page 4 of the report.

Selected questions relevant to this investigation are listed below. All responses appear in detail in the report.

- Does your Transportation Agency/Department use the "AASHTO Roadway Lighting Design Guide (October 2005)"? (page 6) *(Note: The response to this question was 32 Yes and 4 No.)*
- If your Transportation Agency/Department uses the "AASHTO Roadway Lighting Design Guide (October 2005)," what chapters are used the most or are the most important to your state? (page 6)
- What specific tools (i.e., design guides, design aids, manuals, software, etc.) does your Transportation Agency/Department use to perform lighting design or design reviews used for Roadway Lighting Design? (page 12)
- What section (i.e., Traffic Engineering Section, Utilities Engineer, Roadway Design, Maintenance and Operations) of your Transportation Agency/Department is responsible for developing and maintaining roadway lighting specifications? (page 13)
- Is Light Emitting Diode (LED) lighting used by your Transportation Agency/Department? (page 14)
    - How is design accomplished? (page 15)
    - Do you have agency standards or specifications? (page 16)
    - Is reduced illumination permitted? (page 17) *(Note: The response to this question was 4 Yes and 26 No).*
- Have any other new technologies in roadway lighting (e.g., induction, plasma, etc.) been considered or used? (page 18)

Other topics addressed by the survey include sign lighting, roundabouts, work zones, non-highway lighting, light interference and waterway interference.

United States Department of Transportation

FHWA Lighting Handbook, 2012
http://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/
Per the abstract, "This handbook is an update to the 1978 FHWA Lighting Handbook 78-15 as well as the 1983 addendum. It is meant to provide guidance to designers and state, city, and town officials concerning the application of roadway lighting. Supplementing and referring to other resources developed by AASHTO, IES, and CIE, this document contains information on:

- Policy and Guidance—discussing references, policy, and recommendations used by FHWA in evaluating and administering funds for roadway and street lighting projects.
- Basic Terms and Concepts—discussing descriptions of significant terms and concepts used in roadway and street lighting projects.
- Warranting Criteria—including various warranting methods available when considering lighting.
- Lighting Impacts—discussing various impacts (both positive and negative) of lighting systems and ways to control and mitigate.
- Application Considerations—supplementing information provided in the reference documents.

- Other Systems and Issues—discussing additional lighting and non-lighting elements impacting the roadway user."

Chapter 4, "Analysis for Lighting Needs" (page 31), addresses warranting in greater detail, including AASHTO's warranting system and a detailed warranting method example based on geometric factors, operational factors, environmental factors, and crash factors (night and day).

Correspondence
We corresponded by email with Joseph Cheung of FHWA's Safety Office. Cheung replied by email to our written inquiries.

- We asked: *What do you see as some the of the most important new developments covered in the handbook, particularly related to warranting and design criteria (safety metrics, traffic monitoring/screening methods)?*

  Cheung responded: "The update effort of the FHWA *Roadway Lighting Handbook* is to convey to the FHWA Division Office, State DOTs and other Roadway Lighting practitioners the importance of providing roadway lighting to enhance Safety for road users, provide guidance for funding availability and also resources for more detailed design interests. It aims to provide an overview of roadway lighting but does not intend to provide in-depth detail design for warranting and hardware selection, etc."

- *Can you discuss trends in highway lighting (practices, technologies) not covered in the handbook?*

  "I would say that as many state DOTs and municipalities are becoming more energy-focused, the trend is to use LED lighting for new installations or replacement. The other topic of interest is the use of adaptive control for highway lighting."

- *Can you discuss any other items that might be relevant as Caltrans looks at its own warrants and practices: special consideration for particularly complex interchanges or lane geometries, new lighting technologies, energy or maintenance issues, etc.?*

  "While the handbook does not get into the level of detail necessary for complex interchange lighting design, there are different groups within IES looking at the impacts of different lighting scenarios on highway users. I have seen some more state-of-the-art designs for isolated intersections in rural areas or for some freeway types that have a series of detectors/sensors that can detect an approaching vehicle and activate the illuminations as the vehicle travels through the interchange/intersection areas and then turn them off when the vehicle exits that detection area."

Cheung also wrote: "FHWA intends to conduct a webinar in the near future on the updated FHWA Lighting Handbook and will also follow up with a series of lighting workshops late this fall/early spring."

National Transportation Communications for ITS (Intelligent Transportation Systems) Protocol (NTCIP): Object Definitions for Electrical and Lighting Management Systems (ELMS)—NTCIP 1213, Version 2, Publication of the U.S. DOT Intelligent Transportation Systems Working Group for ELMS, 2011
http://www.nema.org/Standards/ComplimentaryDocuments/1213v02-Contents-and-Scope.pdf (2011 edition, content and scope)
http://www.ntcip.org/library/documents/pdf/1213v0219d.pdf (2006 draft edition, full text)

Per the foreword of this publication, "NTCIP 1213 v02 defines the generic reference model and conformance requirements for traffic management centers (TMCs) that wish to provide interfaces to external centers." The publication "defines the Electrical and Lighting Management System (ELMS) data element objects that are supported by the NTCIP. An ELMS is defined as any system capable of monitoring, controlling, and communicating certain electrical and lighting system parameters using NTCIP."

The state DOTs interviewed for this Preliminary Investigation stated an interest in adaptive controls for highway lighting. This U.S. DOT publication is a key reference for this ITS application.

Interview
We spoke with Gridaptive's Jim Frazer, chair of the U.S. DOT NTCIP 1213 Committee.

- **Background.** Frazer discussed the background and history of this document and talked about the development of the framework (the definition of user needs, system features, and the object code). He noted that the three main components of ELMS are streetlight control, revenue-grade energy metering (the ELMS standard is becoming part of the nation's Smart Grid), and safety (ground-fault circuit interruption to protect the public).
- **Required light levels.** Frazer said that the main purpose of NTCIP 1213 is to define control elements for streetlights. Next steps involve determining how much light is really required on the road (see the research that Ronald Gibbons at Virginia Tech is conducting, cited on page 25 of this Preliminary Investigation). From a legal liability standpoint, any agency will need well-defined and accepted lighting values established if it wishes to selectively dim lights as part of an adaptive lighting system.
- **Costs.** Frazer also discussed costs for adaptive lighting technology. On a per-luminaire basis, controller price drops of more than 50 percent are expected soon. He also mentioned that Internet hardware companies are entering this market, which in the past had been dominated by traditional streetlight control companies.
- Frazer talked about advances in **vehicle-to-vehicle** and **vehicle-to-infrastructure** technology and implementation that will drive adaptive lighting applications.
- More information on these topics is available in the following white papers from Gridaptive:
    - **Smart Cities: Intelligent Transportation and Smart Grid Standards for Electrical and Lighting Management Systems**, Gridaptive, 2012 http://www.gridaptive.com/whitepapers/Smart_Cities_-_Intelligent_Transportation_and_Smart_Grid_Standards_for_Electrical_and_Lighting_Management_Systems_.pdf
    - **Smart Cities: Vehicle to Infrastructure and Adaptive Roadway Lighting Communication Standards**, Gridaptive, 2012 http://www.gridaptive.com/whitepapers/Smart%20Cities%20-%20Vehicle%20to%20Infrastructure%20and%20Adaptive%20Roadway%20Lighting%20Communication%20Standards.pdf

Texas DOT's Greg Jones is also a member of this committee. Our interview with Jones appears under "State Standards, Guidance and Practice" on page 21 of this Preliminary Investigation.

European Road Lighting Technologies, FHWA International Technology Exchange Program, 2001
http://international.fhwa.dot.gov/pdfs/euroroadlighting.pdf
Per the abstract, "The objective of this scanning tour was to gather information from European transportation ministries and lighting professionals regarding cutting-edge research and technologies in

highway and roadway lighting systems, including tunnel illumination, sign lighting, and all methods used to design roadway lighting systems. Some of the information could provide a basis on which to update the American Association of State Highway and Transportation Officials' *Informational Guide for Roadway Lighting*.

"In April 2000 the scan team visited Finland, Switzerland, France, Belgium, and the Netherlands. Based on its observations, the panel developed specific recommendations for the U.S. lighting community in such areas as visibility design technique; dynamic road lighting; pavement reflection factors; master lighting plans; lighting techniques for roundabouts, crosswalks, and pedestrian areas; energy-absorbing poles; signs; and equipment quality level and maintenance."

Illuminating Engineering Society

Roadway Lighting—IES RP-8-00, 2000 (reaffirmed in 2005)
http://www.ies.org/store/product/roadway-lighting-1028.cfm
Per the IES website, "This Recommended Practice provides the design basis for lighting roadways, adjacent bikeways, and pedestrian ways. It deals entirely with lighting and does not give advice on construction. It is not intended to be applied to existing lighting systems until such systems are redesigned. This Practice revises and replaces the previous edition, which was published in 1983 and reaffirmed in 1993 and 2005.

"Following an introduction that covers background material on the design criteria, there are three general subject areas discussed in this Practice:

- "Classification definitions that carefully defines key words/concepts as they are used in the Practice with caveats regarding alternate definitions found elsewhere.
- "Design criteria that thoroughly analyzes and illustrates the design process involving illuminance, luminance, and small target visibility (STV).
- "Design considerations that identifies major roadway issues (rural and urban) affecting driver visibility, discusses design aesthetics (coordination of light poles with landscaping), and weighs public scrutiny of glare and sky glow that can lead to lighting ordinances."

Lighting Handbook: Reference and Application, 10th Edition, 2011
http://www.ies.org/handbook/
The IES website states that this handbook presents "the current state of knowledge as it relates to lighting and lighting design." While it addresses the complete range of lighting frameworks, designs and applications, one chapter is dedicated to "Lighting for Transport."

IES Roadway Lighting Committee
http://www.ies.org/committees/committee_details_view.cfm?committeeid=95
The committee's webpage states that its mission is "to establish the scientific principles underlying roadway lighting; to collect data on the results of the application of such principles to actual practice; to prepare such reports thereon as will assist those charged with safety on roadways in minimizing the hazards of night operating conditions."

Interview
We spoke with IES Roadway Lighting Committee member Andrew Silbiger about "Roadway Lighting—IES RP-8-00" and "Lighting Handbook: Reference and Application." Silbiger noted:

- **Revision to RP-8.** A new version of RP-8 had been near completion when the 2011 Lighting Handbook was published. Some topics in the 2011 publication—mesopic lighting and

scotopic/photopic (S/P) ratios, for example—led to debate about their inclusion in the next edition of RP-8. Possible changes are being voted on by the committee, and Silbiger hopes the new version of RP-8 will be approved and published later this year.

    - Silbiger said that the new RP-8 will treat **partial lighting** somewhat differently. Rather than stating, for example, that "three lights are required at an exit," designs will instead target a desired lighting level. This could mean more or fewer luminaires, depending on the design.

- **New technologies.** A challenge of new highway lighting technology is how rapidly it is changing. Improvements in LED technology make it a moving target—"It seems as soon as you write specifications or guidelines, they're out of date."
- Per RP-8, **adaptive lighting** can be accomplished through a wired or wireless central control point. Silbiger said that the publication addresses adaptive lighting for city streets (not highways), and lighting levels are based on pedestrian traffic (not vehicle traffic).
- **Warranting.** Warranting is not within the purview of IES committees or publications.
- Silbiger mentioned again some of the **resources** referenced throughout this Preliminary Investigation: the most recent AASHTO, FHWA and TAC publications, and Ron Gibbons at Virginia Tech.

Transportation Association of Canada

Guide for the Design of Roadway Lighting, 2006
https://onlineservices.tac-atc.ca/English/bookstore/products.cfm?catid=9&subcatid=18&prodid=177
The Transportation Association of Canada (TAC) is the Canadian equivalent of AASHTO. The summary description of this guide follows.

> This Guide is intended to promote uniformity in lighting across Canada by providing guidance in the planning and design of roadway lighting and related outdoor lighting systems.
>
> The 430-page publication is divided into two major sections: Fundamentals and Design:
>
> - *Fundamentals* contains information on lighting theory, obtrusive light, the planning and design process, standards and codes, calculations and the use of computer software in roadway design and maintenance.
> - *Design* applies the principles and information presented in the first section to specific facilities that may require lighting, such as roadways, interchanges, intersections, roundabouts and tunnels. Also included are off-road facilities such as pedestrian and bicycle pathways, weigh scales, rest areas and road signs. This section also provides guidelines for streetscapes, temporary roadway lighting and work zone lighting for road construction areas.
>
> The Guide offers warranting criteria for each roadway application, with the warrants provided as a point-score system, a narrative definition or a combination of both.
>
> In addition, the Guide covers a number other related topics. It emphasizes that roadway lighting, if properly designed, installed and maintained, should reduce vehicle collisions, improve safety for cyclists and pedestrians and enhance personal security. It also discusses ongoing trends in the development of more energy-efficient light sources, as well as the need to consider alternatives to lighting.

State Standards, Guidance and Practice

We collected information from a number of states. This selection was based on several factors: states that Caltrans called out during the Preliminary Investigation kickoff and follow-up calls; a list of lighting guidance documents provided by Caltrans; states with large or complicated highways that might have lighting issues comparable to Caltrans'; states with members on AASHTO's Joint Technical Committee on Highway Lighting and the NTCIP Committee on Roadway Lighting; and participant states in NCHRP project 17-50, "Lead States Initiative for Implementation of the Highway Safety Manual."

California

Caltrans' guidance is provided for the sake of completeness. We have listed major chapter headers relevant to the subject of this Preliminary Investigation.

Caltrans Traffic Manual—Chapter 9, Traffic Signals and Lighting, 2002
www.dot.ca.gov/hq/traffops/signtech/signdel/chp9/chap9.htm

- Section 9-06 - Highway Safety Lighting
- Section 9-07 - Freeway Lighting
- Section 9-08 - Conventional Highway Lighting
- Section 9-09 - Highway Safety Lighting Development Procedures
- Section 9-10 - Highway Safety Lighting Design Standards
- Section 9-11 - Lighting Standards

Caltrans Highway Lighting Safety Benefits—Fact Sheet, 2013
This document (Appendix A to this Preliminary Investigation) presents an overview of highway lighting benefits, including statistics on daytime-versus-nighttime collisions and the safety impacts of lighting. It also describes Caltrans' ongoing Freeway Performance Improvement Initiative (FPII) Demonstration Program, a multiphase effort to test before-and-after safety effects of highway lighting installations in California and update state guidance documents for highway lighting based on program outcomes.

Colorado

CDOT Lighting Design Guide, 2006
http://www.coloradodot.info/business/designsupport/bulletins_manuals/CDOT%20Design%20Guide%2008-19-09.pdf/at_download/file
This manual notes that "The warrants described in this guide match those in the AASHTO Design Guide."

Correspondence
We corresponded by email with Colorado DOT's Dave Ruble, who wrote about the following topics.

- **Lighting design.** "CDOT has a Lighting Design Guide that does answer some of your questions regarding warrants and general design practices." (Note: See link above.)
- **Roles of municipalities and state DOT.** "There are specific laws within Colorado that require incorporated municipalities to maintain the lights on the highway system. Most of the municipalities have franchise agreements with the local utility companies, who in turn maintain the lights. CDOT will pay for the installation of lights within the incorporated municipalities, but the lights have to be the type that the local utility company will maintain. So it can be difficult to try new, innovative products like LEDs in these areas. The locals and the utility companies really drive the lighting design."

- **Lighting beyond municipalities.** "However, in the unincorporated portions of the state, CDOT owns and maintains the lighting systems. CDOT has decided to change all of the CDOT-owned lighting to LED roadway lights. In fact CDOT is currently building the first LED tunnel in the state, which is an 800-foot-long tunnel on I-70. I don't have a lot of information about the plan to change out the lights yet because there is currently an RFP that is being reviewed and the results are secret until the decision has been made on a supplier."

Florida

Correspondence
We corresponded by email with Florida DOT's Chester Henson, who wrote:

"There are only two established policies that we have in Florida."

- **Jurisdictional requirements.** "The first is that all lighting projects must meet the requirements of the Lighting Justification Procedure and that maintenance of the system has to be accepted by the jurisdictional agency unless the Department has accepted the maintenance responsibility."
- **100 percent interchange lighting policy.** "The second is that all interchanges on the Interstate highway system shall be lighted. That policy was only issued this year and it was based on the fact that only 54 of the 549 interchanges on the state highway system were not lighted. Although there is not a policy, nearly all of our six-lane limited-access facilities within large urban boundaries have continuous freeway lighting." Florida did not provide further background or motivation for this practice.

Illinois

Illinois DOT Bureau of Design & Environment Manual—Chapter 56, Highway Lighting, Revised 2013
http://dot.state.il.us/desenv/BDE%20Manual/BDE/pdf/Chapter%2056%20Highway%20Lighting.pdf
Illinois DOT's lighting guidelines are adapted in part from the AASHTO guidance and *NCHRP Report 152*. Sections of Illinois' manual that address the scope of this Preliminary Investigation include:

56-2 Guidelines for Justifying Highway Lighting
  56-2.01 Analyzing Highway Lighting Needs
  56-2.02 Freeways
    56-2.02(a) Continuous Freeway Lighting
    56-2.02(b) Complete Interchange Lighting
    56-2.02(c) Partial Interchange Lighting
    56-2.02(d) Crossroad Ramp Terminal Lighting

56-4 Lighting Projects (New)
  56-4.01 Determine Classifications and Justify Need

56-5 Lighting Design

Interview
We spoke with Mark Seppelt of Illinois DOT. He shared feedback on the following points:

- **Highway lighting in Illinois.** Illinois does "quite a bit of highway lighting." The agency typically adds lighting to complex highway scenarios and configurations. For more routine installations that only just meet warrants, the agency may or may not install lighting. "AASHTO's guide and our own both state that there is not a mandate for lighting even when warrants are met," he said.

However, meeting multiple warrant criteria does makes it more likely that lighting will be included in a project.

- For detailed information on **crash data and safety issues**, Seppelt suggested as a follow-up contact:

  Priscilla Tobias
  State Safety Engineer
  (217) 782-3568
  priscilla.tobias@illinois.gov

- **LED lighting.**
  - Illinois has done quite a bit of work on this topic in the past two to three years, including a multiphase research project evaluating roadway lighting. The research team is a year into the second phase of the research, and the agency is looking to develop a performance specification for lettings to install LED roadway lighting.
  - While the agency has been very active, there are still relatively few LED luminaires installed.
  - Illinois DOT would like to involve other DOTs in developing a multistate specification. The agency sent out a survey on this topic and heard back from a majority of states, with several expressing interest. Illinois would welcome participation from Caltrans.
  - For more information about these research efforts, Seppelt suggested contacting the principal investigator:

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    (217) 244-6288
    rbenekoh@illinois.edu

Minnesota

Minnesota DOT Traffic Engineering Manual, Chapter 10—Lighting of Traffic Facilities, 2007
http://www.dot.state.mn.us/trafficeng/publ/tem/2009/Chapter-10.pdf

Minnesota DOT Roadway Lighting Design Manual, May 2010
http://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway%20Lighting_Design_Manual2.pdf
Although the two publications above cover many of the same topics, per Sue Zarling at MnDOT (see interview below), the governing publication in Minnesota is the 2007 Traffic Engineering Manual. That manual addresses:

- Lighting Project Procedures, including warrants.
- Lighting System Design.
- Construction.
- Operation and Maintenance.

Warrants
MnDOT's warrants closely follow the 2005 AASHTO guide for highway lighting as well as lighting for roundabout intersections, tunnels, underpasses, rest areas, and signs.

Beyond highway applications, page 10-6 of the MnDOT traffic engineering manual notes that "the AASHTO Roadway Lighting Design Guide gives no specific warrants for continuous lighting of roadways other than freeways (roads with fully controlled access, no at-grade intersections)." However,

the MnDOT manual does suggest some general criteria that may apply when considering the installation of lighting. The MnDOT manual states that lighting of at-grade intersections is warranted "if the geometric conditions mentioned in the AASHTO *Roadway Lighting Design Guide* exist or if one or more of the following conditions exists as found in the Minnesota Traffic Engineering Manual:

1. Volume—The traffic signal warrant volumes for the minimum vehicular volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian volume warrant are satisfied for any single hour during conditions other than daylight, excluding the time period between 6:00 a.m. and 6:00 p.m.
2. Crashes—There are three or more crashes per year occurring during conditions other than daylight. Currently, thresholds for ratios of night to day crash rates are being developed for nonfreeway facilities. Check the Traffic Engineering Manual for updates.
3. Intersecting Roadway—The intersecting roadway is lighted.
4. Ambient Light—Illumination in areas adjacent to the intersection adversely affects the drivers' vision.
5. Channelization—The intersection is channelized and the 85th percentile approach speed exceeds 40 miles per hour. A continuous median is not considered as channelization for the purpose of this warrant.
6. School Crossing—Scheduled events occurring at least once per week during the school year make it necessary for 100 or more pedestrians to cross at the school crossing during any single hour in conditions other than daylight, or a traffic engineering study indicates a need for lighting.
7. Signalization—The intersection is signalized.
8. Flashing Beacons—The intersection has a flashing beacon."

Energy Conservation
MnDOT's manual calls out the following verbiage regarding energy conservation from the 1992 Minnesota Statute 216C.19: "After consultation with the commissioner and the commissioner of public safety, the commissioner of transportation shall adopt rules under chapter 14 establishing minimum energy efficiency standards for street, highway and parking lot lighting. The standards must be consistent with overall protection of the public health, safety and welfare. No new highway, street or parking lot lighting may be installed in violation of these rules. Existing lighting equipment, excluding roadway sign lighting, with lamps with initial efficiencies less than 70 lumens per watt must be replaced when worn out with light sources using lamps with initial efficiencies of at least 70 lumens per watt."

Correspondence and Interview
We contacted Sue Zarling, traffic electrical systems engineer with Minnesota DOT. Zarling wrote by email prior to our interview:

> "I contacted all of our districts to find out what they are doing. I can tell you what we say should be looked at in making the determination, but that isn't always what happens when you get out to the districts. Funding becomes a big issue in all of the decisions. Construction dollars are one thing, but the ongoing costs are really an issue.
>
> "We are beginning the process of rewriting the 2010 version of the Lighting manual you refer to. Typically that is done every 2 years, but we got a little behind. There have been a lot of changes since 2010, specifically in regards to the use of LED luminaires. We now have several approved LED luminaires for highway use, and our Metro District will install a few thousand of the luminaires in a section of their area over this next year."

During our follow-up discussion, Zarling made the following additional points:

- **MnDOT guidance documents.** MnDOT closely follows the AASHTO guidelines and has also drawn from the IES manual. The agency is working to bring the two state guidance documents listed above into conformity.
- **Highway lighting in Minnesota.** Funding is a key issue. Highways are lit more in the metro areas, but beyond these core areas, there is more partial interchange lighting.
- **Rural intersections; proactive design.** Zarling said, "One thing we're doing is putting in rural intersection lighting proactively. The installations are not based on crashes at a site, but more loosely when we see that a certain type of site has a configuration or traffic similar to others where there have been problems. We see this helping in some areas—it's another tool in the toolbox."
- **Move to LEDs.** MnDOT has been doing a lot of work and research on LEDs.
    - For a while the issue had been that no LEDs could provide the required light levels at the current freeway pole height (**40 feet**) and spacing (250 feet) equivalent to 250-watt high-pressure sodium (HPS) lamps. Now four products are currently approved for this application. The HPS bulbs had typically been replaced on a four-year cycle, and the state received funding to replace a fourth of the light heads in the Metro District with LEDs. The agency hopes to received continued funding to keep replacing light heads; by comparison, a typical life cycle for LEDs is 18 years.
    - MnDOT also has a specification for LEDs that are mounted at **49 feet** and replace its 400-watt HPS fixtures. There are three manufacturers on the approved products list right now.
    - The agency is working on the light level requirements for a **tower (high mast)** luminaire to replace its HPS high-mast lighting.
    - MnDOT also has an **underpass** specification with one manufacturer on the approved products list.
    - Zarling also cautioned that claims of energy savings with LEDs must be examined carefully, because sometimes reductions in energy use are due in part to reductions in light output.
- **New AASHTO guide.** Zarling believes that the next update to the AASHTO guidance may be predicated on how the committee chooses to address LED lights.
- **Additional contacts.** Zarling suggested the following experts as additional contacts:
    - Ron Gibbons at Virginia Tech, who is conducting lighting research. (See "Research" on page 24 for our interview with Gibbons.)
    - Paul Lutkevich, the IES member on the AASHTO Joint Technical Committee on Highway Lighting:

      Paul Lutkevich
      Parsons Brinckerhoff, Vice President and Technical Director
      (617) 960-4903
      lutkevich@pbworld.com

New Jersey

New Jersey DOT Roadway Design Manual
Last corrected August 2012
Section 11—Highway Lighting Systems
http://www.state.nj.us/transportation/eng/documents/RDM/sec11.shtm
Section 11.3.1, "Warrants for Highway Lighting," is based on the AASHTO design guide. Categories follow below. The "Additional Design Considerations" under Section E appear to be additional warrants not covered in the AASHTO design guide.

A. Continuous Freeway Lighting
B. Complete Interchange Lighting
C. Partial Interchange Lighting
D. Underdeck Lighting or Tunnel Lighting
E. Additional Design Considerations
    1. Ramps
        - Inside radius of entrance or exit ramp is less than 150 feet.
        - Accident data in the ramp area indicates a problem exists.
    2. Acceleration Lanes
        - Stop before acceleration lane.
        - Grade and/or curvature presents a visibility problem, which cannot be corrected through other means.
        - Sidewalks exist to permit pedestrians to cross at the entrance or terminal of a ramp.
    3. Main Line
        - Grade and/or curvature presents a visibility problem, which cannot be corrected through other means.
        - Bridges without shoulders.

        The designer shall obtain the accident data of the location in order to determine the night to day accident ratio. The ratio could dominate the determination if highway lighting is required.

Section 11.8, "Lighting at Intersections," states that all signalized intersections are to be illuminated, with lighting warranted for nonsignalized intersections if they meet any of these volume-based criteria from dusk to dawn:

1. Any right turn movement onto the highway greater than 75 vehicles per hour (VPH).
2. Any left turn movement onto the highway greater than 25 VPH per leg.
3. Through movement for the intersecting roadway greater than 50 VPH in either leg.

Cost and Energy Issues
Section 11.3.2, "Selection of Types of Highway Lighting," states that upon approval, the designer shall then address, analyze and compare such determining factors as initial installation cost, maintenance costs, and energy consumption costs of the remaining system(s).

New York State

New York State DOT Policy on Highway Lighting, December 1979 (reprinted November 1983)
https://www.dot.ny.gov/divisions/operating/oom/transportation-systems/repository/policylight.pdf
NYSDOT's highway warrants reference a 1976 AASHTO publication ("An Information Guide for Roadway Lighting") and a 1974 NCHRP Report ("Report 152: Guidelines for Roadway Lighting Based on Safety Benefits and Costs"). Like the current AASHTO guidelines, it addresses continuous lighting (page 8), interchange lighting (page 8), tunnels and underpasses (page 10), bridges and overpasses (page 10), and other highway features.

New York State DOT Highway Design Manual, Chapter 12—Highway Lighting, Revision 24, 1995
https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_12.pdf
This publication addresses design criteria and illumination procedures, as well as lighting equipment, configuration and hardware. It references the 1979 policy document for warranting.

New York State DOT Standard Specifications, 2008, updated to May 2013 letting
https://www.dot.ny.gov/main/business-center/engineering/specifications/english-spec-repository/espec5-2-13english_0.pdf
Section 670—Highway Lighting System addresses standard materials, construction, measurement and pay specifications for highway lighting.

Interview
We spoke with Norm Schips of New York State DOT. Schips shared the following points:

- **Highway lighting in New York.**
    - With regard to maintenance:
        - Consistent with the New York State Policy on Highway Lighting, in general, NYSDOT may install highway lighting but does not always maintain it; the agency enters into agreements with municipalities to energize and maintain lighting.
        - Lighting varies throughout the state, with highway lighting more common in urban areas such as New York City, Hudson Valley, Long Island, Buffalo and Rochester. However, few if any sections of the Interstate are lit in the Capital District, and Interstate lighting is not predominant statewide.
        - NYSDOT maintains parkway lighting in its Hudson Valley and Long Island Regions both internally and through contracts. Some other locations also perform maintenance of highway lighting, but on a smaller scale.
        - In most cases, highway lighting on conventional state highways is paid for by municipalities, but there is also a fair amount of lighting that is paid for by NYSDOT (for example, in the Central New York Region).
    - The state does limited guide sign lighting and is moving toward higher-intensity sign sheeting in lieu of guide sign lighting. Budgetary constraints are a significant factor in where lighting is used, and Schips has the impression that some other states do more lighting than New York.
- On the topic of how NYSDOT **screens/evaluates** its system to determine where and how highway lighting is needed, Schips said this is based on the Policy on Highway Lighting noted above.
- On the question of how NYSDOT **proactively designs** and implements lighting for new roads or lanes, Schips said this is also consistent with the Policy on Highway Lighting.
- **New technologies.** LEDs are the "topic of the day" among all DOTs, which are deciding whether to move toward LEDs (and why) and are considering what specifications will look like. New York has used LEDs "a little bit" so far.
- **Additional resources.** Schips pointed out that leading university institutes are conducting highway lighting research (see the section "Research Centers" below), and noted a 2011 survey of AASHTO members on highway lighting policies and practices (See "National Agencies and Organizations" above, under "AASHTO").

Oregon

Oregon Department of Transportation Traffic Lighting Design Manual, 2009
http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/traffic_lighting_design_manual.pdf
This manual references both the 2005 AASHTO *Roadway Lighting Design Guide* and the 2000 edition of the IES Lighting Handbook. This guide does not address warrants.

Oregon DOT Lighting Policy and Guidelines, 2003
http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/lighting_policy_and_guidelines.pdf

Energy, Safety and Traffic
On page 1 of the guide, it is noted that "In order to conserve energy while providing necessary lighting for motorist safety, crash rates and geometric layouts are the primary considerations for warranting lighting. Traffic volumes are a supplemental measure in evaluating warrants for lighting. In order to conserve energy while providing necessary lighting for motorist safety, crash rates and geometric layouts are the primary considerations for warranting lighting. Traffic volumes are a supplemental measure in evaluating warrants for lighting."

Warranting
For warranting, Oregon DOT follows 1984 AASHTO guidance, *An Information Guide for Roadway Lighting,* which immediately preceded the latest AASHTO design guide. The short Oregon publication details additions or exceptions to the 1984 AASHTO guidance.

The manual provides further details for the following highway types, addressing geometries, pedestrian/bicycle traffic, crash analysis, and other factors.

- Freeways and Freeway-Like Facilities (Expressways) with Full Access
- Highways Outside City Limits (Non-Freeways)
- Highways Inside City Limits
- Highways Inside City Limits

Correspondence
We corresponded by email with Ernest Kim, who answered our written inquiries.

We asked about:

- *Other ways Oregon DOT screens/evaluates its system to determine where and how highway lighting is needed. (Collisions? Other metrics detailed in state safety plans?)*
- *How Oregon DOT proactively designs and implements lighting for new roads or lanes. (Consideration of projected traffic volume? Other monitoring/screening methods?)*

Kim responded:

- "Usually it is done through case-by-case decisions for new roadway lighting design and installation, considering traffic volume, the nighttime accident rate, and necessity of lighting."
- "ODOT policy recommends the 'partial interchange lighting' method as standard. Unless a special condition is expected on the roadway, it is common design practice to follow the partial interchange lighting method, focusing on traffic merge and diverge points and intersections."
- "If it is a more complex interchange design, a higher light level may be considered within the range of the IES RP-8 (Roadway Lighting) recommendations."

We also asked about:

- *Any other items that might be relevant as Caltrans looks at its own warrants and practices: special consideration for particularly complex interchanges or lane geometries, new lighting technologies you're exploring—whatever might not be in Oregon DOT's formal documentation.*

Kim responded:

- "About new technology, ODOT is doing a few LED lighting replacement projects as pilot projects. The results are expected to be available in summer 2014."

Pennsylvania

Correspondence
We corresponded by email with Dave Rosenberger. His comments follow:

> **Traffic density; safety review.** "Interstate highway lighting in Pennsylvania is designed around the AASHTO *Roadway Lighting Design Guide*. Lighting warrants are analyzed and used in conjunction with the density of the area to determine partial interchange, complete interchange, or continuous lighting. Additionally, lighting may be recommended by a safety review committee for areas with high accident rates."

Texas

Texas DOT Highway Illumination Manual, 2003
http://onlinemanuals.txdot.gov/txdotmanuals/hwi/hwi.pdf
The chapters in Texas DOT's highway illumination manual include:

- Lighting Systems, Highway Eligibility, and Warrants
- Master Lighting Plans
- Lighting Agreements
- Lighting Equipment
- Lighting Design and Layout
- Electrical Systems
- Temporary Lighting
- Construction and Maintenance Guidelines

Interview
We spoke with Greg Jones, transportation engineer with Texas DOT. Jones is also a member of the NTCIP ELMS subcommittee.

Jones shared the following points:

- **Highway lighting in Texas.** Jones believes that, generally, California lights highways less than Texas.

- **Eligibility requirements.** Texas DOT's warrants expand upon AASHTO guidance in that there is a stated eligibility requirement for highway lighting. As noted in the process summary on page 2-3 of the agency's guide, a district must first establish eligibility of roadway lighting before establishing a warrant. Jones noted that all state highways are eligible for lighting classified as safety lighting (Chapter 2, Section 3, pages 2-7). If a highway is eligible for safety lighting, then the warrants can be applied to decide if lighting should be added. If there is a safety need for lighting, Texas DOT usually uses the Warrant Case SL-3 (Chapter 2, Section 3, pages 2-8 and 2-9). An example of eligibility criteria, in this case for "Continuous Lighting," follows:

The following roadways are eligible for continuous lighting systems:

- Urban freeways that are multi-lane divided facilities for which full control of access is provided
- Multi-lane arterial highways with partial control of access where the following conditions exist:
  - Access is provided to abutting property.
  - At-grade crossings are provided at minor streets and roads.
  - Where grade separation structures are provided at major crossings of arterial highways, streets, and roads.

- **Manual update.** Texas DOT's Highway Illumination Manual is undergoing revision, but the changes are expected to be minor.
- **Crash data analysis.** The ratio of night-to-day crashes is a warranting criterion that appears throughout Texas' manual, as drawn from AASHTO guidance. Jones noted that this kind of data is very hard to obtain and hard to use, and often the agency relies on "engineering judgment" as stated in the document.
- **Complex/novel geometries.** Jones indicated that the manual sufficiently addresses the road configurations that need to be lit on Texas highways.
- **New technologies.** Per Jones, LEDs are "coming along" in Texas. LED technology has just recently been able to perform similarly to existing highway lighting, and the state began trying LEDs within the last few years. Texas DOT will start the process of prequalifying LED products. The agency has also looked at adaptive lighting and conducted a few projects, but it hasn't really caught on. Texas DOT has tried plasma lighting too, but only at a few locations.
- **Underpasses.** Texas DOT has used 150-watt induction fixtures for underpasses. However, since these don't direct light well, they must be mounted over main lanes, which requires traffic closure for maintenance. Jones expects side-mounted directional LEDs to eventually take over as the technology of choice for underpasses.

Washington State

Washington State DOT Design Manual, June 2009, Chapter 1040—Illumination
http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1040.pdf
Section 1040.05—Required Illumination (page 1040-5) notes that "design matrices identify the following design levels for illumination on all Preservation and Improvement projects: basic design level, evaluate upgrade, and full standards." Design diagrams with prescribed geometries begin on page 1049-19 of the manual. Included among the designs are these related to highways:

(1) Freeway Off-Ramps and On-Ramps.
(2) Freeway Ramp Terminals.
(3) Freeway On-Ramps With Ramp Meter Signals.
(4) Freeway-to-Freeway Ramp Connections.
(5) HOT (High-Occupancy Toll) Lane Enter/Exit Zones.
(6) Lane Reduction.
(7) Add Lane Channelization.
(18) Safety Rest Areas.
(20) Tunnels.

In addition, Section 1040.05—Additional Illumination (page 1040-9) details conditions for additional illumination:

- Diminished Levels of Service.
- Nighttime Collision Frequency.
- Nighttime Pedestrian Accident Locations.

Further considerations are presented on pages 1040-10 to 1040-11 for highways, ramps, highway-to-highway ramp connections, and short tunnels/underpasses.

Interview

We spoke with Ted Bailey, Signals, Illumination & ITS Engineer. Bailey shared the following points:

- **Prescriptive program.** WSDOT's manual is based in part on lighting criteria in *IES RP-8-00: American National Standard Practice for Roadway Lighting*, though "in some ways WSDOT's point spacing and technical evaluation requirements are more prescriptive than IES." Bailey said that given his knowledge of Caltrans' practices, he believes that WSDOT's practices are likely more "restrictive and prescriptive."

- **Agency issues/state safety plan.** WSDOT is actively looking for ways to put out the "least amount of light possible" while still meeting design manual standards. The agency's current strategy is to consider installing LEDs at locations where lighting currently doesn't meet standards and the replacement technology will be as good or better. Bailey noted that WSDOT is moving toward the AASHTO Highway Safety Manual SafetyAnalyst approach, which requires data-based evidence for implementing safety changes.

- **Illumination reform.** Bailey provided Appendix B, which provides "an overview of WSDOT's illumination reform efforts. This is a working document that is intended to coordinate work related to illumination asset management." Items include:

    - Five LED projects under way in Washington.
    - A $125,000 research project on illumination for state highways, scheduled to begin in July 2013 with the University of Washington. The fact-finding project will help establish national practices on lighting among state DOTs.
    - Illumination asset management—defining and capturing information on current assets.
    - Illumination Asset Management Steering Committee—finalizing the six-year, $15.5 million project list for illumination; revising the design manual; developing new product evaluation.
    - Project delivery guidance—LED equipment specifications.

- **New technologies**
    - With adaptive lighting technology, LED lighting levels can adjust to actual traffic. Bailey discussed the LED Adaptive Lighting project at US 101 Black Lake Blvd Interchange. It is also summarized in a press release at http://www.wsdot.wa.gov/News/2013/04/19_LED_phase_two.htm. WSDOT can discuss further with Caltrans the other state agencies that have expressed an interest in this work.
    - Whiter/brighter lights could possibly lead to revised uniformity and light-level requirements.

- **Research**. In addition to the University of Washington study noted in "Illumination Reform" above, WSDOT would also be open to considering pooled fund efforts with states like California in seeking common solutions or standards.

Research

Although state lighting practice and policy were the primary interest for this Preliminary Investigation, we have also provided a brief section on current research directions. Below we describe three leading U.S. research centers on highway lighting and present nine relevant research citations.

Research Centers

Virginia Tech Transportation Institute
www.vtti.vt.edu/research/cibss/index.html
The institute's Center for Infrastructure-Based Safety Systems addresses highway lighting among other areas:

> Researchers with the Center for Infrastructure-Based Safety Systems (CIBSS) focus their endeavors on roadway-based safety systems such as lighting, visibility treatments, pavement markings, signage, signals, barriers, the interaction of visibility with roadway design and weather considerations. The goal of CIBSS is to conduct research and development efforts that advance knowledge and provide solutions to real-world issues.

Interview
We interviewed Ron Gibbons, director of Virginia Tech's Center for Infrastructure-Based Safety Systems (two research citations of Gibbons' are noted under "Research and Publications" below).

- **LED lighting.** Gibbons described LEDs as the "biggest thing going on now" in roadway lighting technology. He said that LED technology is getting to a level where it's a suitable option for a lot of applications, including highways. Discussion points related to LEDs include:
    - **Color temperature**
        - The very near-white light of LEDs, compared with the amber light produced by traditional HPS lamps, can impact drivers' and pedestrians' visual perception and lighting requirements.
        - Gibbons noted that mesopic factors have not shown a significant impact for major highways.
    - **Lighting control**
        - **Optical control**, to prevent light trespass and light pollution—particularly compared with older "glare bomb" type lights
        - **Electrical control**, with adaptive lighting that uses the "instant on" and dimming features of LEDs to help save energy. Gibbons cited a transition to controlled LED lighting in the city of Los Angeles.
- **"Street" vs. "roadway" lighting.** Gibbon noted a growing trend toward distinguishing between lighting for streets (which involve an interaction of vehicles and pedestrians) and lighting for roadways (which involve only vehicles). Drivers have different lighting requirements and visual tasks in the different scenarios, and making a distinction between these two types of lighting is becoming more common.
- **Research in progress.** Gibbons is working on an FHWA strategic research initiative addressing reduced highway lighting on roadways.
    - Gibbons said that adaptive lighting could yield energy savings of 25 to 75 percent nationwide. The lower figure of 25 percent would equate to $1.5 billion per year in the United States.

- Gibbons, like Frazer (see the interview on page 24 of this Preliminary Investigation) noted the possible legal ramifications of reduced lighting as one of the motivations for research on this topic.
- A report is expected in September of this year. The FHWA contact for this research is:

  Craig Thor
  FHWA Office of Safety Research and Development
  (202) 493-3338
  craig.thor@dot.gov

Rensselaer Polytechnic Institute Lighting Research Center, Troy, New York
http://www.lrc.rpi.edu/programs/transportation/index.asp
Transportation Lighting is one of several program areas listed as part of the center:

> The Transportation Lighting and Safety group at the Lighting Research Center evaluates solutions for improving lighting, visibility, safety and security on vehicles, roadways, airplanes and runways, and in the workplace. Lighting is an important part of the safety toolbox, and rapid developments in lighting technologies demand new approaches for more efficient and effective use of energy to meet demands for safety in transportation and the workplace while reinforcing environmental stewardship. The LRC's approach of carrying *science to safety* is evidenced by the LRC's focus not only on a basic understanding of how we see, but also on real-world, field evaluations and demonstrations of sound approaches that have tangible benefits.

The scope of the center's research includes roadway lighting, safety beacons, and vehicle headlamps.

Texas A&M Transportation Institute, College Station, Texas
http://tti.tamu.edu/group/visibility/research-areas/lighting/
One of the research areas under TTI's Visibility program is "Lighting":

> TTI researchers are investigating many aspects of visibility and lighting as new technologies are developed and innovative applications are designed. For example, TTI researchers have evaluated the impact of overhead lighting and on-coming headlight glare on the legibility of traffic signs. TTI has also studied the impact of roadway lighting on pavement marking visibility. As the use of light emitting diodes (LEDs) increases, TTI is using its unique facilities and photometric measuring devices, including its Visibility Research Laboratory, to assess how to measure the reported improvements in visibility from adding LEDs to existing traffic control devices. Between staffing and state-of-the-art equipment, TTI is and will continue to remain one of the premier leaders in transportation-related lighting research.

Research Publications

"Exploratory Evaluation of the Impact of Spectral Power Distributions on Driver Performance,"
Ronald Gibbons and Jason Meyer, Virginia Tech Transportation Institute, *Transportation Research Board 92nd Annual Meeting Compendium of Papers*, 2013
Citation at http://pubsindex.trb.org/view/1242216
Per the abstract: "The purpose of this project was to provide an initial investigation into the effects of different light source spectral distributions on detection and color recognition of roadway objects and pedestrians. This project included an investigation of both the light source spectrum from the overhead lighting spectrums as well as that from the vehicle headlamp. In order to investigate this, high-pressure sodium (HPS) and light emitting diode (LED) overhead lighting systems were considered, as well as headlamps filtered to resemble LED and the amber HPS sources. The detection and color recognition of

pedestrians and wooden targets were evaluated by driver participants under controlled combinations of overhead and headlamp lighting using a similar protocol to studies that have already been performed at the Virginia Tech Transportation Institute. The main conclusions from this investigation indicate that: 1) There is not a significant difference between the spectrum of the vehicle headlamps selected in terms of the detection of pedestrians and targets located immediately alongside the roadway. 2) Overhead lighting is a significant factor in the detection and color recognition of pedestrian clothing, but results indicate it's the intensity not necessarily the color of the lighting that makes it a significant factor. 3) Spectral components of overhead lighting and headlamp lighting may play a much more significant role in pedestrians located peripherally, rather than strictly along the roadway."

Guidelines for Continuous and Safety Roadway Lighting, H. Gene Hawkins, Texas A&M Transportation Institute, 2012
Research summary: http://library.ctr.utexas.edu/hostedPDFs/txdot/psr/6645.pdf
This research summary states that "During the late night and early morning hours, the hourly traffic volumes on a road can be less than 1 percent of the ADT, raising the question as to the benefits of keeping the roadway lighting on during such low-volume conditions. … The research team evaluated the benefits of a freeway lighting curfew through the conduct of several research activities, the most significant of which included an evaluation of freeway crash records to evaluate the impact of turning off freeway lighting during some portions of the late-night and/or early-morning hours. …

"The research team recommended that freeway lighting curfews be limited to locations and time periods where the traffic volumes are 100 vehicles per hour per lane or less. Due to the potential impact of alcohol on traffic safety, initial implementation of lighting curfews should not begin before 2:00 a.m. or at all on Friday or Saturday nights. Lighting curfews should not include locations where lighting was installed with safety funds or on the basis of a safety study. Lighting curfews may also need to be suspended for unique situations such as special events, weather events, and evacuations."

New Lighting Technologies and Roadway Lighting: An Informational Brochure, Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, 2012
https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-10-14_RoadwayLighting-InformationalBrochure.pdf
This short publication discusses new options for roadway lighting and "provides some information about these developments and how they might be incorporated into lighting practices for several types of roadways and locations in New York State."

New Technologies and Opportunities in Roadway Lighting, Ronald Gibbons, Transportation Research Board 90th Annual Meeting Presentation, 2011
http://amonline.trb.org/1683t1/1
This presentation provides an overview of the issues related to new highway lighting technologies, including alternative light sources (LED, induction, fluorescent lamps) and adaptive lighting.

Guidelines for Roadway Lighting Based on Safety Benefits and Costs, NCHRP project 05-19, 2009
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=878
This project was terminated in 2009 because "Few states have used *NCHRP Report 152* (*Warrants for Highway Lighting*, 1974) for evaluating lighting requirements because the warrants are difficult to implement and the agencies do not have the required accident-history data. Furthermore, these and other current lighting warrants address existing facilities only and do not provide sufficient guidance for determining the requirement for lighting on new roadway facilities."

Despite the early termination of the project, three project deliverables are available:

- **Literature Review: Review of the Safety Benefits and Other Effects of Roadway Lighting**
  http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP05-19_LitReview.pdf
  The abstract of this literature review states that "a number of studies on the effects of roadway lighting on safety, crime, perceptions of security, economic development and light pollution are summarized. There is a good amount of variability among published findings, and most likely there are biases that tend to inflate the benefits of roadway lighting in terms of nighttime crash reduction and crime reduction. Nonetheless, the literature reviewed in the present report suggests that roadway lighting can contribute to reductions in nighttime crashes and to reductions in crime."

- **Analysis of Safety Effects for the Presence of Roadway Lighting**
  http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP05-19_SafetyReport.pdf
  This report presents "a statistical analysis to evaluate the association between the presence of fixed roadway lighting and crashes at intersections, interchanges, and along freeway segments. Electronic roadway inventory data were appended to crash and lighting presence data from several state transportation agencies. The presence of roadway lighting, geometric design, and traffic control features were included in statistical models of nighttime and daytime crash frequency. Night-day crash ratios from negative binomial regression and log-linear models were compared to night-day crash ratios computed only from crash data.

  "The results indicate that the night-day crash ratios are lower at intersections with fixed roadway lighting when compared to intersections without lighting, when controlling for various roadway and traffic control features present at intersections. When computing the night-day ratios at interchanges and along freeway segments, it could not be concluded in the present study that the presence of fixed roadway lighting is associated with a statistically significant reduction in the night-day crash ratio."

- **Analysis of Visual Performance Benefits from Roadway Lighting**
  http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP05-19_VisibilityBenefits.pdf
  "Several analyses of the visual performance of drivers under different roadway lighting conditions were conducted using simulations based on photometrically accurate lighting software. The analyses assessed the role of different lighting characteristics as they affect visibility for drivers of different age groups. Analyses were conducted using the relative visual performance model, a model of suprathreshold visibility based on the luminance contrast, background luminance, and size of a visual target. In general, the analyses were consistent with the notion that lighting generally improves visibility and by inference, safety, when it provides illumination where potential hazards are likely to be located."

"Effects of Road Lighting: An Analysis Based on Dutch Accident Statistics 1987–2006," Per Ole Wanvik, *Accident Analysis & Prevention*, Vol. 41, No. 1, Jan. 2009: 123-128.
http://www.sciencedirect.com/science/article/pii/S0001457508001917
The abstract states that "this study estimated the safety effect of road lighting on accidents in darkness on Dutch roads, using data from an interactive database containing 763,000 injury accidents and 3.3 million property damage accidents covering the period 1987-2006. Two estimators of effect are were, and the results were combined by applying techniques of meta-analysis. Injury accidents were reduced by 50 percent. This effect was larger than the effects found in most of the earlier studies."

Lighting for Driving: Roads, Vehicles, Signs, and Signals, Peter R. Boyce, CRC Press, 2009.
http://www.worldcat.org/title/lighting-for-driving-roads-vehicles-signs-and-signals/oclc/166358367
Chapter 4 of this handbook is "Road Lighting." Sections include The Technology of Road Lighting, Metrics of Road Lighting, Road Lighting Standards, Road Lighting in Practice, Spectral Effects, and The Benefits of Road Lighting.

"Safety of Motorway Lighting," Jean-François Bruneau, Denis Morin and Marcel Pouliot, *Transportation Research Record 1758*, 2001: 1-5.
http://trb.metapress.com/content/7603602814156234
In this research, "the safety aspects of motorway lighting and its capacity to prevent nighttime accidents were examined. The analysis was based on a night/day accident rate ratio method to compare the safety benefits of two alternatives to dark motorways: continuous lighting and interchange lighting alone. Various sources of data were used to calculate night/day accident rate ratios, such as traffic volume records, accident databases, and field surveys. Three categories of accidents were used: fatal and injury accidents, property damage only, and all accidents. The results were similar to those from recent literature. Continuous lighting reduces the overall accident rate by 33 percent ($p < 0.001$) in comparison with interchange lighting alone and by 49 percent ($p < 0.05$) compared with dark motorways. Furthermore, a breakdown by categories of average daily traffic for these comparisons revealed that accident reductions are still valid regardless of traffic flow."

Warrants for Highway Lighting, N. E. Walton and N. J. Rowan, *NCHRP Report 152*, 1974
Citation at http://trid.trb.org/view.aspx?id=25610
Although this NCHRP reference is nearly 40 years old, it is still cited in states' current lighting manuals as a resource. Per the abstract, "The report presents a design process for highway lighting, based on the concept that the purpose of lighting is to improve nighttime visual communications efficiency through provision of the motorist's informational needs, which are classified on the basis of varying geometric, operational and environmental conditions within the highway system. A priority model has been developed based on lighting effectiveness, vehicles or people served, light intensity, size of facility, and annual costs. The report illustrates how to apply the process and how to make cost-effectiveness evaluations of lighting-design alternatives."

HIGHWAY LIGHTING SAFETY BENEFITS - FACT SHEET

June 17, 2013

- **The purpose of highway lighting is to attain a level of visibility which enables motorists to see quickly, distinctly, and with certainty all significant of the highway (its direction and surroundings) and any obstacles on or at the entrance of the highway. Visibility is a very important component of traffic safety.**

- Nationwide accident statistics show that more than **50 percent of fatal collisions occur during the hours of darkness**. Because only 25 percent of travel occurs during the same period, **the fatality rate is about three times higher at night** than during the day.

- The investment of public funds in highway lighting returns benefits to the public in several ways**. Lighting benefits motorists by improving their ability to see highway geometry and other vehicles. This results in greater driver confidence and improved safety, particularly in inclement weather**. Lighting may also improve highway capacity.

- Highway lighting is **proven safety countermeasure to improve traffic safety. Various** research and studies **suggested that the addition of lighting could reduce 20 to 60 percent DARK collisions.** Research has demonstrated that lighting improves driver performance during critical peak and "peak shoulder" periods when volumes, speeds and lane changing are high.

- **Highway lighting has had a tremendous affect on severe collision numbers and rates when installed in corridors (in other states) and along shorter freeway segments in California metropolitan area freeways.**

- Caltrans Freeway Performance Improvement Initiative (FPII) - Demonstration Program (Phase 0) **had pilot projects completed in District 3 and District 12 where highway lighting were installed on lineal freeway segments either on curve or tangent alignment. BEFORE / AFTER studies were conducted and the results show significant DARK collisions reduction benefits:**

Caltrans Freeway Performance Improvement Initiative (FPII) - Demonstration Program (Phase 0)

- **D3, SAC-51, PM 5.100 / PM 5.899 – "Marconi Curve" Project (EA# 03 – 2E9004)**
  Install Highway Lighting & Open Graded AC

  BEFORE (from 11-01-2006 to 08-30-2008):
  DARK = 72; WET = 61; ALL = 155; FAT = 1; INJ = 64
  AFTER (from12-01-2008 to 09-30-2010):
  DARK = 25; WET = 17; ALL = 76; FAT = 1; INJ = 30
  65% reduction in DARK collisions and 72% reduction in WET collisions.
  53% reduction in DARK - Injury collisions and 51% reduction in ALL collisions.

"MARCONI CURVE" - Location 1: WITHOUT LIGHTING (BEFORE)

“MARCONI CURVE” - Location 1: WITH LIGHTING (AFTER)

“MARCONI CURVE” - Location 2: WITHOUT LIGHTING (BEFORE)

“MARCONI CURVE” - Location 2: WITH LIGHTING (AFTER)

“MARCONI CURVE” - Location 3: WITHOUT LIGHTING (BEFORE)

“MARCONI CURVE” - Location 3: WITH LIGHTING (AFTER)

Caltrans Freeway Performance Improvement Initiative (FPII) - Demonstration Program (Phase 0)

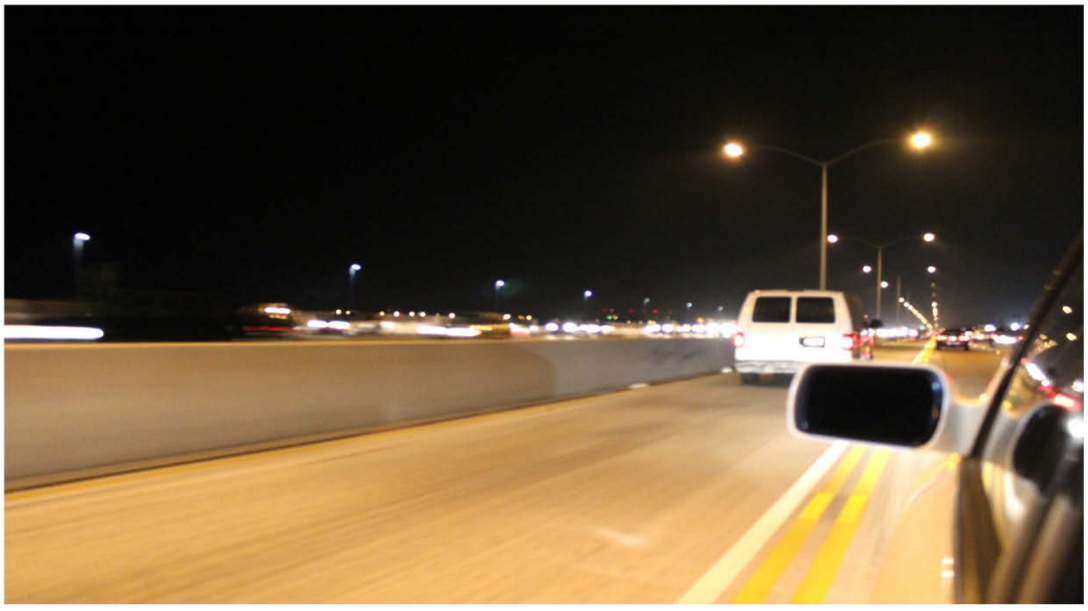
- **D12, ORA-405, PM 20.8 / PM 23.1: Median Highway Lighting (EA# 12 – 0G6904)**

  BEFORE (Investigations started 01-01-2000 to 06-30-2007 Const. last quarter):
  DARK = 597; FAT = 16; INJ = 161
  AFTER (Construction finished 11-21-2007 to current available data of 06-30-2011):
  DARK = 251; FAT = 2; INJ = 47
  88% reduction in DARK – Fatal collisions.
  71% reduction in DARK – Injury collisions *a*nd 58% reduction in total DARK collision

ORA – 405, PM 20.8 / PM 23.1 Median Lighting

ORA - 405 Safety Lighting Project

WITHOUT LIGHT



WITH LIGHT

- **Caltrans Freeway Performance Improvement Initiative (FPII) Demonstration Program (Phase 1)** continues based on the success of (**Phase 0)** with the participation of 9 Caltrans Districts (3, 4, 5, 6, 7, 8, 10, 11 12).

- **FPII – Demo Program (Phase 1)** identified freeway corridors for investigations via Collision Analysis and Screening Efforts of the Strategic Highway Safety Plan – Challenge Area 5 (SHSP - CA5). There were 22 Freeway Corridors selected for investigation in 9 Caltran Districts. As a result, 11 safety improvement projects ($56 million) were initiated and **Highway Lighting** is one of the **Primary Counter Measures recommended** to mitigate the DARK concentration of fatal and severe injury collisions.

  - D4, ALA-580, PM R0.393 / PM R5.90 (b/w JCT-205 and Flynn Road).
  - D5, SB-101, PM 13.48 / PM 22.53 (b/w Garden Street and Fairview Ave).
  - D6, KER-9, PM 23.10 / PM 27.32 (b/w Bella Terrace OC and Minkler UP Bridge).
  - D7, LA-105 at LA-110 Interchange.
    LA–105 at LA-710 Interchange.
  - D8, SBD-10 (b/w Ontario Airport and JCT-15).
    RIV-60 (b/w SBD Co line and JCT-215).
  - D10, STA-99, PM R11.7 / PM R15.0 (b/w Whitmore Ave and Tuolumne Blvd)).
  - D11, SD-78 (b/w JCT-5 and JCT-15).
  - D12, ORA-91 at ORA -55 Interchange.

- Caltrans Traffic Operations is in the process to update the Highway Lighting Policy which will guide our practices to improve the safety and reliability of complex California metropolitan freeway systems during the hours of darkness.

- Pending the new update Highway Lighting Policy, Caltrans Traffic Operations will utilize the proven safety benefits of Highway Lighting projects from our Freeway Performance Improvements Initiative (FPII) to guide our practices. In addition to Caltrans Traffic Manual Chapter 9 and Caltrans Highway Lighting Guidelines, Caltrans Traffic Operations will also consult with the following publications regarding Highway Lighting issues:
  - **AASHTO** – Roadway Lighting Design Guide (October 2005), Chapter3, Section 3.2: Warrants Conditions for the Continuous Freeway Lighting.
  - **FHWA - Highway Safety Manual** (13.13.2.1): guidelines for the crash effects (CMFs) of providing Highway Lighting.
  - **NCHRP-152**, and other **States** (Oregon, Minnesota…) offer specific warrants / guidelines for Continuous Highway Lighting.

- There are lighting products and technologies currently available to address the energy usage, and maintenance life cycle cost plus other concerns such as: worker safety and operational delay caused by maintenance activities.

  - High Pressure Sodium (**HPS**) light has general service life of 20,000 hrs (5 years if used 10 hrs/day). HPS light is currently in usage on CA Hwy Systems.

  - Light-Emitting Diode (**LED**) light has general service life of 50,000 hours (14 years if used 10 hrs/day) with energy saving up to 60% comparing to HPS light. **Caltrans is replacing the HPS with LED when the HPS bulbs burned out.**

  - **INDUCTION** light has general service life of 100,000 hours (up to 30 years). (Installed on Imperial Highway (SR-90) in the City of Brea, Orange County).

Washington State Department of Transportation

Illumination Reform Overview:

The purpose of this document is to provide an overview of WSDOTs illumination reform efforts.This is a working document that is intended to coordinate work related to illumination asset management.

1. LED Projects Underway*(See SharePoint Site – Underdevelopment, for more information)*
   a. US 101 Black Lake Blvd Interchange LED Adaptive Lighting Retrofit
   b. SCR – Indian John Hill Rest Area (I-90 Near Ellensburg)
   c. OR – I-5 / 93rd Ave interchange
   d. ER – I-90 Spokane; P3 projects (1 project includes High Mast LED Luminaires)
   e. NWR – I-5 & 116th St NE Interchange SPUI in Marysville – 30 to 40 light standards
   f. NCR – SR 150 in the City of Chelan Vicinity

2. Illumination for State Highways Research (July 1, 2013 to December 31st, 2014) – *Lead: Ted Bailey*

Microsoft Word 97 - 2003 Document

3. Illumination Asset Management – *Lead: Chris Erickson*
   a. SiMMS Steering Committee- Defining and capturing existing illumination system asset information.
4. Illumination Asset Management Steering Committee – *Lead: Ted Bailey*
   a. Finalizing the 6yr (15-17 to 19-21 biennium's) P3 Major Electrical ProgramThe project list includes $15.5 million for illumination projects.
   b. Reviewing *Design Manual* Chapter 1040-Illumination requirements.
   c. Developing a new products evaluation process for LED luminaires
5. Project Delivery Guidance – *Lead: Keith Calais*

a. LED Equipment Specifications (Use Proprietary and/or short list of "prequalified products" ONLY, DO NOT USE performance specifications for the time being.) Contract HQ Traffic Operations for guidance.
b. LED Technology and Project information
    i. SharePoint web site (Underdevelopment) *–Lead: Michele Villnave*