CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 15-001
UILU-ENG-2015-2001
ISSN: 0197-9191

LED Street Lighting Evaluation—Phase II: LED Specification and Life-Cycle Cost Analysis

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Research Report No. FHWA-ICT-15-001
A report of the findings of
ICT-R27-123
Street Lighting Technologies—LED Street Lighting Evaluation, Phase II

Illinois Center for Transportation

January 2015

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-15-001		

4. Title and Subtitle	5. Report Date
LED Street Lighting Evaluation—Phase II: Led Specification and Life-Cycle Cost Analysis	January 2015
	6. Performing Organization Code
7. Author(s) Rahim F. Benekohal, Christopher Gregerson, and Juan Medina	8. Performing Organization Report No. ICT-15-001 UILU-ENG-2015-2001
9. Performing Organization Name and Address Illinois Center for Transportation Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 N. Mathews Ave., MC-250 Urbana, IL 61801	10. Work Unit No. (TRAIS) 11. Contract or Grant No. R27-123 (Phase II)
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 E. Ash St. Springfield, IL 62704	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Phase II of this study focused on developing a draft specification for LED luminaires to be used by IDOT and a life-cycle cost analysis (LCCA) tool for solid state lighting technologies. The team also researched the latest developments related to dirt depreciation factors for LED luminaires and other general developments on solid state lighting. A final draft specification was developed that included best practices from states and cities that already had their own specification, as well as feedback from several state DOTs staff, a few experts in roadway lighting, and six LED luminaire manufacturers. This process is recommended for the development of future specifications. A spreadsheet to conduct LCCA based on net present value was also developed. The spreadsheet contains unit costs of typical items used in roadway lighting projects, and it is completely customizable by the user. The life-cycle cost of HPS, LED, plasma, and induction lighting designs can be compared side by side in the output table. There are significant trade-offs between larger initial investments for LED and lower maintenance/light consumption costs over the life of the project. Presently, LED lighting does not offer significant cost advantages over other technologies used in highway lighting in most of the four scenarios analyzed. However, assuming re-lamping and re-ballasting cycles of 4 years for HPS, and a cost of $845 per LED luminaire (half of current cost reported by IDOT), HPS and LED produced the most economical lighting solutions with the exception of the conventional interchange project in which LED was 8.3% more expensive than HPS. Ongoing dirt depreciation research and trends in the lighting industry, such as adaptive lighting, should be monitored to take advantage of developments and to ensure that the most qualified products are specified and purchased. In addition to LCCA, other factors may also be considered in deciding which type of luminaires to use.

17. Key Words	18. Distribution Statement
LED, HPS, plasma, CMH, solid state lighting, state specification, roadway luminaire, life-cycle cost, net present value, dirt depreciation factor	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	64 pp. + appendices	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENT, DISCLAIMER, MANUFACTURERS' NAMES

This publication is based on the results of ICT-R27-123, **Street Lighting Technologies—LED Street Lighting Evaluation, Phase II.** ICT-R27-123 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation, Division of Highways; and the U.S. Department of Transportation, Federal Highway Administration.

Members of the Technical Review Panel were the following:

- Mark Seppelt, IDOT – Chair
- Yogesh Gautam, IDOT
- Randall Laninga, IDOT
- Filiberto Sotelo, IDOT (replaced Dave Piper)
- Ryan Sheley, IDOT (replaced Mike Ripka)
- Steven Gobelman, IDOT (replaced Craig Mitckes)
- Tim Peters, IDOT (an invited guest)
- Joseph Vespa, IDOT
- Bernie Griffin, IDOT (replaced Dennis Huckaba)
- Dean Mentjes, FHWA
- Joseph Cheung, FHWA (replaced Carl Andersen)

It should be noted that the TRP considered it important to have industry experts in on the panel and asked Dr. Ron Gibbons and Paul Lutkevich to join. Dr. Gibbons was involved from the beginning of the Phase II study and Mr. Lutkevich joined the panel after the Street and Area Lighting Conference held on September 8 to 11, 2013.

EXECUTIVE SUMMARY

This report presents the findings and conclusions of Phase II of the LED roadway lighting study conducted by the University of Illinois. Phase II mainly focused on tasks leading to the development of two products: a draft specification document for LED luminaires to be used by IDOT, and a life-cycle cost analysis (LCCA) tool for solid state lighting technologies. The team also researched the latest developments related to dirt depreciation factors for LED luminaires, as well as the state-of-the-art luminaires using other technologies such as plasma, ceramic metal halide (CMH), induction, and further improvements to high pressure sodium (HPS).

The process used in developing this specification was unique, and that resulted in a comprehensive specification. This preliminary version of the specification was drafted based on “best practices” of the states and cities that already had their own specification. Then, the researchers worked with the project’s TRP to develop a draft version of the specification. Feedback on the draft version was obtained from several state DOTs staff, a few experts in roadway lighting, and six LED luminaire manufacturers. Then, a final draft specification was developed which is a comprehensive specification that incorporates different perspectives and is expected to fit the needs of IDOT. This process proved to be successful and it is recommended for the development of future specifications.

The research team also developed a spreadsheet to conduct LCCA. The analysis is based on the net present value of the project for a given design period, and conforms to the guidelines in the latest *Recommended Practice for the Economic Analysis of Lighting* (IES RP-31-14). The spreadsheet contains unit costs of typical items used in roadway lighting projects along various types of roadways. The user can include any additional items if needed or use different values for items such as the price of electricity, inflation rate, re-lamping periods, etc. The life-cycle cost of HPS, LED, plasma, and induction lighting designs can be compared side-by-side in the output table.

This report includes examples of LCCAs for four different facilities (a freeway segment, an interchange with standard and high mast poles, and an urban arterial) using lighting designs provided by IDOT engineers for each of the facilities and lighting technologies. Results show the following:

- There are significant trade-offs between larger initial investments for LED and lower maintenance/light consumption costs over the life of the project.

- The total costs over the life of a project (in their net present value) are very sensitive to input values related not only to the luminaire costs but also to the agency’s policies regarding maintenance (re-lamping and re-ballasting).

- LED lighting has seen a significant reduction in cost during the life of this project, if this trend continues LED lighting may be more competitive with other technologies.

- Presently, LED lighting does not offer significant cost advantages over other technologies used in highway lighting in most of the four scenarios. However, assuming re-lamping and re-ballasting cycles of 4 years for HPS, and a cost of $845 per LED luminaire (half of current cost reported by IDOT), HPS and LED produced the most economical lighting solutions in the four scenarios with the exception of the conventional interchange project in which LED was 8.3% more expensive than HPS.

In addition to LCCA, other factors may be considered in deciding which type of luminaire to use. Those factors may include glare, color rendering, visibility, safety benefits, future directions in lighting

technology, preference of the public and other stakeholders, direction and level of encouragement from top managers and policy makers, aesthetics and appearance of the project, etc.

Current knowledge on dirt depreciation factors is evolving. Ongoing dirt depreciation research and trends in the lighting industry, such as adaptive lighting, should be monitored to take advantage of technological developments and to ensure that the most qualified products are specified and purchased.

CONTENTS

CHAPTER 1 INTRODUCTION

Phase I of this study focused on field testing of selected light-emitting diode (LED) luminaires for street lighting and their comparisons with high-pressure sodium (HPS) luminaires. It evaluated three promising streetlight LEDs from three different manufacturers. Four units from each of the three LED manufacturers and four units from one HPS manufacturer were obtained and installed on a regular two-lane roadway in Rantoul, Illinois, near the University of Illinois.

The luminance and illuminance levels of the luminaires were measured in the field using the procedure recommended by IES in RP-8. The field data were also compared with the values computed from the commercially available lighting software (AGi32) supplied by Lighting Analysts, Inc. The two-volume report from Phase I has been published and it can be downloaded from ICT website (https://apps.ict.illinois.edu/projects/getfile.asp?id=3066 and https://apps.ict.illinois.edu/projects/getfile.asp?id=3067).

The Phase I study provided very useful information about performance of LED roadway luminaires, determined the feasibility of using LED luminaires on typical IDOT roadways, and determined ways to save energy and reduce the frequency of maintenance through the use of LEDs. While the field evaluation answered many questions for IDOT, there were still several items that remained to be addressed.

Phase II of the study is aimed at answering those questions and providing IDOT with a draft specification that can be used for future projects for which LED luminaires will be installed. The main objectives of Phase II are as follows:

- Develop a proposed LED luminaire specification for IDOT.
- Develop a life-cycle cost analysis (LCCA) tool for solid state lighting (SSL) technologies (which include LEDs) and their comparison from an economic stand point.
- Research and keep track of the latest developments in lumen dirt depreciation factors for LEDs.
- Keep track of new developments in SSL technologies.

This report presents the activities conducted, as well and the findings and products of Phase II of the study. The main product of this study is a proposed LED specification for roadway luminaires. It describes how the initial efforts were directed at gathering information to determine the current state-of-practice of all states and major cities. This information was essential to develop a first draft of the specification, which was discussed several times with the Technical Review Panel for this project, and then with representatives of several departments of transportation, consultants, and manufacturers. The result is a product that has evolved based on a significant amount of feedback from stakeholders of different perspectives. A copy of the proposed LED luminaire specifications is included in Appendix A.

The research team developed a tool in the form of a spreadsheet to perform LCCA. This tool is in line with the recent IES recommendations (contained in RP-41-14) on how to perform an economic analysis of a lighting project. It uses the net present value (NPV) analysis method. The LCCA tool allows users to incorporate standard items and unit cost for projects along various types of roadways, e.g. freeway segments, interchanges, and intersections. It also allows the user to adjust for depreciation, re-lamping, and ballast replacement costs, as well as costs related to entire luminaire replacements. The spreadsheet is customizable by the user to include the most relevant items and their costs, cost of electricity, inflation rate, and any other element that affects the outcome of an LCCA. This flexibility allows the user to obtain realistic numbers that reflect the latest costs and benefits. The main output is the total cost of the project for the entire analysis period using the input designs generated by the engineer. This allows for direct comparison of different technologies and it is expected to serve as a decision support tool for IDOT. A more detailed description of the tool is provided in Chapter 4 and in the instruction file that is delivered with the spreadsheet.

Results of case studies in which luminaire designs were created for different technologies at a freeway segment, an interchange with regular poles and high mast, and an urban intersection along an arterial are also presented and discussed in this report.

Information gathered through surveys, teleconferences, site visits, conferences, and meetings provides a general overview of the trends in the lighting industry for roadway applications. This includes the potential use of technologies other than HPS or LED and the analysis of lesser-known issues such as the approximate values for a dirt depreciation factor. Summaries of the site visits are included in Chapter 5, and the teleconferences with DOTs and the written feedback from manufacturers on the proposed LED specifications are described in Chapters 6 and 7, respectively.

CHAPTER 2 LITERATURE REVIEW

2.1 LAMP LUMEN DEPRECIATION AND LUMINAIRE DIRT DEPRECIATION

A series of documents containing relevant information on the estimation of the lamp lumen depreciation (LLD) and especially on the luminaire dirt depreciation (LDD) were reviewed. Most of the documents on LDD are about HPS luminaires not LED. Thus, the publications did not lead to a conclusion as to which LDD values should be used for LEDs.

The Lighting Handbook (IESNA 2014) provides guidance on how lighting system depreciation should be estimated, indicating that it is imperative to use LLD and LDD factors that are valid and based on realistic information or judgment. For roadway lighting, LLD and LDD are said to be two main light loss factors. The other contributing factors may include ambient temperature, dirt and moisture in the nearby environment, voltage to luminaire, ballast and lamp factor, luminaire surface depreciation, and burnouts. The total light loss factor is the product of all of these contributing factors.

As described in the handbook, aging of lamps produces light loss. Its amount should be accurately determined by referring to manufacturers' statistics for the performance of each particular type. Fortunately, there are lumen depreciation graphs and tables available for practically every kind of lamp from most manufacturers. Accuracy here is important because this loss is one of the two largest ones—the other factor being LDD. Even though these statements were written when the roadway lighting market was clearly dominated by HPS, they are equally valid and relevant for LED luminaires today.

While some of these factors are known with good precision for HPS that is not the case for LED luminaires. For HPS luminaires, *The Lighting Handbook* provides approximate values for dirt depreciation factors. The LDD for HPS depends on the exposure (ranging from 0 to 8 years) and the type of ambient conditions to which the luminaire is exposed (ranging from very clean, to clean, moderate, dirty, and very dirty), as shown in Figure 2.1. The figure is taken from *The Lighting Handbook*; RP-8 (IES 2000) discusses the LDD factor using the same figure.

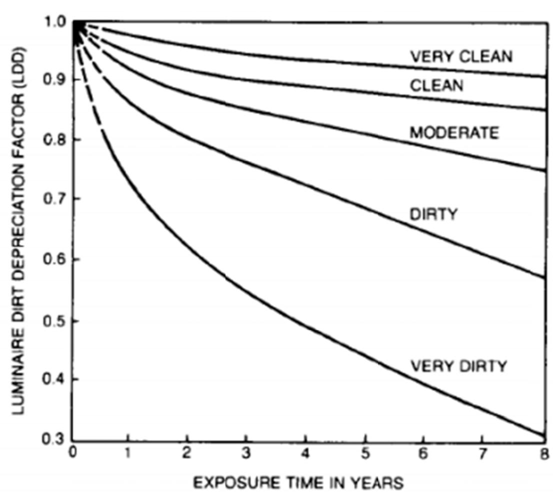

Figure 2.1 Chart for estimating roadway luminaire dirt depreciation factor for enclosed and gasketed luminaires (taken from *The Lighting Handbook,* 9th edition, Figure 22–25).

It is noted that values to generate Figure 2.1 were developed for standard roadway luminaires using HPS and lens covers. However, new designs using alternative technologies such as LEDs may differ significantly from those using HPS. LED luminaires may or may not use refractors or lens covers, and the resulting shape exposed to ambient condition may have a different dirt accumulation rate over time. Moreover, given the maintenance requirements of LED luminaires, which are expected to last more than 10 years without replacing the luminaire or re-lamping, there is great uncertainty about approximate values for the LDD factor.

Experts in the lighting industry have expressed their opinion on LDD and have agreed that more research is needed to provide a conclusive answer regarding the LDD factor. The research team discussed LDD with several knowledgeable people in the lighting industry and could not ascertain a consensus among them.

At the Municipal Solid State Lighting Consortium (MSSLC), 2011 Southeast Region Workshop in Tampa, Florida, sponsored by the U.S. Department of Energy (U.S. DOE) (Kauffman, 2011), it was mentioned that the luminaire cleaning cycle could be characterized by the location type (residential, commercial, industrial, construction, etc.) and that the optimal cleaning frequency should be determined from an economic analysis based on the location type.

The same presentation mentions that field data from two sites with LED roadway luminaires (on I-35W in Minnesota and in Oakland, California) indicated LDD values of around 3.5% per year, calculated by comparing the measured lumens from a luminaire removed from the field (with dirty lenses) with the lenses of the same luminaire after they had been cleaned. The need for more data was pointed out, both in terms of the number of sites and the length of service. In addition, an important recommendation was made to consider the potential for changes in the light distribution pattern on luminaires with exposed secondary optics as they get dirty and require special cleaning.

However, given the few available supporting field data sets for the use of various LDD factors for LEDs compared with those of HPS roadway luminaires, it is common to find reports with the same or similar values (Kinzey and Myer, Myer et al., Royer et al.) being used. As more data become available in the near future, improved estimates for the LDD of LED luminaires are expected. There is ongoing research at Virginia Tech Transportation Institute to measure LLD. That research will continue for one more year, and the results will provide very valuable information about LLD, including LDD. After the results of that study are published, the LDD issues should be reassessed to see whether changes in LED specifications are justified.

2.2 STANDARD TESTS AND LUMINAIRE PERFORMANCE REQUIREMENTS

Writing the specification required gathering information on current standards that regulate testing and performance requirements related to roadway luminaires—and to LED luminaires in particular. Most of these standards were brought to the research team's attention by referring to specifications from other states and through news updates from the IES and U.S. DOE.

The following standards are included in the proposed specification described in the next chapter:

- ANSI C136: American National Standard for Roadway and Area Lighting Equipment
  - ANSI C136.2: Luminaire Voltage Classification (Draft 2014)
  - ANSI C136.22-2004: Internal Labeling of Luminaires (Revised 2009)
  - ANSI C136.31: Luminaire Vibration (Revised 2014)

ANSI C136.37: Solid State Light Sources Used in Roadway and Area Lighting (2011)

ANSI C136.41: Dimming Control Between and External Locking Type Photocontrol and Ballast or Driver (2013)

ANSI C78.377: Specifications for the Chromaticity of Solid State Lighting Products (2011)

ANSI/IEC 60529: Degrees of Protection Provided by Enclosures (IP Code) (2004)

ASTM B117: Standard Practice for Operating Salt Spray (Fog) Apparatus (2011)

IEC 61347-1: General and Safety Requirements for Lamp Control Gear (2008)

IEEE C62.41.1: Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits (2002)

IEEE C62.41.2: Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits (2002)

IEEE C62.45: Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits (2002)

IES LM-79: Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products (2008)

IES LM-80: Approved Method for Measuring Lumen Maintenance of LED Light Sources (2008)

IES LM-84: Approved Method for Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines, and Luminaires (2014)

IES RP-8: Roadway Lighting (ANSI Approved) (2014)

IES TM-15: Luminaire Classification System for Outdoor Luminaires (2011)

IES TM-21: Projecting Long Term Lumen Maintenance of LED Light Sources (2011)

IES TM-28: Prediction of Lumen Maintenance of LED Lamps and Luminaires (2014)

UL 1449: Surge Protective Devices (2014) (Prev. 2006)

UL 1598: Luminaires (Revised 2012)

UL 8750: Standard for Light Emitting Diode (LED) Equipment for Use in Lighting Products

Additional revisions to current standards, as well as new developments, are periodically released and are listed on the website of the U.S. DOE at http://www1.eere.energy.gov/buildings/ssl/standards.html

2.3 OTHER LIGHTING TECHNOLOGIES

Several publications were identified as sources about various emerging roadway lighting technologies. This section briefly describes the results of the literature research and provides the current state of the art in roadway luminaires. In addition, a later section includes comments from industry representatives. Those comments may be useful but at the same time might present a biased view from specific companies about industry trends. These comments and opinions were gathered during the Lighting Fair International convention in Philadelphia in April 2013 and at the annual Street and Area Lighting Conference in September 2013 in Phoenix.

2.3.1 Brief Research on Alternative Technologies

Other technologies briefly studied during this project are ceramic metal halide (CMH), light-emitting plasma (LEP), and induction fluorescent. While this project focused mainly on LED luminaires, these alternative technologies were briefly investigated to see how viable they would be compared with LED.

2.3.1.1 Ceramic Metal Halide Lamp

Sometimes called a ceramic discharge metal halide (CDM) lamp, the ceramic metal halide (CMH) lamp is, according to Wikipedia (http://en.wikipedia.org/wiki/Ceramic_discharge_metal-halide_lamp) "a relatively new source of light that is a variation of the metal halide lamp, which itself is a variation of the old (high-pressure) mercury-vapor lamp. The discharge is contained in a ceramic tube, usually made of sintered alumina, similar to what has been used in the high-pressure sodium lamp. During operation, the temperature of this ceramic tube can exceed 1200 kelvins. The ceramic tube is filled with mercury, argon and metal halide salts. Because of the high wall temperature, the metal halide salts are partly vaporized. Inside the hot plasma, these salts are dissociated into metallic atoms and iodine.

The Wikipedia page also states: "The metallic atoms are the main source of light in these lamps, creating a bluish light that is close to daylight with a CRI (color rendering index) of up to 96. The exact correlated color temperature and CRI depend on the specific mixture of metal halide salts. There are also warm-white CDM lamps, with somewhat lower CRI (78-82) which still give a more clear and natural-looking light than the old mercury-vapor and sodium-vapor lamps when used as street lights, besides being more economical to use."

2.3.1.2 Light-Emitting Plasma

Plasma lighting systems are defined in the National Lighting Product Information Program (NLPIP) report (http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/plasma/plasmaSystems.asp) as "electrodeless metal halide lamps that produce light directly from an arc discharge operated under high pressure. The arc discharge is powered by a high-frequency electromagnetic field generated externally to the lamp. This is different from conventional high-intensity discharge (HID) lamps which have electrodes whithin the arc tube that convey current to sustain the arc discharge." Light-emitting plasma lamps being smaller in size than HID lamps may be easier to direct the light output/optical design.

2.3.1.3 Induction Fluorescent

In electrodeless induction luminaires, mercury vapor in the discharge vessel is electrically excited to produce shortwave ultraviolet light, which then excites internal phosphors to produce visible light. These lamps have been available since 1990 and, unlike an incandescent lamp or conventional fluorescent lamps, there is no electrical connection going inside the glass bulb; the energy is transferred through the glass envelope solely by electromagnetic induction (http://en.wikipedia.org/wiki/Electrodeless_lamp#Magnetic_induction_lamps).

An NCHRP study (Project No. 20-7/305) on analysis of new highway lighting technologies completed in August 2013 (Bullough and Radetsky) is a very good source of information about LED and other technologies. The NCHRP study was conducted by the NLPIP, at Rensselaer Polytechnic Institute).The following table (Table 4.1 in the NCHRP report) summarizes the performance characteristics of various lighting technologies. The application notes column describes a summary of that project's findings.

Light Source Performance Characteristics and Application Notes (from Table 4.1, NCHRP 20-7/305)

Light Source	Typical Wattage (W)	Luminous Efficacy (lm/W)	Correlated Color Temp. (K)	Color Rendering Index	Operating Life (hr.)	Lumen Maint. (%)	Application Notes
High-pressure sodium	35–400	80–120	2100	22	24,000–30,000	90%	Baseline source for roadway lighting
Ceramic metal halide	70–400	60–110	2800–4200	65–90	10,000–20,000	70%–80%	Recent developments have improved life Similar performance and distribution as HPS Potential advantage for mesopic vision
Induction	55–200	60–90	2700–6500	70–90	60,000	80%–90%	Similar efficacy to HPS systems Lower uniformity often requires shorter pole spacing Luminaire size may be too large to provide distribution Potential advantage for mesopic vision
Light-emitting diode	55–300	70–120	3000–8000	30–90	30,000–100,000	85%	Increasing efficacy beginning to exceed HPS Systems often have higher uniformity than HPS and MH systems Rapidly decreasing cost of equipment Potential advantage for mesopic vision
Electrodeless high-intensity discharge*	100–1000	50–94	4000–6000	70–95	30,000–50,000	70%–90%	Potential advantage for mesopic vision

*Also referred to as light-emitting plasma.

It should be noted that the findings of the NCHRP study showed that 288-W plasma luminaires can meet the Illuminating Engineering Society (IES) RP-8 lighting criteria for freeways. However, the findings also showed that LED luminaires tested required 31% less power, on average, when compared with plasma luminaires.

The NCHRP study does not make any recommendations about the most suitable applications for each technology. Specific application suitability depends on many factors, including luminaire performance and system parameters (mounting height, pole spacing, lighting criteria, etc.).

The NCHRP study concluded that “based on the information reviewed for this project and the performance analyses that were conducted to compare roadway lighting systems using different light source technologies, it appears that for LED technologies in particular, efficiency and photometric performance have evolved in recent years to the point that LED roadway lighting is presently a feasible choice and can often lead to reductions in energy use of around 15% or greater, or life-cycle cost reductions in the long term, depending upon the initial cost of LED luminaires. However, specific luminaires using LED sources can have a wide range of performance, and should be judged on an individual luminaire basis."

2.3.2 Comments from Industry Representatives

To get some insight into the future of alternative roadway lighting technologies, the research team sought opinion and comments from industry representatives and people who are in charge of technological development. The following comments are prefaced by the company they come from and should be treated as comments from individuals in the company rather than official policy. These comments were obtained during the Lighting Fair International convention in Philadelphia in April 2013.

An LEP manufacturer (Luxim) staff member claimed that LEP is better at high illuminance than LED, has cheaper mast units, and has the same life cycle. The company is working with some state DOTs on installations. The staff member claimed that LED has to be scaled up to high illuminance, which causes higher price points. He also stated there is a major issue with thermal management of LEPs because the temperature outside the bulb can reach 700°F, but that it doesn’t affect the lifespan of the luminaire. He also said that LEP has a hot restrike time of 2 minutes. He claimed that the payback period for a LEP retrofit installation is 2 to 5 years, while LED luminaires have an expected lifetime of 50,000 hours. The staff member stated that CMH is good for indoor applications but is not worthwhile for outdoor applications. He said that the main cause of failure is solder failure in joints caused by high temperature inside the fixture.

A staff member from another **LEP manufacturer (Alphalite),** claimed that their luminaires use a reflector to get better coverage than HPS and LED, which means fewer fixtures are required. He claimed that LEP has the same lifetime and same lumen output as LED.

A U.S. DOE staff member claimed that plasma and induction lighting have reached their technological peak and there won’t be much improvement in the future. While LED is more expensive now, it is seen as becoming much cheaper and with higher lumens per watt ratio in the future. U.S. DOE is focusing only on LED for future research.

A private consultant claimed that CMH has the same energy efficiency as LED, but a much lower lumen efficacy.

A lighting manufacturer (GE) staff member claimed that the cost is about even between induction and LED, but the LED cost is expected to go down. The efficacy of induction is much lower because of the reflector and higher heat. While the claimed life cycle for induction is high, it is really lower than stated because they start to burn out around 60,000 hours. Also, the dirt depreciation is much worse on induction both inside and out. The staff member stated that GE is not pursuing induction in the future and is focusing on LED.

2.3.3 Comments Received During Visits to Lighting Manufacturers' Facilities

The research team scheduled meetings with three major LED manufacturers (Cooper, GE, and Acuity) at their facilities in summer 2013. In addition, a site visit to the CREE facilities in Wisconsin took place in late 2012, and a meeting was held with Philips staff in a suburb of Chicago in early 2013.

One company indicated that LED technology is developing quicker than plasma technology. They indicated that plasma still has reliability and cost issues that may limit its commercial viability. They claim induction fails in very cold conditions, and is only good for use in parking lots. They also stated that the high heat in induction luminaires causes problems with the transformers.

Another company indicated that for them LED currently is economically viable. They looked at other technologies and found that it wasn't worth the resource allocation to develop them. They stated that the other technologies do not have the volume to move down the cost curve at the rate that LED is. They also said that other technologies have comparable or worse electric complexity when compared with that of LED. According to this company, two years ago the "VHS vs. Betamax format" argument occurred with respect to LED and the other technologies—and LED won. The company expects to be selling 80% LED luminaires by 2020 according to a market research study conducted by Strategies Unlimited.

CHAPTER 3 PROCESS FOR WRITING THE SPECIFICATION

Because the main focus of this phase of the project was to provide IDOT with a specification for LED luminaires, the process of creating this specification is discussed in this section. The proposed specification can be found in Appendix A.

On the basis of the information gathered in Phase I of this study, about the different technologies in roadway lighting and insights about the operation of LED luminaires, the first step in Phase II was to gather additional information on the progress other states have made regarding specifications for LED roadway luminaires.

An electronic questionnaire was developed to gather the latest information about LED specifications used by other state departments of transportation (DOTs). The first step in developing this survey was to contact the U.S. Department of Energy (U.S. DOE), which had conducted a similar survey about LED luminaires geared toward the manufacturers and all users of the luminaires rather than about just roadway applications. The questions on the U.S. DOE survey were used to aid the research group in determining the types of questions to ask as well as how to best obtain usable information from the respondents.

The survey was created in fall 2012 by the research team and formatted to be web-based. The final draft version of the survey was sent to this project's Technical Review Panel (TRP) for comments and approval. The researchers used www.surveygizmo.com based on past experiences and the fact that the survey questions could be modeled adequately on the website. A copy of the actual survey can be found in Appendix B.

A database was created containing contact information for engineers or personnel in charge of lighting projects in DOTs from all 50 states and 25 cities and counties. This information was gathered through DOT, city, and county websites, with a focus on searching for personnel in the design or operations of highway divisions or those in charge of the design manual. In addition, participants' names and contact information were obtained from a recent meeting of AASHTO and TRB design and visibility committees.

On December 24, 2012, the survey was sent out with a deadline of January 18, 2013, to ensure that recipients had sufficient time to answer all questions. The instructions provided with the survey link stated that the estimated time to complete the survey was between 5 and 10 minutes and that the purpose of the survey was to "assess the state of LED technology with regard to roadway lighting for highways and freeways and to better understand the cost savings that can be gained by upgrading current roadway lighting fixtures to LEDs." It also explained that the survey was being used to "better understand how prevalent LED roadway lighting is around the country and further understand the state of roadway lighting specifications in different DOTs."

The survey results were gathered and analyzed in spring 2013. From the 50 states and 25 cities and counties, a total of 40 responses were obtained from 34 states and 6 cities and counties. Of the 40 responses, 18 of them mentioned LED specifications (in addition to the LED specification of the City of Los Angeles, which was later obtained). On the basis of the surveys, it was determined that only 5 states or cities had complete LED specifications, 7 states were in the development process, and 4 additional states had LED specifications for special uses: toll plazas in New Hampshire, parking lots in Connecticut, rest areas in North Carolina, and local and atrial streets in San Jose, California.

The survey results helped the research team in identifying the following specifications that had a wide breadth coverage of items and that had been implemented by the states of Colorado, Minnesota, Texas, and Utah; and the cities of Seattle and Los Angeles (a specification from Georgia was also identified and later used by the research team in the process of writing the proposed specification for IDOT).

Then, these specifications, along with the U.S. DOE's Municipal Solid State Lighting Consortium (MSSLC) model specifications, were summarized by item in an Excel spreadsheet. This was done to be able to quickly compare the content of each specification and the values used for each item. Every item in the specifications was categorized with a comment to include the exact wording in the document, so that it was clear which items were included in each specification. The TRP was given this spreadsheet in July 2013, along with items recommended by the research team to be included in the specification, asking the TRP members to provide feedback on the recommendations.

After reviewing the feedback received from the TRP during fall 2013, it was determined that the draft specification would follow the MSSLC model specifications but be adjusted for the specific items decided on by the TRP and the research team. Thus, the first version of the UI draft specification included the items that were agreed on previously, along with values that were obtained based on the values from other state specifications. This first draft was presented to the TRP to obtain feedback on the format, item values, and wording, and to solicit any other suggestions from the panel. Many members of the TRP were concerned with the length of the specification and suggested that a short and a long version of the specification be created. The short version was intended to contain specific performance items relating to the luminaire, while the long version followed the more-detailed model specification format.

As the specification development process continued, several teleconferences were held between IDOT and the researchers relating to both the long and short versions. These teleconferences were used to discuss item values, relay research discoveries, and attempt to fine tune the two versions of the specifications. IDOT ultimately decided that the two specifications were not working and that the format of the long specification needed to be changed. The specifications were then rewritten in a format similar to the other IDOT special provisions, and it was decided that this would be the final format for the draft specifications.

More items and additional sections were incorporated into the new version, with input from several IDOT engineering experts, and it was finalized before being presented to the TRP for review. The researchers discussed with the TRP about which items to keep, delete, or edit, and a new draft version was submitted to them after those revisions were complete. With TRP and IDOT approval, the draft version was sent out in spring 2014 to several state DOTs or consultants who had developed specifications for states, cities, and municipalities, along with several manufacturers. Teleconferences were scheduled with the state DOTs and consultants, while the manufacturers were asked to provide written comments on the draft specifications.

Teleconferences with the following entities were conducted between June 23 and July 10, 2014, to discuss their comments on the draft of the LED specification: Minnesota, Utah, Georgia, Michigan, Indiana, Colorado, and the Illinois State Toll Highway Authority. In addition, teleconferences were held with a consultant in central Illinois and a consultant in Georgia. After each teleconference, a summary of the discussions was prepared and sent to interviewee to review and make comments as well as to approve its release to the public. The summaries of these teleconferences, with approval from the participants, can be found in Chapter 6. In addition, a summary of the manufacturers' feedback, which was received electronically via email, can be found in Chapter 7.

The teleconferences and feedback were used to update the draft specifications one final time before they were sent to IDOT for approval in summer 2014.

A meeting was held with the TRP on August 20, 2014, for their final review and comments. At that meeting, the results of a life-cycle cost analysis for a sample design were shared with the panel members. The research team then updated the UI draft specification and prepared its final version, which can be found in Appendix A.

CHAPTER 4 LIFE-CYCLE COST ANALYSIS

In addition to producing a specification for LED luminaires, this phase of the study developed a life-cycle cost analysis (LCCA) tool that was used by the research team and subsequently may be used by IDOT to compare the long-term costs of using different lighting technologies, particularly for new installations.

As a result, a spreadsheet was developed for estimating the LCCA for installations using any of the following light sources: HPS, LED, light-emitting plasma (LEP), or ceramic metal halide (CMH). The four options can be analyzed side by side after imputing the items and quantity of materials expected to be used for each design. The total expected cost for a given analysis period and each technology is estimated using a net present value (NPV) approach, which is consistent with the procedures described in IES RP-31-14, “Recommended Practice for the Economic Analysis of Lighting.”

Initially, the researchers used the LCCA spreadsheet developed in Phase I of this project, but they found that it needed several format changes in order to incorporate four different scenarios. Therefore, a different LCCA Excel sheet was developed for each scenario, but the researchers decided that an overall LCCA would be necessary to provide IDOT with future flexibility.

The final version of the LCCA is a two-sheet Excel workbook with the first sheet containing several input boxes for all items that contribute cost to a lighting project. This sheet is labeled “ENTRY” and contains an input box for each item and each of seven different types of luminaires: HPS, HPS high mast, LED, LED high mast, LEP, LEP high mast, and CMH. At the bottom of the ENTRY sheet is a summary of the output, containing the net present value of the project using different luminaire types.

The second sheet is where the unit cost values for all items are stored along with the different variables such as maintenance costs, discount factor, inflation factor, present worth calculations, etc. The unit cost values are based on data provided by IDOT in June 2014. The current version of the LCCA includes a “re-lamping and ballast replacing cost” that is applied to HPS and CMH luminaires with a given periodicity (e.g., 4 years). This periodicity can be easily modified by the user. Similarly, all luminaires are subject to replacement after their expected life; therefore, this is included as a “luminaire replacement maintenance cost.” The life of the luminaire is currently set at 263,000 hours (~30 years) for HPS and CMH luminaires, and it is based on the number of expected hours of light output for LED and LEP luminaires, taking into account the expected lamp use per day. For example, an LED luminaire with an expected usable life of 70,000 hours and 12 hours of daily use would have a lifetime of about 16 years, after which it will be replaced. The current value for the “re-lamping and ballast replacing cost” is set to $250 and the “luminaire replacement maintenance cost” is $550 based on average values provided by IDOT in February 2014, but these can be easily modified by the user if necessary.

Currently, the LCCA does not consider dimming, remote communication access to the luminaires, or intelligent light management, but these items could be easily incorporated to the formulation in the future if needed.

A detailed LCCA is necessary because the initial cost of LED luminaries is higher than HPS, but LEDs will potentially last longer and require less maintenance. Also, LED manufacturers claim that the luminaires require less frequent re-lamping than HPS luminaires. On the other hand, when HPS lamps are replaced, the lens cover and refractor are also cleaned, reducing the dirt depreciation factor. Normally the re-lamping of HPS luminaires happens every 3 to 4 years, but because LEDs do not ordinarily require maintenance for 10 years or more, more dirt may accumulate over the years. One option is to require "washing" the LED luminaires every so many years (e.g., 4 years). If "washing" is required, then it affects life-cycle cost, and a calculation for such cost should be added for LED and LEP luminaires.

The final LCCA spreadsheet is one of the products submitted to IDOT as part of this study, together with a short document describing the basic structure and use of this tool.

4.1 CASE STUDIES

The TRP identified four types of lighting projects for which the LCCA was conducted: (1) a freeway segment, (2) an interchange, (3) an interchange using high mast, and (4) an intersection on an urban arterial. For each project type, a lighting design was generated taking into account optimal luminaire spacing and the amount of materials needed to complete such installation. Thus, for each project type, one design was required for each technology (HPS, LED, LEP, and CMH), which resulted in four different spacings and four different bills of materials. IDOT performed the calculations, including finding the optimal spacing in AGi32 and estimating the resources needed for the complete design. Induction luminaires were initially considered in the analysis, but after conducting initial AGi32 runs, IDOT found that there was no feasible spacing for these luminaires, so the design for this technology was not generated.

For the LCCA, the TRP also provided an itemized list for each unit cost including the luminaire, pole, foundation, wiring, etc., as well as the wattage of the luminaire and the re-lamping or luminaire replacement schedule. The LCCA was conducted for specific luminaires determined by IDOT. The characteristics of the luminaires are shown in Table 4.1.

Table 4.1 Characteristics of the Luminaires Used in the LCCA

	LUMINAIRE INPUT						
	HPS	HPS, High Mast	LED	LED, High Mast	Plasma	Plasma, High Mast	CMH
Luminaire cost ($)	$600	$1,250	$1,690	$1,800	$1,200	$1,900	$800
Wattage	400	400	285	285	280	540	315
Lamp life, HPS & CMH (h) or Luminaire life, LED & Plasma (h)	24,000	24,000	70,000	70,000	50,000	50,000	30,000
Luminaire life (h)	263,000	263,000					263,000
Luminaire lifetime (year)	30.0	30.0	16.0	16.0	11.4	11.4	30.0
No. of luminaire replacements	0	0	1	1	2	2	0

The luminaire lifetime for HPS and CMH was based on an estimated luminaire life of 263,000 hours. On the other hand, for LED and plasma luminaires the lifetime was found based on the lamp life and 12 hours of assumed lamp use per day. For example for LED, the luminaire lifetime was $((70{,}000\ hr)/(12\ hr/day))/(365\ day/year) \approx 16\ years$. Thus, assuming an analysis period of 30 years, the LED luminaire is expected to be replaced once.

As described above, in addition to replacing the luminaire at the end of their lifetime, HPS and CMH needed periodic re-lamping and ballast replacing.

The results of the LCCA for each project are presented next, showing the difference in the expected cost, projected back to net present value for the whole analysis period (30 years) under four scenarios.

Scenario 1 (current policies):

2-year re-lamping cycle for HPS

3-year re-lamping cycle for CMH

Scenario 2 (policies with improved HPS and CMH):

4-year re-lamping cycle for HPS

5-year re-lamping cycle for CMH

Scenario 3 (same as Scenario 2 and reduction in cost of LED luminaire by ½)

4-year re-lamping cycle for HPS

5-year re-lamping cycle for CMH

½ of the LED luminaire cost

Scenario 4 (same as Scenario 3 with new generation HPS – longer re-lamping cycle and thus a less conservative policy)

6-year re-lamping cycle for HPS

5-year re-lamping cycle for CMH

½ of the LED luminaire cost

These scenarios vary in the re-lamping cycles for HPS and CMH, with longer cycles reflecting improved products and less conservative estimates, and in the cost of the LED luminaires, with lower costs reflecting current industry trends.

4.1.1 Project 1: Freeway Segment

A freeway segment with a total length of 3800 ft and luminaires along the median with twin davit arms was selected for this project. The luminaires are expected to provide lighting for three lanes in each direction of traffic (roadway width = 36 ft), as shown in the short section from Figure 4.1.

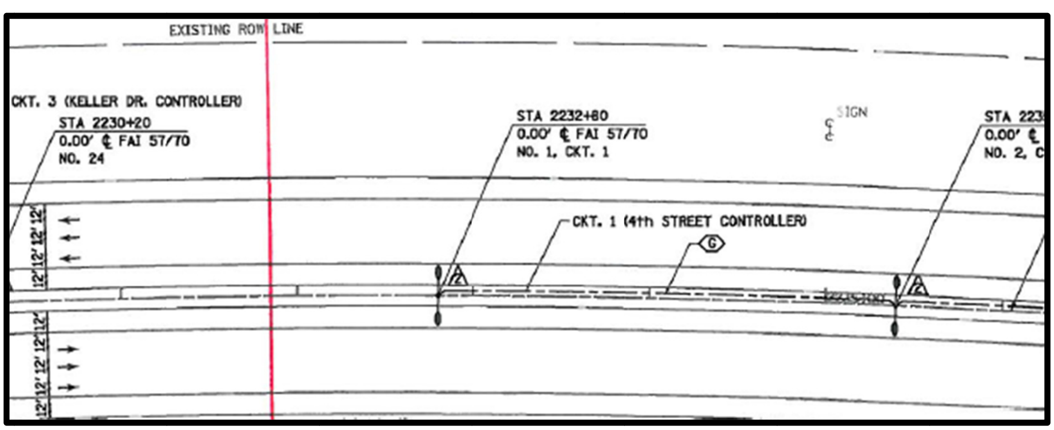

Figure 4.1 Sample image of freeway section.

The designs for the four technologies using AGi32 resulted in installations with the optimal pole spacing and mounting height shown in Table 4.2. Results show that the least number of poles and luminaires are required using the 400W HPS luminaires (largest pole spacing) because they could achieve a higher mounting height than designs using plasma and CMH luminaires.

Table 4.2 Optimal Lighting Design for a Typical Freeway Segment

	HPS	LED	Plasma	CMH
Spacing Mainline Typical Section (ft) - Opposite	260	220	235	175
Mounting Heigth (ft)	48	48	44	40
Total Poles (twin arm)	15	18	16	22
Total Luminaires	30	36	32	44

In terms of the LCCA for the total analysis period (30 years), the results from Scenario 1 are shown in Table 4.3. Recall that for this scenario, re-lamping and re-ballasting is conducted every 2 years for the HPS luminaires and every 3 year for CMH. Under such conditions, the total project cost converted to net present value is the lowest for plasma ($327,712), followed by HPS (5.4% higher), LED (7.9% higher), and CMH (23.1% higher).

Table 4.3 Results of LCCA for a Typical Freeway Segment Under Scenario 1

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$185,046	$228,763	$190,440	$233,325
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$2,683	$0	$0	$1,769
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$5,344.57**	**$3,470.28**	**$4,289.75**	**$3,864.87**

Luminaires	30	36	32	44
Costs from all luminaires	$160,337.24	$124,930.00	$137,272.05	$170,054.09
Total Project Cost	**$345,383.24**	**$353,693.00**	**$327,712.05**	**$403,379.09**

Modifying the re-lamping period to 4 years for HPS and 5 years for CMH, accounting for improved products with lower maintenance requirements, resulted in changes to the order in which the different technologies rank in terms of the total project cost, as shown in Table 4.4. Thus, if maintenance for HPS and CMH is less frequent, HPS results in the most favorable technology for this project ($302,359), followed by plasma (8.4% higher), LED (17% higher), and CMH (20.9% higher).

Table 4.4 Results of LCCA for a Typical Freeway Segment Under Scenario 2

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$185,046	$228,763	$190,440	$233,325
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$3,470.28**	**$4,289.75**	**$3,004.86**

Luminaires	30	36	32	44
Costs from all luminaires	$117,313.50	$124,930.00	$137,272.05	$132,213.82
Total Project Cost	**$302,359.50**	**$353,693.00**	**$327,712.05**	**$365,538.82**

Then, conditions in Scenario 2 were modified by reducing the cost of LED luminaires to one half of their current IDOT estimate, bringing the cost down to $845 per luminaire. The results from this third scenario are shown in Table 4.5 and indicate that the net present value of the project using HPS ($302,359) or LED ($301,899) is practically the same and the lowest, whereas plasma and CMH are expected to increase the cost by about 8.6% and 21.1%, respectively.

Table 4.5 Results of LCCA for a Typical Freeway Segment Under Scenario 3

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$185,046	$198,343	$190,440	$233,325
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	30	36	32	44
Costs from all luminaires	$117,313.50	$103,556.41	$137,272.05	$132,213.82
Total Project Cost	**$302,359.50**	**$301,899.41**	**$327,712.05**	**$365,538.82**

Finally, Scenario 4 shows the effects of having a less conservative re-lamping policy which extends the re-lamping cycle for HPS luminaires to 6 years (Table 4.6). This change obviously decreased the cost for an HPS installation to $286,680, which resulted in a total cost that was 5% lower than using the LED installation.

Table 4.6 Results of LCCA for a Typical Freeway Segment Under Scenario 4

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$185,046	$198,343	$190,440	$233,325
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$726	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,387.81**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	30	36	32	44
Costs from all luminaires	$101,634.40	$103,556.41	$137,272.05	$132,213.82
Total Project Cost	**$286,680.40**	**$301,899.41**	**$327,712.05**	**$365,538.82**

4.1.2 Project 2: Conventional Interchange

A conventional interchange, such as the one depicted in Figure 4.2, was used for this project. Poles were located outside of the paved area on both sides of the roadway in opposite arrangement. There were two lanes per direction; thus, the road width to be covered by the luminaire was 24 ft. The median width was 64 ft.

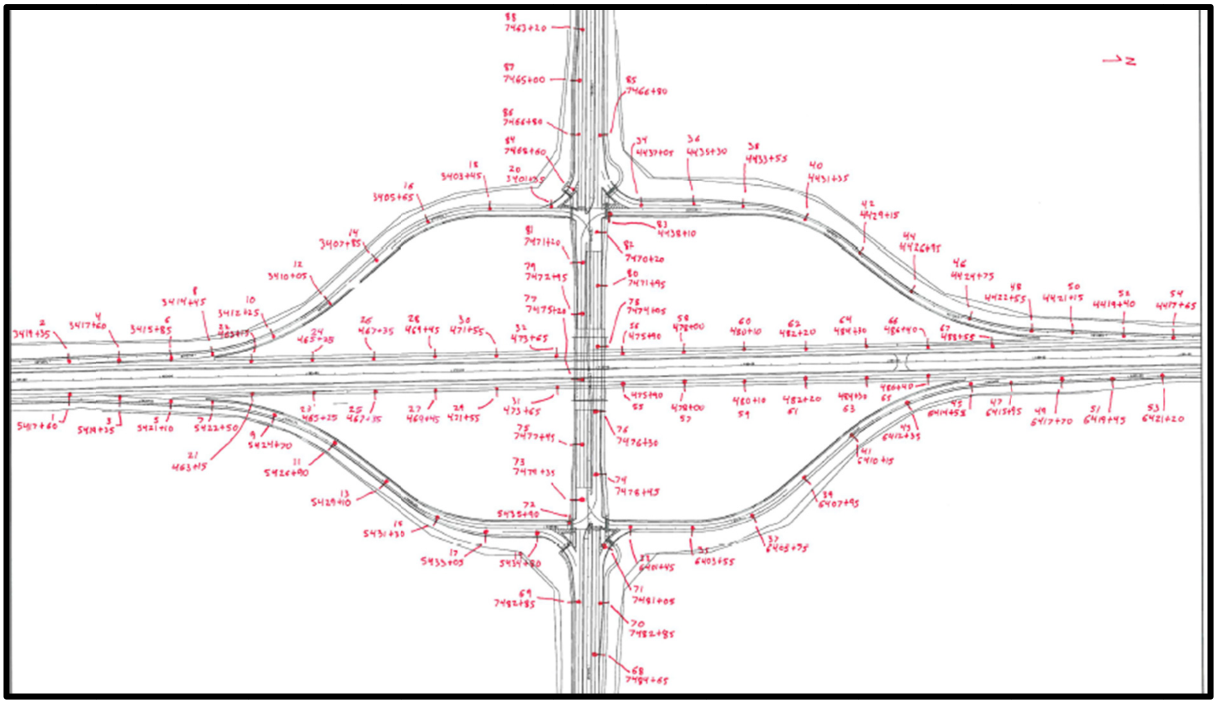

Figure 4.2 Sample image of the conventional interchange (LED design shown).

The designs for the four technologies using AGi32 resulted in installations with the optimal pole spacing and mounting height shown in Table 4.7. The spacing between poles changes with the section within the interchange, and Table 4.7 shows only the pole spacing on the mainline near the overpass and away from the ramps, giving a rough idea of the light output and distribution from a luminaire. Note that the pole arrangement is opposite on the mainline, on the outer side along the ramps, and staggered on the overpass.

Table 4.7 Optimal Lighting Design for a Conventional Interchange

	HPS	LED	Plasma	CMH
Spacing Mainline Typical Section (ft)- Opposite	270	210	250	170
Mounting Heigth (ft)	50	45	45	40
Total Poles (single arm)	64	88	71	109
Total Luminaires	70	94	79	115

*Six existing combination poles (with one or two luminaires are not included in the costs)

An LCCA for this project was conducted for the four scenarios described above. Results from Scenario 1 are shown in Table 4.8, where the project using HPS luminaires resulted in the lowest net present value ($862,321) compared with plasma (2.4% higher), LED (11.4% higher), and CMH (29.7% higher).

Table 4.8 Results of LCCA for a Conventional Interchange Under Scenario 1

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$488,201	$633,954	$543,919	$673,815
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$2,683	$0	$0	$1,769
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$5,344.57**	**$3,470.28**	**$4,289.75**	**$3,864.87**

Luminaires	70	94	79	115
Costs from all luminaires	$374,120.22	$326,206.11	$338,890.37	$444,459.56
Total Project Cost	**$862,321.22**	**$960,160.36**	**$882,809.37**	**$1,118,274.56**

Results from Scenario 2, with re-lamping and re-ballasting every 4 years and 5 years for HPS and CMH, respectively, further reduced costs for these technologies and increased the differences between HPS and LED and plasma, as shown in Table 4.9. Under this scenario, the total project cost with HPS was $761.932 compared with plasma (15.9% higher), LED (26% higher), and CMH (33.8% higher).

Table 4.9 Results of LCCA for a Conventional Interchange Under Scenario 2

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$488,201	$633,954	$543,919	$673,815
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$3,470.28**	**$4,289.75**	**$3,004.86**

Luminaires	70	94	79	115
Costs from all luminaires	$273,731.49	$326,206.11	$338,890.37	$345,558.86
Total Project Cost	**$761,932.49**	**$960,160.36**	**$882,809.37**	**$1,019,373.86**

The results for Scenario 3, where the initial cost of the LED luminaires is dropped to one half their current estimate and other conditions from Scenario 2 are kept, are shown in Table 4.9. For the conventional interchange in this project, after the LED luminaire cost was reduced to $845, the HPS solution seems to be the most economical option as long as the re-lamping and re-ballasting is done every 4 years ($761.932), with the LED solution trailing in cost by about 8.3%.

Table 4.9 Results of LCCA for a Conventional Interchange Under Scenario 3

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$488,201	$554,524	$543,919	$673,815
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	70	94	79	115
Costs from all luminaires	$273,731.49	$270,397.29	$338,890.37	$345,558.86
Total Project Cost	**$761,932.49**	**$824,921.54**	**$882,809.37**	**$1,019,373.86**

Finally, Scenario 4 used a less conservative re-lamping cycle of 6 years for the HPS luminaires, further reducing the total cost of this installation (Table 4.10). Under these conditions, the difference in the total cost of the HPS and the LED installation for the conventional interchange scenario was close to $100,000, or 12% over the design period.

Table 4.10 Results of LCCA for a Conventional Interchange Under Scenario 4

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$488,201	$554,524	$543,919	$673,815
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$726	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,387.81**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	70	94	79	115
Costs from all luminaires	$237,146.94	$270,397.29	$338,890.37	$345,558.86
Total Project Cost	**$725,347.94**	**$824,921.54**	**$882,809.37**	**$1,019,373.86**

4.1.3 Project 3: Interchange with High Mast

An interchange similar to the one used in the previous project was analyzed using high-mast installations. The roadway configuration was similar, with two lanes per direction on the mainline (a 24-ft width) and a 64-ft-wide median. Figure 4.3 is a sample depiction of the interchange showing the LED design.

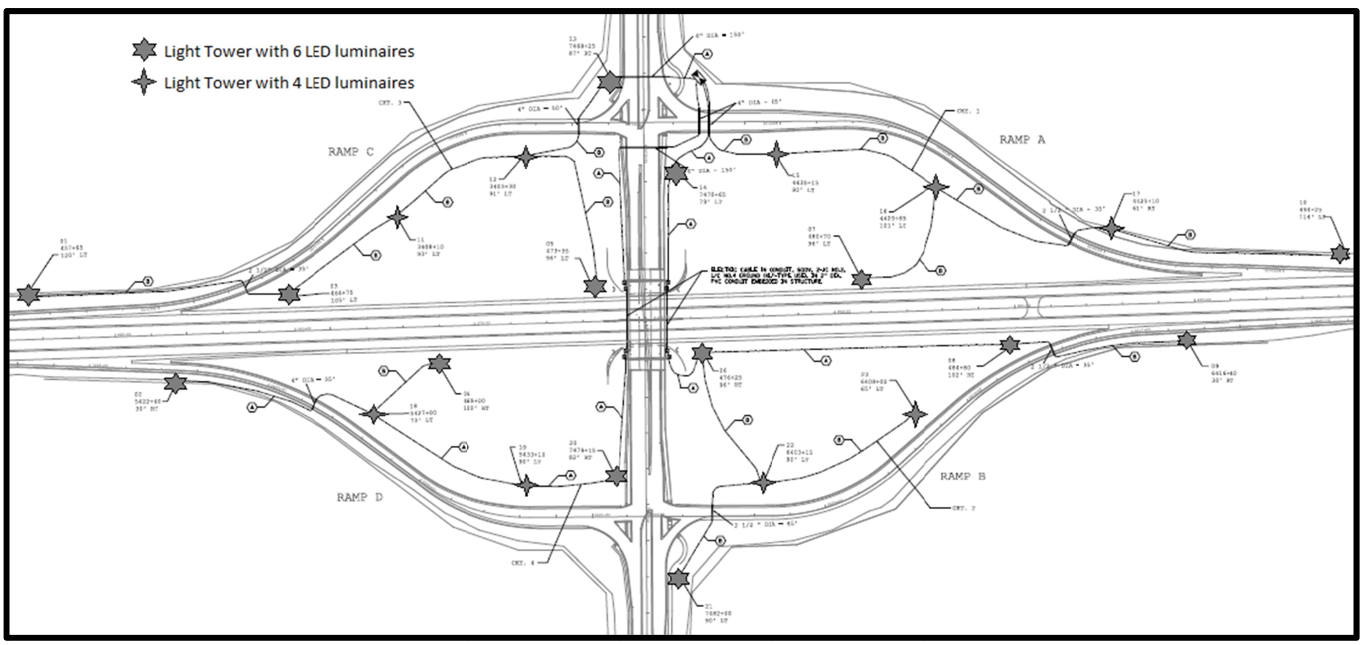

Figure 4.3 Sample image of the conventional interchange with high-mast lighting (LED design shown).

The designs included only HPS, LED, and plasma solutions, given that CMH was not a viable option for this project. A summary of the results from AGi32 is shown in Table 4.11. Different tower heights were used in some designs to optimize the use of the luminaire outputs. For example, the HPS design used seven 110-ft towers near the overpass and the ramp's entry and exit points, while the plasma design had four 120-ft towers near the overpass only. Each tower was equipped with 4 or 6 luminaires for mounting heights of 100 ft and 110 ft, whereas all 120-ft towers had 6 luminaires.

Table 4.11 Optimal Lighting Design for a Conventional Interchange with High-Mast Lighting

	HPS	LED	Plasma
Spacing Mainline Typical Section (ft) - Staggered	790	910	685
Mounting Heigth (ft)	100-110	110	110-120
Total Towers (100 and 110 ft)	21	23	29
Total Luminaires	108	120	138

The LCCA for Scenario 1 on the interchange with high-mast lighting is shown in Table 4.12. Estimates showed that the lowest costs were obtained with HPS ($1,849,707) and LED ($1,935,318), with a difference of 4.6% between them. On the other hand, the cost of the project using plasma showed an increase in the expected costs of about 57.4% with respect to the HPS costs.

Table 4.12 Results of LCCA for an Interchange with High-Mast Lighting Under Scenario 1

Present Value for Project	HPS, H.M.	LED, H.M.	Plasma, H.M.
Initial Installation Total Cost	$1,272,493	$1,509,611	$1,945,802
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,651	$3,397
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$2,683	$0	$0
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$3,593
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$5,344.57**	**$3,547.57**	**$6,990.46**

Luminaires	108	120	138
Costs from all luminaires	$577,214.05	$425,707.87	$964,683.22
Total Project Cost	**$1,849,707.05**	**$1,935,318.87**	**$2,910,485.22**

Reducing the maintenance requirements for HPS and changing the re-lamping and re-ballasting frequency from 2 years to 4 years further reduced the total cost of the project to $1,694,821, as shown in Table 4.13, resulting in 14.2% higher costs for LED and 71.7% higher costs for plasma.

Table 4.13 Results of LCCA for an Interchange with High-Mast Lighting Under Scenario 2

Present Value for Project	HPS, H.M.	LED, H.M.	Plasma, H.M.
Initial Installation Total Cost	$1,272,493	$1,509,611	$1,945,802
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,651	$3,397
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$3,593
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$3,547.57**	**$6,990.46**

Luminaires	108	120	138
Costs from all luminaires	$422,328.59	$425,707.87	$964,683.22
Total Project Cost	**$1,694,821.59**	**$1,935,318.87**	**$2,910,485.22**

The results for Scenario 3 look more favorable for LED, and reducing the cost of the LED luminaires brought down the difference with HPS to an increase in price of only 3.3% with a total cost of $1,751,436, as shown in Table 4.14. Thus, for Scenario 3 it seems that HPS and LED alternatives would yield similar costs for both types of interchange lighting designs (regular poles or high mast), whereas the current cost of installing and operating plasma luminaires seems to be significantly higher.

Table 4.14 Results of LCCA for an Interchange with High-Mast Lighting Under Scenario 3

Present Value for Project	HPS, H.M.	LED, H.M.	Plasma, H.M.
Initial Installation Total Cost	$1,272,493	$1,401,611	$1,945,802
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,019	$3,397
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$3,593
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$2,915.21**	**$6,990.46**

Luminaires	108	120	138
Costs from all luminaires	$422,328.59	$349,825.30	$964,683.22
Total Project Cost	**$1,694,821.59**	**$1,751,436.30**	**$2,910,485.22**

Finally, if a less conservative policy that extends the re-lamping cycle of the HPS luminaires to 6 years is used instead of the 4 years considered in scenarios 2 and 3, the total cost over the design period is reduced by $56,445. Under these conditions, the total cost of the HPS installation is 6.5% lower than the cost of the project using the LED installation (Table 4.15).

Table 4.15 Results of LCCA for an Interchange with High-Mast Lighting Under Scenario 4

Present Value for Project	HPS, H.M.	LED, H.M.	Plasma, H.M.
Initial Installation Total Cost	$1,272,493	$1,401,611	$1,945,802
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,019	$3,397
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$726	$0	$0
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$3,593
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,387.81**	**$2,915.21**	**$6,990.46**

Luminaires	108	120	138
Costs from all luminaires	$365,883.85	$349,825.30	$964,683.22
Total Project Cost	**$1,638,376.85**	**$1,751,436.30**	**$2,910,485.22**

4.1.4 Project 4: Intersection on Arterial

The fourth project type selected for an economic analysis was the lighting at and around an intersection on an urban arterial covering about 1500 ft on the major road and about 1000 ft on the minor road, with the intersection approximately centered in both directions. The main and minor roads had two lanes in each direction (with 12-ft lanes), and the intersection had channelized right turn lanes. The main road had exclusive dual left-turn lanes, and the minor road had single exclusive but shorter left-turn pockets. A sample image of the project geometry, displaying the design of the LED lighting, is shown in Figure 4.4.

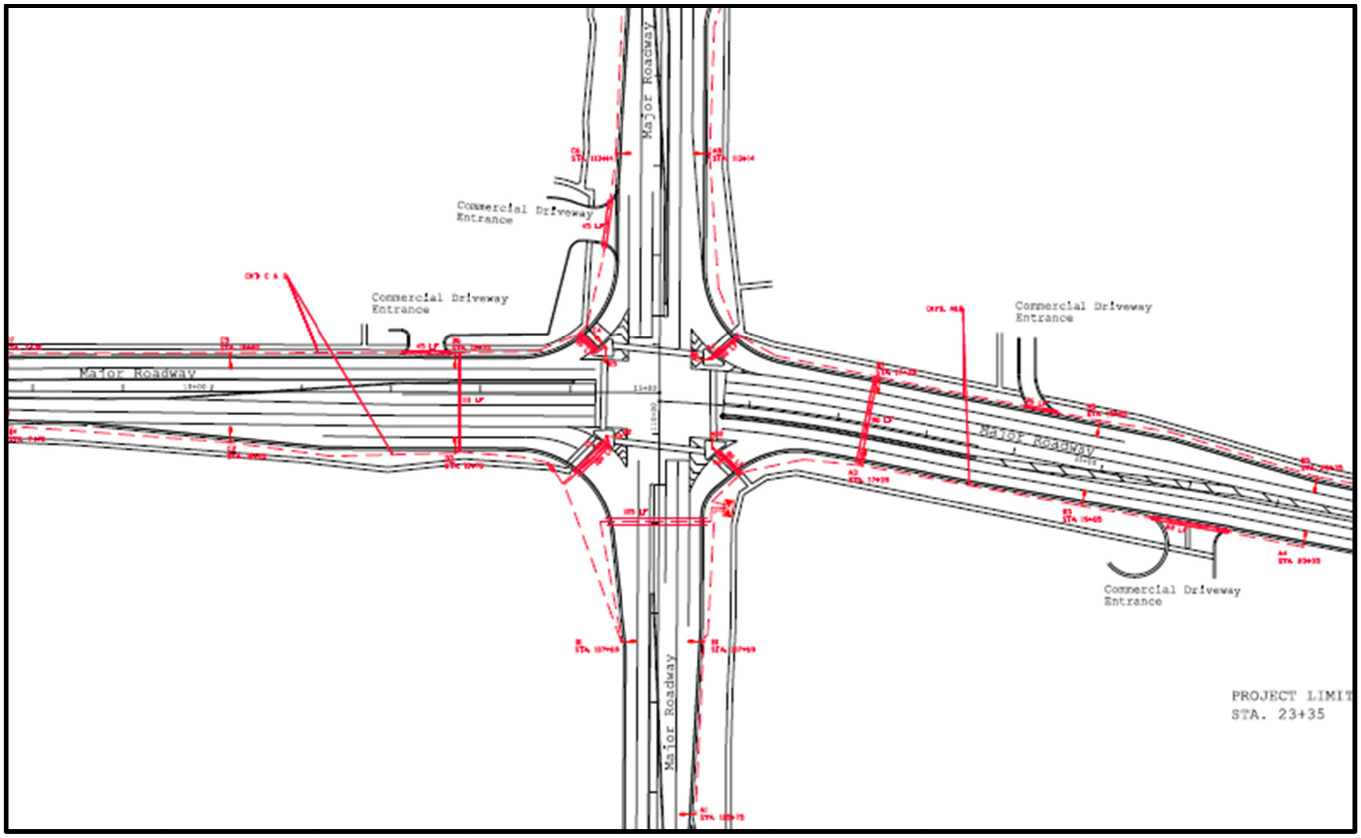

Figure 4.4 Sample image of the intersection on an urban arterial (LED design shown).

Similar to other projects, the optimal lighting design for all four technologies was generated using AGi32, and it is summarized in Table 4.16. It is noted that all four designs resulted in a mounting height of 50ft, and the poles were set in an opposite arrangement. From Table 4.16, it seems that the designs of HPS and LED are similar.

Table 4.16 Optimal Lighting Design for Intersection on an Urban Arterial

	HPS	**LED**	**Plasma**	**CMH**
Spacing Major Roadway Typical Section (ft) - Opposite	240	250	110	150
Mounting Heigth (ft)	50	50	50	50
Total Poles (single arm)	24	22	46	32
Total Luminaires	28	30	54	40

The LCCA for Scenario 1 (see Table 4.17) indicated that LED had the lowest costs, followed closely (only 1.7% higher) by HPS. However, the costs for CMH were 17% higher and for plasma were 64% higher than the costs for LED.

Table 4.17 Results of LCCA for an Intersection on an Urban Arterial Under Scenario 1

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$209,578	$249,266	$348,678	$258,778
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$2,683	$0	$0	$1,769
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$5,344.57**	**$3,470.28**	**$4,289.75**	**$3,864.87**

Luminaires	28	30	54	40
Costs from all luminaires	$149,648.09	$104,108.33	$231,646.58	$154,594.63
Total Project Cost	**$359,226.09**	**$353,374.33**	**$580,324.58**	**$413,372.63**

In Scenario 2, HPS had the lowest costs and LED was 10.8% higher than HPS. However, the CMH alternative was 18.9% and plasma was 81.2% more expensive than HPS. These results are shown in Table 4.18.

Table 4.18 Results of LCCA for an Intersection on an Urban Arterial Under Scenario 2

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$209,578	$249,266	$348,678	$258,778
Present Value for Life Cycle Luminaire Replacement Cost	$0	$1,574	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$3,470.28**	**$4,289.75**	**$3,004.86**

Luminaires	28	30	54	40
Costs from all luminaires	$109,492.60	$104,108.33	$231,646.58	$120,194.39
Total Project Cost	**$319,070.60**	**$353,374.33**	**$580,324.58**	**$378,972.39**

In Scenario 3, it is shown that reducing the cost of the LED luminaires to one half their current estimated cost resulted in slightly lower total project costs than with the HPS design (by about 2.9%). The third best option was CMH, but it resulted in 22.2% higher costs than the LED design. The plasma alternative was 87% more expensive than LED.

Table 4.19 Results of LCCA for an Intersection on an Urban Arterial Under Scenario 3

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$209,578	$223,916	$348,678	$258,778
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$1,249	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,910.45**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	28	30	54	40
Costs from all luminaires	$109,492.60	$86,297.01	$231,646.58	$120,194.39
Total Project Cost	**$319,070.60**	**$310,213.01**	**$580,324.58**	**$378,972.39**

Finally, Table 4.20 shows the results of Scenario 4, where the re-lamping cycle of HPS was increased to 6 years assuming a less conservative policy. This assumption resulted in a total cost of the project using HPS to be slightly lower than cost using LED by about 2%.

Table 4.20 Results of LCCA for an Intersection on an Urban Arterial Under Scenario 4

Present Value for Project	HPS	LED	Plasma	CMH
Initial Installation Total Cost	$209,578	$223,916	$348,678	$258,778
Present Value for Life Cycle Luminaire Replacement Cost	$0	$980	$2,427	$0
Present Value for Life Cycle Relamping and Ballast Replacement Cost	$726	$0	$0	$909
Present Value for Life Cycle Energy Cost	$2,662	$1,896	$1,863	$2,096
TOTAL PRESENT VALUE for the analysis period (PER LUMINAIRE)	**$3,387.81**	**$2,876.57**	**$4,289.75**	**$3,004.86**

Luminaires	28	30	54	40
Costs from all luminaires	$94,858.77	$86,297.01	$231,646.58	$120,194.39
Total Project Cost	**$304,436.77**	**$310,213.01**	**$580,324.58**	**$378,972.39**

4.1.5 Summary Life-Cycle Cost Analysis Case Studies

Results from the LCCA of the four projects, each under four scenarios, with realistic designs obtained from real site plans and calculations using AGi32, showed the significant trade-offs between larger initial investments and lower maintenance/light consumption costs over the life of the project. By analyzing the four scenarios, it was observed that the total costs over the life of a project (in their net present value) are very sensitive to input values related not only to the luminaire costs but also to the agency's policies regarding maintenance (re-lamping and re-ballasting).

Thus, the accuracy of input values for an LCCA is extremely important to produce realistic estimates that reflect the true costs for an agency. For the LCCA to be a trusted decision tool support, all input values need to be reliable.

With this caveat, and taking the favorable conditions in Scenario 3 (especially for HPS and LED) as a reference point, these two technologies produced the two most economical lighting solutions in the four sample projects, with only a few percent points of difference between them with the exception of the conventional interchange project, where LED was up to 8.3% more expensive than HPS. The assumptions from these analyses considered that the cost of LED luminaires will decrease based on recent trends and estimates from industry, and also that HPS will become more reliable, such that a 4-year re-lamping and re-ballasting period is realistic. It should be noted that energy costs, inflation, and interest rates also played an important role in these calculations. If a less conservative re-lamping policy of a 6-year cycle is assumed, the above-mentioned figure changed to 12%.

As recommended in the economic analysis guide by IES (RP-31-14), the estimation and consideration of the total costs of a lighting project is only one of the several dimensions the engineer and decision makers should leverage. Other dimensions may include glare, color rendering, visibility, safety benefits, and aesthetic appeal of the luminaire. As stated in RP-31-14, "a lighting system is purchased for the benefits it produces," and economic return is only one of such potential benefits.

In addition to the economic analysis and the other dimensions mentioned in the previous paragraph, other factors should be considered in selecting a suitable lighting system. These factors may include the trends in technology (is it a mature technology that is becoming obsolete, such as HPS, or is it a developing one that will be technology for the future?), preference of the public or other stakeholders, encouragement from top managers and policy makers, aesthetics and appearance of the project, promotion of technology as an economic development engine, piloting the technology to learn its features, and similar considerations.

CHAPTER 5 MANUFACTURER SITE VISITS

The research team organized site visits to the main facilities of some of the major manufacturers of LED roadway luminaires in the United States. The visits were aimed at gathering firsthand information on a variety of issues related to LED roadway lighting products and, more specifically, regarding the design, production, testing, quality assurance, product maintenance, warranty, installation, retrofits, and future trends, among other topics. Visits were made to Cooper Lighting, GE, and Acuity in summer 2013.

5.1 COOPER LIGHTING FACILITIES (PEACHTREE CITY, GEORGIA)

This visit was conducted on August 6, 2013. Cooper Lighting has development and testing facilities at the Peachtree City location. The research team observed the electrical, temperature, and salt spray testing facilities where some of the specifications of the luminaires were obtained. Then, the light output testing team explained the procedure to obtain the BUG rating and the light output levels using an integrating sphere with spectroradiometer. The research team also had access to the production room where some of the fixtures are assembled for distribution, as well as the manufacturing/shop rooms where new products are tested in their developing stages.

At a later meeting, Cooper engineers provided specific information on LED roadway luminaires and answered questions about several aspects of their products. A summary of the responses and the information provided during the visit is described as follows:

5.1.1 Warranty

The driver contains the electrolytic capacitors that become the limiting factor to the life cycle of the luminaire, and Cooper is in the process of improving the driver to increase the luminaire lifetime while trying to limit the impact on the cost of the final product. The warranty covers the entire product, and it covers a replacement when 10% or more of the LEDs on each square are burned out.

5.1.2 Issues with Regard to Retrofits

It was expressed by the company that the biggest issue with regard to retrofitting luminaires is convincing the users that better lighting leads to safer roadways. Cooper also does layout testing but cannot test every layout. They noted that the MSSLC is working on a table for equivalencies of HPS wattages and LED wattages.

5.1.3 Product Testing

The photometric lab is NVLAP certified. In addition, they conduct rain tests, ANSI vibration tests, dust tests, UV sun-loading tests, temperature shock tests, heat and cold tests, and surge protection tests. Cooper said it is very difficult to obtain light output measurements from a light output test following a dust test.

Their second-generation LED roadway luminaire is ready. The company said it is the first one designed from the ground up and has the following characteristics:

- Square LED board design with 2, 3, 4, and 6 LED squares
- Heat sink

- Drainage opening
- IP-66 approved
- Tool-less entry
- Power and surge protection on door for easy replacement
- Quality 10 kV or 20 kV surge protector (UL-1449) dual mode rated (3 MOV, 3 fuse) and meeting ANSI standards
- Option for bubble level (but also comes with a flat surface for separate bubble-level use), and designed for quick installation and repair.

5.1.4 Future Trends/Development

Cooper claims that 200 lpw will be achieved in the future and that the best luminaires currently are 100 to 140 lpw.

The cost pattern is that in 2008, the LED and driver were ~70% of the entire cost; by 2010, they were ~65%; and by 2015, they will be ~45% of overall cost.

In the future, Cooper wants to make HV-AC luminaires for roadway applications. They will have an indoor HV LED in the next year. It will not have a driver, which will increase efficiency and reduce cost.

They will not use reflectors for LED, and currently they do not envision using lenses on the luminaire.

They said that in the future, a long-life photo control will be necessary.

Cooper also stated that in the future, their luminaires will have a better CRI and lower glare, and will be the #1 optics in the industry.

5.1.5 Dirt Depreciation Factor

The company recommended choosing materials less susceptible to dirt depreciation and lamp depreciation.

They are comfortable with a 0.9 dirt depreciation factor.

5.1.6 Alternate Technologies

LED is expected to take over Cooper's entire product catalog in the future, with about 25% of the catalog being LED by 2015 and outdoor lighting changing quicker than indoor. Currently, LED lumen output was said to be at 15,000 and increasing, but that is much lower than plasma at 25,000 and 40,000 and is moving lower in the future.

It was stated that plasma-based lighting may have more reliability and cost issues, making it less commercially viable at the moment.

Induction lighting may have issues in cold weather, with the heat from the bulb affecting the transformers. It is seen as a more viable application for parking lots (24-hour usage) than for roadways.

5.2 GE FACILITIES (HENDERSONVILLE, NORTH CAROLINA)

The GE facilities were visited on August 7, 2013, the day immediately after visiting Cooper Lighting. The research team toured the facilities where most of the roadway luminaires are produced, including the assembly line for LED products and the area where new product lines will be located. Much of the testing is performed elsewhere, but facilities for the rain test, the salt spray test, and some of the lifetime and temperature tests were observed during the visit. After the tour was concluded, the research team met GE representatives to discuss topics on the LED specification and to gather information about GE’s LED roadway luminaires.

5.2.1 Warranty

GE said the day burner situation is in their warranty, which is not the case for other companies.

The GE driver is rated to last 100,000 hours, and it has a 0.01% per 1000-hour failure rating.

Ninety-nine percent of LEDs fail “short” (short circuit), so the 1% LED failure doesn’t affect the rest of LEDs.

The warranty covers the electrical system of HID for 5 years, including the ballast, which is rated at 100,000-hour lifetime for HID.

GE also offers a 10-year warranty when required by the agency letting the bid, and it was mentioned that the industry is moving in that direction. Currently, a warranty of 7 to 10 years is considered standard.

5.2.2 Issues with Regard to Retrofits

The focus of GE is on performance requirements rather than interchangeability.

GE wants to optimize application efficacy instead of fixture/system efficacy.

5.2.3 Payback Period or Return on Investment Length

GE is meeting or exceeding the predictive energy savings in their current installations, which in general are conservative.

5.2.4 Product Testing

The GE photometric lab was not NVLAP certified at the time of our visit, but they stated that work is in progress for the certification. Their facility in Cleveland, Ohio, is already NVLAP certified.

GE conducts a vibration test on the roadway luminaires and believes that this test should be mandated.

Some of the testing for the LED roadway luminaires is conducted at the visited facility, and the remaining tests are conducted at the Cleveland facility.

5.2.5 Future Trends/Development

GE said that projections by market researcher Strategies Unlimited indicate that the marketplace will be 80% LED by 2020.

GE lights are scalable right now, and they can build in upgrades in the next few years.

Integrating new LED technology, GE drivers with surge protection, increased lpw (about 90 to 100 lpw for their best products), and fully integrated systems (wireless) are topics the company is actively pursuing for future developments.

5.2.6 Dirt Depreciation Factor

It was stated that a dirt depreciation factor of 0.9 is moderately accurate and that GE is comfortable with a value of 0.95.

GE mentioned that for a specification document, the depreciation specified should be at the system level via TM-21 projections.

5.2.7 Alternate Technologies

They believe that LED is economically viable and currently has a better economic outlook than other technologies. Other technologies do not have the volume to move down the cost curve at the rate that LED does because the other technologies have comparable or worse electric complexity.

5.3 ACUITY FACILITIES (GRANVILLE, OHIO)

This facility was visited on August 15, 2013. At this location, Acuity does not have a production facility, but they conduct testing of the luminaires. Representatives provided a tour of the testing facilities, including surge protection, temperature, and lifetime testing. Later, the research team met with the representatives to discuss their LED roadway products and the specification development. A summary of the comments from that meeting are described next.

5.3.1 Warranty

Acuity said their relationship with chip manufacturers is good, and the chips are warrantied 90 days from reel.

Warranty becomes a financial liability if it gets extended too far, but the weakest component of the luminaire (the driver) is expected to last 10+ years.

5.3.2 Issues with Regard to Retrofits

The focus is light on task and has a high coefficient of utilization.

Acuity estimations indicate that a new installation will have only about a 3% increase in pole spacing compared with a retrofit.

The main color temperature design is set for 4000 K, but there are options for 5000 K.

Previous issues with their 480-V driver have been corrected.

Acuity provided the Illinois Tollway with 1700 LED roadway luminaires for a cost of about $550 each. This retrofit reduced the consumption rate from 400 W with HPS to 280 W with LED luminaires.

5.3.3 Product Testing

Acuity stated that pole dampeners should always be required, but on their vibration test, they go above 1 or 1.5 g.

Representatives discussed their testing, including temperature (hot, not cold, and no-shock test), humidity (and salt), ultraviolet, dust/dirt (IP-65), bugs, harmonics (electrical and pole), and voltage spikes.

All roadway luminaires are run through LM-79, and all chips are LM-80 compliant.

They are UL and NVLAP certified at all facilities, and they conduct FCC testing.

They have a reference list for validation testing, including electrical systems, and can provide a list of all tests.

Acuity has its own surge protection, which is standard for roadway luminaires. They conduct a 20 kV/10 kA surge test at 6 hits with a 1-minute hit and 1-minute spacing.

Their salt fog test has a rating of 6 under ASTM D654.

They claim that their luminaire has electrical immunity in accordance with ANSI/IEEE C64.41.

5.3.4 Future Trends/Development

Acuity stated that a lot of effort is put into keeping heat away, and their 140W luminaires can replace 250/296W HPS luminaires.

For the future, they are looking into a photo control that has a long life, equal to that of the fixture (around 20 years), and are also looking at low-voltage dimming. Many of their current LED luminaires already have photo-control capabilities.

They said the industry is moving toward warmer colors closer to where HPS is (lower kelvin temperatures).

5.3.5 Lens, Filtering, and Luminaire Washing

Acuity uses acrylic lens and suggested washing the luminaire every 3 years.

5.3.6 Alternate Technologies

This topic was not discussed at length, but the general assessment of Acuity representatives supports the trends described for the other two manufacturers discussed in this chapter.

CHAPTER 6 TELECONFERENCES WITH STATE DEPARTMENTS OF TRANSPORTATION AND INDUSTRY EXPERTS

Telephone interviews were scheduled in summer 2014 with state DOT representatives and industry experts. Several days before the interview, the interviewees were given a copy of draft version of the proposed specification. The interviews typically lasted one hour, and in some cases they were a little longer. A summary of the interview was written and sent to the interviewee to make sure discussions were properly captured. Interviewee feedback was incorporated into the summaries, and permission of the interviewees was secured before the write-ups were provided to other people (public).

Interviews were held with industry experts and representatives from the following states. The date of the interview is provided.

- Minnesota: June 23
- Illinois Tollway: June 24
- Utah: June 25
- Michigan: July 8
- Indiana: July 8
- Colorado: July 9
- Joseph Marsh (consultant who developed Georgia's LED specification): July 7
- Tom Burtness (lighting consultant for Champaign-Urbana, Illinois): July 10

6.1 MINNESOTA DEPARTMENT OF TRANSPORTATION

6.1.1 General Information

The Minnesota Department of Transportation (MnDOT) has installed several hundred LED luminaires in Metro District roadways and has received $5 million to further retrofit LED luminaires. MnDOT has used other technologies very little in the past (induction in rest areas, metal halide in mast arms) and is focusing only on LED now.

6.1.2 Minnesota Specification

MnDOT is continually updating their specification, with the last big update including the 7-pin photocell receptacle, but they have also specified a driver with dimming capabilities.

They believe that their testing and documentation requirements weed out less-reputable manufacturers, so they don't need specific language.

MnDOT has a separate specification for roadway and underpass luminaires. They are developing a high-mast specification that may be available in the future. They have not developed a specification for tunnels yet.

6.1.3 General Comments About Proposed UI Specification

They think IDOT's requirements could be difficult for current manufacturers to meet but are doable. They said that the Restriction of Hazardous Substances (RoHS) doesn't work for transient suppression, but it does for other devices. The new RP-8 document will not contain requirements about illuminance, but AASHTO is keeping them. MnDOT thinks that IDOT should require the luminaire to be wired for a 7-pin receptacle in addition to being designed for it.

There may be a problem with such a high temperature (55°C) maximum on the driver range.

The specification does not need to be detailed on the drive current and should provide leeway for manufacturers as long as they meet requirements for light levels and longevity. Being specific could rule out some luminaires that may work well for IDOT's needs. The specification should be more specific when it comes to using the word "scalable" (define what it means), and MnDOT wondered why IDOT has the 90-degree rotation requirement.

MnDOT suggested including a statement for shoulder width in the roadway data section. Also, "semi-cutoff" (as shown in the luminaire data section of the proposed UI specification) isn't a term used any more. In the same section, specifying the type (as in Type III) isn't necessary as long as the required light levels on the road are met.

6.1.4 Warranty

MnDOT has a 10-year warranty and found no problems with this requirement. They added the 10% individual LED failure stipulation after receiving comments from manufacturers about the initial 5% value.

During the warranty period, only luminaires that fail are replaced, not sets of luminaires. MnDOT has a good relationship with manufacturers, so they don't feel the need to insert language into the specs about mass replacement, should it be required. Major issues would be addressed with the manufacturer to work out an acceptable solution.

6.1.5 Testing

MnDOT requires light level documentation from an independent lab. They then run the light levels using Visual to verify what is being sent in. They do not retest the light level of luminaires purchased at an independent lab—they rely on the testing documentation provided by the manufacturers. MnDOT has a light meter mounted on a vehicle and can collect data at posted speeds, and light levels will be checked for installed luminaires in the future using that meter.

Once manufacturers submit all of their documentation and meet all of the criteria in the specification, MnDOT requires that two luminaires be provided for visual inspection and placement in the field by MnDOT electricians. The light pattern of the luminaires is then reviewed. If there are no issues, the luminaires are placed on the approved products list. Only luminaires on the approved products list can be purchased by contractors for use on a MnDOT project.

There have been no issues with the luminaires that are currently installed.

6.1.6 Depreciation

MnDOT's dirt depreciation value is still at 0.9, and they are still using a 70,000-hour life cycle. They said that the light loss factor is different for every LED manufacturer and that we should include language dealing with light loss factor in our specification.

6.1.7 Cleaning

MnDOT currently does not clean their luminaires but stated that one luminaire taken down from the I-35W bridge was a little dirtier than expected. Virginia Tech has expressed an interest in testing luminaires on the I-35W bridge with respect to dirt depreciation.

6.1.8 Life-Cycle Cost Analysis and Payback

MnDOT stated that they are reaching their payback within 10 years (converting HPS to LED). They have a 4-year re-lamping cycle for HPS and said the cost for lane control and re-lamping cancels out any savings from using the longer-lasting HPS bulb. They are using the actual cost of lane closure and labor—not the user cost (travel delay, etc.), which they obtain from previously known costs for lane control.

6.1.9 Other Comments About Proposed UI Specification

They noted that the light-loss factor is missing from the document.

They asked whether the ability to shield a requirement or an option?

MnDOT said LED end-of-life indication is a good idea, but is flashing for a few seconds at turn-on going to be noticed by anyone?

They noted that 90-degree rotation is a way some manufacturers change their light patterns while others use different light panels to do it. They asked what advantage 90-degree rotation provides?

They also asked the purpose of specifying the drive current of 750 mA if the manufacturer meets all other requirements.

MnDOT is interested in what manufacturers say related to the warranty language, including labor costs and replacing all luminaires in a system if one fails prior to the warranty ending.

They said AASHTO is putting together a “model” specification for states to use. AASHTO is looking at existing state LED specifications to help develop this specification (a best practice approach).

6.2 ILLINOIS STATE TOLL HIGHWAY AUTHORITY

6.2.1 General Comments About Proposed UI Specification

The Illinois Tollway stated that, overall, the specification looks good and has a lot of technical information.

They recommended that IDOT require submittal documents of all requested items throughout the specification, such as tests or accreditation. This includes the manufacturer’s experience in LED and luminaires for roadway lighting.

It was suggested that IDOT would need a separate specification for things like underpasses because there are items in the specification, such as photocells, that wouldn’t apply outside of roadway luminaires.

The Tollway noted that the Method of Measurement section was missing.

They also noted that if the specification says reflectors are not allowed in the luminaire, it would eliminate a major LED manufacturer.

They stated that the phrase “made in the United States” is too stringent and that using “manufactured” or “assembled” in place of “made” would not cause as much of an issue with manufacturers. They also said that the meaning of the words “assembled” and “manufactured” should be as specific as possible.

They noted that the luminaire finish and luster requirements seem to be too detailed and said it is hard to measure those in field.

6.2.2 Warranty

They asked whether the power supply or surge protector will be tested by IDOT to make sure that it passes the stated criteria. Also, they wondered how color shift outside of the allowed range is expected to be determined.

The requirement that the manufacturers pay for labor was pointed out as being a big potential issue. Manufacturers would not agree with the requirement, and/or it would make the luminaires cost more than they would save.

The Illinois Tollway liked the idea of testing the luminaires before the warranty expired but stated that we should be specific about the timeline and how the testing will be conducted. They also noted that there could be an issue with charging the manufacturer for all of the testing costs.

6.2.3 Testing

The Illinois Tollway suggested that we include a requirement that all luminaires be tested and rated for 3G vibration. They also stated that requiring testing on all three axes is a good idea, but it would have to be added to the criteria analyzed because it is not part of it.

The Tollway noted that the independent witness requirement is probably unnecessary because major manufacturers pride themselves on their reputation and would not do anything to harm that. Also, because the labs are accredited, there would be no reason to think that the reports would be falsified. The Tollway also said the cost for the independent witness could be high, and possibly cost prohibitive, depending on project size.

6.2.4 Design of Luminaire

The Illinois Tollway noted that the end-of-life indication may not be possible yet, so we should check with manufacturers about it. They stated that it may not be worth the extra cost.

The Tollway also noted that if a photocell controller is not specified on the luminaire, the luminaire should have a shorting cap.

6.2.5 Electrical

The Illinois Tollway stated that limiting the drive current to a specific value, especially under 1 A, may be a detriment and cause issues with the manufacturers. Many manufacturers are trending toward driving the luminaires at higher current to reduce the number of LEDs required to provide the necessary lumens. Limiting potentially requires specifying a higher-cost product and may be a special order with long lead times.

The Illinois Tollway stated that the NEMA/ANSI standards for electrical testing should be spelled out and that we should ask for the electrical testing reports.

6.2.6 Depreciation

The Illinois Tollway said we should be more stringent with our depreciation and set our 50,000 limit at 10% instead of 15% (L90 instead of L85)

6.2.7 Other Information About LEDs

The Illinois Tollway maintains an approved list of devices that can be used on projects and keeps documentation related to those approved products on file. Currently, there are eight companies on the approved list: American Electric Lighting, Cooper Lighting, Cree, General Electric Lighting Solutions, Illumitex, Kenall, Leotek, and Philips (from Section 1067.09b of the Illinois Tollway Supplemental Specifications) .

They release a revised specification every year unless there are any significant changes that need to be made midyear.

They do not conduct a life-cycle cost analysis.

The Illinois Tollway noted that they are planning to install LED luminaires on 35 miles of I-90 and plan to have 70 to 90 miles of their total 286 miles lit by LED luminaires by the end of next year.

HPS luminaires are re-lamped as needed, but the Tollway is planning to use a connected system with the LED luminaires to better track any outages or issues.

6.3 UTAH DEPARTMENT OF TRANSPORTATION

6.3.1 Comments About Proposed UI Specification

The Utah Department of Transportation (UDOT) stated that our specification is very broad and very detailed at the same time. They provided examples of the light pattern and large lumen range. They also noted that we specify a BUG rating, but there were no values for the backlight and glare ratings, which could be an issue when luminaires are installed.

UDOT stated that specs should be kept uncomplicated while still hitting the necessary points to ensure that only quality bids are submitted. Overcomplicating the specs would increase costs and limit the abilities of the manufacturers to bid on the work.

UDOT stated that there is information in the proposed UI specification that is also included in documents that are referenced (such as LM-79, LM 80, IP 66), rendering the material in the specification unnecessary.

UDOT suggested that we tighten up our performance-based items in the specification.

UDOT recommended that someone write in the date the luminaire was installed with an indelible marker pen to ensure that it can be tracked if replaced after a number of years.

UDOT stated that in their experience, any failures of the drivers or other items occur soon after installation.

6.3.2 Other Technologies

UDOT used induction in the past, but they required a 480V circuit. This necessitated a step down for the fixture, which many manufacturers were not willing to do. The cost of the individual luminaires never came down, which made them undesirable to UDOT. They were also undesirable because the light is not a point source and therefore cannot be controlled.

UDOT stated that we should avoid metal halide at all costs.

6.3.3 Warranty

UDOT stated that a 10-year warranty makes sense. They also said it is difficult to figure out how to deal with maintenance costs when a luminaire fails. Currently, they required the manufacturer to send them a few dozen replacement drivers that a UDOT crew uses as replacements for failed ones. They have had to replace about ten of them (out of about 800 LED luminaires from Philips). The failure often happens within 2 months of installation.

6.3.4 Depreciation

UDOT stated that as the LEDs get older, in order to ensure the light levels remain the same, there is a higher power draw in the luminaire.

UDOT said they use a 0.9 light loss factor (LLF) in their calculations.

UDOT plans to increase their driver life expectancy to 100,000 hours and suggested that we make sure to hold the manufacturers to how long we want the driver to last. They also stated that it may be worth asking the manufacturers to provide replacement drivers if we expect the luminaire to last 30 years.

UDOT stated that they did not have sufficient resources to clean their luminaires.

6.3.5 Testing

UDOT said they don’t currently perform independent testing after the bid process is completed because they trust the manufacturers and have a good relationship with them, but they do ask for all testing documents to review before accepting the luminaires.

UDOT stated that the manufacturers have a reputation to maintain in order to be successful, so they have no reason to lie or falsify documents. UDOT also noted that if the labs are accredited then there is no reason to suspect that the documents are falsified in any way.

UDOT added that requiring manufacturers to pay for labor will drive the cost up, that retesting drives the cost high, and that it is hard to specify what items they have to pay for.

6.3.6 Long-Lasting High-Pressure Sodium and Life-Cycle Cost Analysis

UDOT stated that they no longer like dealing with HPS because those luminaires are too difficult to maintain with all the different parts that can have issues. They also stated that all the lane closures and maintenance costs outweigh any benefits of these longer-lasting bulbs.

UDOT stated that they do not conduct a life-cycle cost analysis because of time constraints and the fact that it was difficult to calculate losses from theft and vandalism of the wiring. In an attempt to combat some of the theft, UDOT used aluminum wiring. Even though aluminum wiring requires more maintenance, it seems to have reduced the amount of theft.

6.3.7 Photocell

Currently, UDOT has a photocell on a pedestal connected to a circuit that controls when the luminaires are turned on and off. They are working with a contractor to develop a control system in which the lights can be controlled remotely and turned on and off based on an atomic clock. This control system would also allow UDOT to check voltage losses caused by theft or other malfunctions.

6.3.8 General Information

UDOT currently has 800 cobra-head LED luminaires, which are upgraded Philips luminaires with two drivers. They plan to install 68 high-mast, 100-foot poles along I-15 south of the Salt Lake Valley in the future, which would contain a little over 200 LED luminaires. This project has not yet been awarded, but Cooper is the strongest contender. The project would start around the end of the summer, but the lights would not be installed and running for at least a year.

UDOT stated that they plan to change the specs rather significantly in the future because a lot of things are different since the last time they were published (January 2012). However, this update will probably not be released until 2016 when the next standard specification book is released by UDOT.

UDOT stated that in developing their specification, certain desired luminaire features were identified and then the specs were written around them to ensure that only quality bids were submitted for projects. UDOT suggested following this procedure as well. UDOT also has separate sections for high mast and understructures within their specification, but they don't repeat anything from other sections.

6.4 MICHIGAN DEPARTMENT OF TRANSPORTATION

6.4.1 General Information

Michigan currently has thousands of LED luminaires installed on its state and federal highways and plans to expand throughout the entire state. Eighty percent of its luminaires are in the Detroit metro area.

The Michigan Department of Transportation (MDOT) specification was updated last month with "Made in USA" requirements, although the specific wording was not provided. MDOT said that products from overseas had failed, which was why they wanted to add the "Made in USA" requirement.

Their specification is applicable to all types of luminaires including bridge, high mast, roadway, etc. Before the specification was written, MDOT had put in 100-foot towers at interchanges, but they were found to be ineffective. They would illuminate the grass but put very few lumens on the actual roads. Currently, MDOT is either tearing down the towers and lighting the interchange in a different manner or retrofitting the towers with directional LED luminaires.

MDOT stated that they have converted much of their wire to aluminum from copper to combat theft and to save money because copper wire is twice as expensive as aluminum wire.

6.4.2 Other Technologies

MDOT had a pilot program with induction and plasma but did not expand the program after it ended. MDOT stated that the performance of LED luminaires beats everything else.

6.4.3 Project Bid Restrictions

Currently, they know three specific manufacturers can meet their specification, but because they don't have any specific language for manufacturer qualifications, if another manufacturer can meet all of the bullet points in the specification, they can't say no to their bid. However, they feel confident that their specification is stringent enough to receive bids only from quality manufacturers.

6.4.4 Warranty

Currently, MDOT requires a 10-year warranty but stated that IDOT would have to be careful with what the manufacturers' warranties cover because some manufacturers cover driver failures only. They tried to get labor covered in the warranty but found it too difficult.

6.4.5 Depreciation

MDOT stated that some manufacturers are using a value of 0.92 for dirt depreciation, but MDOT standardized it to 0.9 after taking photometric data measurements. They are not planning to clean the fixtures because manufacturers claim that the luminaires are self-cleaning.

Currently, MDOT has an L90 value of 50,000 hours and an L70 value of 100,000 hours, but they stated that based on the current technology, there is a wide range that can be used.

6.4.6 Life-Cycle Cost Analysis

MDOT uses a simple payback period for smaller projects, but more complex projects do require consultants to provide a full LCCA.

The payback period varies from project to project, but they have found it to be as low as 2 years. They take into account the rebates that utilities give based on reducing the load on the system, and a 2-year re-lamping cycle for HPS is used in comparisons.

6.4.5 Photocell

Currently, the photocell section is in a different specification. A 5-pin photo control is required, but MDOT is considering a 7-pin requirement.

MDOT stated that one photo control is currently located on top of a cabinet that controls a network of luminaires. They were in the process of negotiating a public-private partnership contract, which wireless control was a part of, covering the whole Detroit metro area. However, MDOT stated that they were unsure about the cost effectiveness of wireless control.

6.4.6 Comments About Proposed UI Specification

MDOT suggested limiting the amount of information in the specification and keeping only the important information so as not to increase the cost or limit the manufacturer's design capabilities. The first and last sentence of the "Manufacturer Experience" paragraph should be removed. Language about the IEC IP66 rating should be included instead of stating that it is suitable for direct spray.

In the "Photometric Performance" paragraph, MDOT suggested adding the language "project specific" for the sentence that begins "In addition, complete point-by-point illuminance, luminance …"

In the warranty section, MDOT suggested changing "no cost to department" to "no cost to project." In addition, MDOT suggested deleting the sentence requiring the manufacturer to pay for labor as well as the paragraph referencing testing the luminaires near the end of the warranty period.

MDOT suggested reducing the required hours for the salt spray test in the housing section from 5000 hours to 3000 hours. Not many manufacturers conduct the test for 5000 hours.

MDOT suggested deleting the sentence "Upon unplugging the driver wiring the entire driver assembly shall remove for maintenance" because only a quick-disconnect requirement is needed. Reducing the surge suppression requirement from 10 kV/10 kA to 10 kV/5 kA was also suggested based on information they have received from manufacturers.

MDOT stated that retesting luminaires is probably not necessary or cost effective. They added that they currently have a large project that is supposed to be under warranty for 15 years. The language in the contract states that after 12 years, the manufacturer is required to upgrade the luminaires and make sure the system is still functioning properly. This is to ensure that the system is not severely outdated and keeps up with the development of the technology.

MDOT also recommended that where the proposed specification says that a failed luminaire shall be replaced by an "exact replacement," we should instead ask for the most recent analog of that luminaire because the old luminaire will most likely be outdated.

6.5 INDIANA DEPARTMENT OF TRANSPORTATION

6.5.1 General Information

Several models of LED luminaires have been installed on an interstate interchange and at a rest area in order to compare the performance. In the near future, the Indiana Department of Transportation (INDOT) plans to install additional models for further testing.

INDOT stated that new HPS luminaires generally gain full brightness after a 6- to 9-month burn-in period. INDOT specifications have separate sections (Installation, Luminaire Identification, etc.) and language for high mast, bridge, roadway, etc. INDOT stated that this has worked well for them.

They plan to revise their specification later this year (2014) or early next year (2015).

6.5.2 Other Technologies

At several at-grade intersections on high-volume roadways, LED and plasma luminaires will be installed for additional comparisons. INDOT stated that no onsite photometric tests were conducted immediately after the installations became operational.

The light source for projects is selected by the project designer after running a life-cycle cost analysis.

6.5.3 Project Bid Restrictions

INDOT currently has no language for specific experience or production requirements from bid companies. However, they ask for luminaire tests by independent labs and a warranty to ensure they receive quality products.

INDOT doesn't retest any luminaires, but for any submissions it reviews catalog cuts, test results, etc.

6.5.4 Life-Cycle Cost Analysis

INDOT has a cost comparison analysis sheet in their design manual that they use to conduct LCCAs. To determine a re-lamping schedule for solid-state lighting (SSL) technologies, they refer to the standard warranty that manufacturers use. For comparison, they use a 3-year re-lamping cycle for HPS luminaires.

INDOT stated that maintenance costs are included in their LCCA and those costs were obtained from previous lighting contracts. On the basis of LCCA, designers have found that HPS is still the least expensive. They are not currently using longer-lasting HPS bulbs but may test them in the future.

6.5.5 Warranty

INDOT requires a 5-year warranty for any lighting project. However, they stated that for future LED or other SSL projects, they may want to increase it to 8 to 10 years because that is the direction the industry is headed.

They were also potentially heading toward adopting an approved products list for SSL luminaires and stated that they were worried about creating separate specs for every different SSL technology.

INDOT requires a contact name, phone number, and email address for someone who can address any warranty issues they have in the future.

6.5.6 Depreciation

Currently, INDOT uses an L70 value of 50,000 hours but may increase it in the future if that is the way the technology is heading. INDOT uses a dirt depreciation factor in their design procedure of 0.87, and variations have to be approved by the Traffic Administration Office.

6.5.7 Photocell

INDOT will be adding a section about photocells in the future. Currently, INDOT does not have photocells on individual luminaires but would like them in the future in case they want to have the option to dim the luminaires.

6.5.8 Comments About Proposed UI Specification

INDOT suggested including language about IP66 rating on the housing to ensure protection against dust and water leakage, and specific values for our BUG rating, such as what Minnesota uses (3-0-3).

INDOT also suggested that it would be useful to have a requirement that a surge protector auto resets after a strike (to be ready for the next strike) because trying to identify luminaires that have been struck can be difficult. They also stated that if the surge protector requires a manual reset and receives another strike before the surge protector is reset, it can fry the luminaire.

The end-of-life indicator was new to them, and they had not seen it in any other specification or literature previously reviewed.

INDOT stated that we should consider including a maximum junction temperature, perhaps 130°F, in the new specification. The specific temperature limit to be included should be researched.

6.6 COLORADO DEPARTMENT OF TRANSPORTATION

6.6.1 General Information

The Colorado Department of Transportation (CDOT) put their LED roadway luminaire special provision together in conjunction with a consultant. CDOT stated that they had a good relationship with their consultant and that a lot of the technical language in the special provision came from the consultant.

Their special provision is used for lighting on new roadway construction and applies to the heads rather than the arm or pole. CDOT has just begun installing LEDs on roadways. This plan started about a year ago when around 10,000 LED luminaires were purchased and spread around the state. CDOT has left it up to the localities to decide when they are going to install the luminaires, but the most likely scenario is that they will go in once a bulb burns out in the current HPS luminaire. These new luminaires will be located on state and federal highways.

CDOT stated that high mast, bridges, and tunnels all have their own special situations, so this specification does not apply to them. Because the latest version of their special provision came out in January 2014, they are not planning to update it in the near future.

6.6.2 Other Technologies

CDOT looked at plasma and induction for cost effectiveness and durability. Durability is important to CDOT because the state has large rural areas that make it difficult and time intensive to maintain the lights.

They haven't ruled out induction for tunnels yet, but a recent tunnel project is using LED luminaires.

CDOT stated, though, that all roadway luminaires would be LED in the future.

6.6.3 Bid Limitations

CDOT stated that in their RFPs, they call for bids to come from companies that are both manufacturers and suppliers rather than just suppliers. They have an approved product list (APL) but not for LEDs yet. However, the manufacturer selected for the 10,000-luminaire purchase made sure to get on the APL, regardless. CDOT said they would have an APL for LED luminaires in the future.

6.6.4 Warranty

CDOT requires a minimum of 10 years for warranties submitted, and the only companies that have balked at that requirement were less-reputable vendors. Their research showed that all reputable vendors could meet a 10-year warranty.

CDO's special provision requires a technical support contact to be available within 24 hours of the original call, and it requires that no additional cost be added for this technical support.

6.6.5 Testing

CDOT does not believe that retesting is an issue because they have a very technically defined specification and have also tested many LEDs in the field—and they work every time. However, CDOT said they may discuss retesting with their specification consultant to see whether it may be necessary and what the cost would be.

CDOT has had manufacturer representatives in the field during past installations, but they didn't require it in this specification.

6.6.6 Depreciation

CDOT does not see dirt depreciation or cleaning of the luminaires as an issue with LEDs. They use 70,000 hours in their specification and believe that this value is the most reasonable with the current technology, but they may change it in the future, depending on the development of LED luminaires.

6.6.7 Life-Cycle Cost Analysis

CDOT does not conduct a LCCA because they already decided to use LED luminaires.

6.6.8 Photocell

CDOT may consider expanding their specification to include wireless control in the future. However, they said that wireless was going to be difficult because of the mountainous terrain in the state.

During the development of the current specification, 5-pin or 7-pin photo control hadn't been decided upon or certified yet, which is why it isn't contained in the document. They are looking at possibly adding it in the future.

6.6.7 Comments About Proposed UI Specification

CDOT said that IDOT may want to consider tightening up the technical requirements of the specification and to do that a local consultant may be of some use.

CDOT also recommended that the proposed UI specification be modified to better define terms and possible to move the warranty start time to the letting date.

6.7 CONSULTANT FOR GEORGIA DEPARTMENT OF TRANSPORTATION

6.7.1 General Information

Joseph Marsh, the consultant, said that the GDOT specification is still a work in progress, but is close to being finalized. The final version will be similar in length to the proposed UI specification, but the wording will be different. GDOT's specification is used for roadway, bridge, tunnel, and high-mast luminaires. The GDOT specification is expected to refer to a specific document, when applicable, instead of stating a particular number (i.e., instead of stating a 70,000 hour lifetime, the specification will refer to the IES testing document). This is to ensure that the specification stays up to date when those documents are updated. However, where GDOT wants to be more stringent than the documents, a specific number is used.

The GDOT specification is also expected to be a bit conservative with numbers in the specification because the technology is still new.

Georgia has LED luminaires installed all over the state (numbering in the thousands). Many of them are installed around the new roundabouts being constructed in the state.

The specification that GDOT is developing will be used to approve fixtures they want to install in the future, such as the large project on the northwest corridor north of Atlanta on a three-lane freeway.

The GDOT administration wants to be on the cutting edge with respect to new technology.

6.7.2 Other Technologies

Georgia is also looking to install ceramic metal halide (CMH) and induction luminaires in order to test and compare them to LED luminaires. There is a current project in which three different tunnels will each be installed with one technology (one with 400 LED luminaires and the other two with 150 to 200 induction and CMH luminaires) in order to try to get a like-for-like comparison.

At I-400 and Winward Avenue, there was a one-for-one replacement with light-emitting plasma luminaires (LEP). GDOT said that the uniformity appeared to be significantly off, and before lighting the rest of the interchange, they conducted lighting calculations. So far, LEP has not been expanded in that area.

6.7.3 Testing/Qualification

GDOT maintains a qualified products list (QPL), which a company has to be on before they can bid on a project.

GDOT said that the requirement in the draft UI specification that bidders have a certain number of years of experience and number of installations may be difficult to justify because manufacturers with good products but without the required experience or installations could complain and possibly sue. GDOT also said that as long as a product is tested at an independent laboratory and passes all of the other requirements in a specification, it should be fine to be used to bid on a project.

6.7.4 Warranty

GDOT had a long discussion about the warranty, with many different lengths being suggested, but they finally settled on a 5-year warranty. There had also been a discussion about what would be covered under the warranty. Currently, GDOT specifies that all costs, including labor and transportation, will be borne by the manufacturer.

However, GDOT does not maintain its own maintenance crew, so the cities, counties, etc. take responsibility for any maintenance of the luminaires. GDOT said that even though the warranty was explicit, there may be an issue with communication between GDOT and the localities when the maintenance crew would just replace the luminaire and not request a replacement from the manufacturer, per the warranty. Unless there were failures in the initial installation period or soon thereafter, the replacements might be made outside the warranty.

6.7.5 Dirt Depreciation and Cleaning

The luminaire dirt depreciation factor (LDD) and luminaire lumen depreciation factor (LLD) were intentionally left out of the GDOT specification. LDD was omitted because there is still no consensus on what it should be; LLD was omitted because it is luminaire specific—so there is no “cover all” value. It was noted that IES currently funds a specification to study dirt depreciation over time.

There were some calculations made to find an overall light loss factor (LLF), which turned out to be 0.75 or lower, but the confidence wasn’t there to include it in the specification. GDOT decided on a value of 0.8 for LLF in order to encourage LED luminaires, but it does not appear in the specification.

GDOT has no plans to clean luminaires because, as previously discussed, they don’t have their own maintenance crews and the localities might decide not to clean them.

6.7.6 Life-Cycle Cost Analysis

Before a project begins, either a quick or an all-encompassing LCCA is conducted. The more in-depth analysis results in an Excel worksheet that includes maintenance costs along with an 8-year driver/part replacement cycle. HPS luminaires are on a 6-year re-lamping cycle that is provided by GDOT.

LEDs are still expensive, but the prices are coming down. The payback period is now around 12 years for a small roundabout project. The more comprehensive LCCA does not include very detail costs such as lost time for drivers, etc.

6.7.7 Photocell

At this time, there is only one item about a photo-control receptacle in GDOT’s specification. It discusses rotation restrictions because the photocell is currently not seen as integral.

6.8 CONSULTANT FOR CHAMPAIGN-URBANA, ILLINOIS

6.8.1 General Information

Mr. Burtness primarily works with municipalities, and one of the projects he is currently working on is with the City of Urbana to install 22 LED luminaires in a parking lot. He writes both specs and master planning documents for cities and municipalities. He said that the specs were always project based.

6.8.2 Other Technologies

He is currently working with LED and has worked with other technologies as well. He said that the U.S. Department of Energy was planning to tighten the regulations on ceramic metal halide (CMH) luminaires. He said that LED luminaires are a "replacement technology" and would be the standard technology in the near future, similar to the way flat screens replaced CRT monitors.

6.8.3 Limiting Bids

He said he writes his specs in a detailed manner to be as selective as possible for bids. The Urbana project had a pre-approval process that he found worked well for bidding. He said that a lot of the fly-by-night companies are going out of business and that the major manufacturers could meet IDOT's experience requirements.

6.8.4 Warranty

All of the specs he writes have a 10-year warranty requirement. In mid-2013, the standard was 5 years, but everyone switched to 10 after a couple of the major manufacturers made 10 years the standard.

His warranty requirements covered full materials delivered to the site, but not labor. Many municipalities, cities, etc. have their own maintenance staff, which makes replacement easy. He also said that requiring manufacturers to cover labor costs adds a lot of cost to the bid.

He said it was unclear what IDOT's labor cost requirement in the proposed specification actually covered. His warranties do not have technical support requirements because he and his clients never saw a need for it and didn't think the additional cost was necessary.

6.8.5 Depreciation

He does not expect a specific dirt depreciation factor; he puts the onus on manufacturers to explain and prove their own depreciation factors. This also includes the lumen loss factor.

He uses an L70 value of 50,000 hours as a minimum. Originally, manufacturers stated that 100,000 hours was easily met, but because they couldn't accurately predict how the luminaires would act over the 20 year timeline, they are backing up to 50,000 hours to coincide with the 10-year warranty that is provided. The manufacturers are confident their luminaires can function for 15 to 20 years, but they want to be a bit more realistic and conservative when it comes to depreciation. Luminaire failures usually occur in the first 6 months if they are defective, but if they pass that threshold, there usually are no major issues.

He said that some luminaire locations would probably require cleaning and that the design of luminaires for those locations should allow for cleaning of the luminaire via a fire hose or something of similar pressure.

6.8.6 Life-Cycle Cost Analysis

He does some first-order approximation LCCAs but only if the client needs a financial justification for installing LED luminaires. He recommends using a 4-year re-lamping cycle for HPS and CMH luminaires.

6.8.7 Photocells

He recommended that IDOT focus on how they want to specify for the light hitting the roadway (lumens on pavement). He said that this is much easier to do with the new photo controls. He also said that in the future, when luminaires are not being replaced in sets and there is a mix-and-match set of them along a roadway, photo controls will make it easy to have uniform light on the roadway.

He said that dimming could also be used to combat depreciation. For example, purchasing a luminaire that provided more lumens than necessary, then dimming it to 70% and slowly increasing the light levels over time so the light output is constant.

He said that 5- and 7-pin requirements in specs should be required to be wired for 0 to 10 V, and he expects that reliable light management technologies will be available in 2015.

CHAPTER 7 MANUFACTURER FEEDBACK ON THE DRAFT SPECIFICATIONS

Six manufacturers were asked to provide feedback on IDOT's draft proposed specification: Acuity, Cooper, Cree, GE, Philips, and Lumlux (Relume). Cooper, GE, and Relume participated in Phase I of this study. Acuity, Cree, and Philips are major lighting companies with a customer base in Illinois. A representative for each of the companies (often a technical person) was contacted via email. A copy of the draft proposed specification was emailed to them, and they were asked to send their written comments within 2 weeks. There was no phone interview with them.

Feedback from the six manufacturers was useful to the research team and the TRP, and it is summarized in this section. It should be noted that the proposed specification the manufacturers reviewed has since been modified, and it is different from the final proposed specification included in Appendix A.

Comments from the manufacturers are shown without identifying their affiliation, given that express consent to disclose their individual opinions was not requested. Comments are numbered for presentation purposes regardless of who provided them; thus, comment 1 in one section may have been provided by a different manufacturer than comment 1 in another section.

The original text of the draft specification submitted to the manufacturers is shown in *italic* font. Sections or paragraphs without comments are not shown.

7.1 COMMENTS ABOUT THE HEADER SECTION

Comment 1: "In the other DOT specification development projects that we have been involved in, they typically evolve over time from being very robust and quality focused at the start to somewhat watered down by the time they are released. Much of what you are specifying here is very standard and expected for an LED luminaire—UL certs, LM-79, TM-21, salt spray, 3g vibration, etc. Other requirements, such as end-of-life indication technology and 100% US made, may be somewhat "out of the norm" for most major streetlight manufacturers, and as such will end up driving the price of the fixture up significantly. You might end up specifying a $1,500 fixture when the rest of the country is buying $600 ones. It's the old trade-off between cost and quality, I guess."

Comment 2: "I see no reference to Design Lights Consortium specifications. These are very common now for these types of applications and you may consider referring to those."

7.2 COMMENTS ABOUT DESCRIPTION SECTION

Comment 1: "Why isn't there a normative references section in this document listing all the standards relevant to the document?"

7.3 GENERAL

"The entire luminaire including the housing, driver and optical assembly shall be manufactured and assembled in the continental U.S.A. The luminaire shall be assembled by and the luminaire housing and optical assembly shall be manufactured by the same manufacturer."

Comment 1: "I am curious if there is such an LED luminaire available on the market. I do not know of one! In general, I think it may be very difficult to find suitable LED luminaires that will meet some of the criteria you have spelled out here. In particular: I don't know of an LED luminaire that has 100% of its components manufactured in the US. It is possible to do, but I don't know of any manufacturer that has a standard product as such."

Comment 2: "I would eliminate this sentence or reference the appropriate "Buy America/Buy American statute. This statement as written is too vague as written. In addition by requiring USA made drivers and optical assemblies, this will limit lighting fixture suppliers that will be able to participate in the bid process. It will also limit lumen package options due to component availability. We would like to participate in bid process, but depending how this is worded could result in no-quote."

Comment 3: "There are very few LED luminaires that can claim "Made in USA" per the FTC guidelines. Most are "Assembled in USA" of components sourced in US and from foreign sources."

Comment 4: "Not likely to be all USA components (driver, circuit board, etc.). Final luminaire assembly in USA is more realistic."

"Internal Luminaire Connections. Quick connect/disconnect plugs shall be supplied between the discrete electrical components within the luminaire such as the driver, surge protection device, terminal block and optical assembly for easy removal. The quick connect/disconnect plugs shall be operable without the use of tools while wearing insulated gloves."

Comment 1: "Why would a quick disconnect be required on the terminal block?"

Comment 2: "What type of disconnect would this be?"

"Circuiting should be designed such that individual LED failures will not impact the operation of the other LED's."

Comment 1: "There are two types of LED failures and 2 basic wring topologies. Short circuit and open circuit LED failures and wiring that is series and wiring that is parallel/series. In general shorts are protected against in both topologies to some extent but with differing effect based on topology. In cases of open circuits (low probability event) either topology is susceptible to multi-LED failures in event of an open circuit. To our knowledge all LED Luminaire suppliers used one of the two topologies."

"Manufacturer Experience. The luminaire shall be designed to an expected 30 year lifespan and shall be a standard product of an established roadway luminaire manufacturer."

Comment 1: "Most are not designed for this. 20 years is more likely."

Comment 2: "A 30 year service life generally exceeds the life span that can be modeled using modeling methods and realistic and obtainable reliability information to state such with any confidence. 20 years is a more realistic expected service life, but even at that point there is extremely limited data that can be used to predict onset of wear out and wear out failure rate growth."

"Labels, Decals and Standards. All luminaires shall have labels and decals in accordance with ANSI C136.22. The luminaire shall be UL Listed and shall be in compliance with UL 8750 and UL 1598 as suitable for wet locations and direct spray. It shall be identified as such by the holographic UL tag/sticker on the inside of the luminaire."

Comment 1: "UL, ETL, and CSA are all approved test organizations to perform and List products to UL test standards. There are many manufacturers that use Intertek ETL for UL certification. Stating that products must be UL Listed will unnecessarily eliminate many mfrs."

Comment 2: "Replace UL listed with certified by National Recognized Testing Laboratory (NRTL) to conform to. Remove direct spray."

Comment 3: "Direct spray from any direction is not a criteria in UL wet location. This must be defined in the form of a referenced test standard (such as an IP rating per IEC 60529) or by documenting the owner's desired test protocol."

Comment 4: "Define what standard. Is this a specification for an IP rating?"

"The luminaire shall be in compliance with ANSI C136.37. The luminaire and components, shall be RoHS compliant and the luminaire shall be listed and labeled in accordance with the U.S. Department of Energy Lighting Facts Program: http://www.lightingfacts.com."

Comment 1: "RoHS has two versions. You must be explicit about the year version. Also unless the product is CE marked, RoHS compliance in US generally means the product is compliant with the material restrictions of RoHS, and should be stated as such."

Comment 2: "We submit all luminaires to the Design Lights Consortium for approval. DLC was formed long before the Lighting facts program and provides similar information to the customers. We can obtain Lighting Facts labels if required."

Comment 3: "RoHS is European directive that the US does not have any influence. Therefore it is difficult for US companies to strictly adhere to RoHS and there are not any penalties for those not in compliance. Hence, MSSLC and ANSI C136 do not require luminaires to be RoHS certified. However, LED drivers and LED light arrays are sold internationally and hence these components are RoHS listed."

Comment 4: "We do not recommend using DOE LF in this case. DOE LF does not set a performance metric minimum and is a "truth in advertising" program. We recommend using DLC's QPL as the performance requirements with its attendant DOE LF Verification Testing program as a means to ensure ongoing compliance with ratings."

"Photometric Performance. Photometric and colorimetric values shall be determined from total spectral radiant flux measurements using a spectroradiometer."

Comment 1: "This statement should simply reference the appropriate EISNA test methodology such as LM-79 rather than go into the instrumentation details."

"Photometric testing shall be according to IESNA recommendations and include complete LM-79 test reports. Data reports as a minimum shall yield an isofootcandle chart, with max candela point and half candela trace indicated, an isocandela diagram, maximum plane and maximum cone plots of candela, a candlepower table (house and street side), a coefficient of utilization chart, a luminous flux distribution table, spectral distribution plots, chromaticity plots, and other standard report outputs of the above mentioned tests."

Comment 1: "Recommends IDOT review the desired minimum reporting requirements based on what they will actually use confirmation and verification. The iso-candela plot has fallen into disuse and is generally no longer informative to end users since the advent of computer based viewers and application software. Minimize the necessary reporting to what IDOT will really look at.”

“LM-79 and LM-80 Testing. Luminaires shall be tested according to IESNA LM-79 and LM-80.”

Comment 1: “LM-80 is testing protocol to determine LLD for the LED—not a luminaire test”.

Comment 2: “LM-80 is an inappropriate item in this as it is specific to LED packages and not luminaires.”

Comment 3: “This is not a luminaire test.”

“Lumen maintenance reports shall be according to IES LM-80 at the specified drive current with a minimum of 20 light source samples tested for a minimum of 10,000 hours.”

Comment 1: “LM-80 is a good reliability metric, but only covers lumen maintenance, not catastrophic failures. I do realize you call out an acceptance of no more than 10% failing, however you may consider defining a failure mode. I suggest “If the LED fails catastrophically, the predominant failure mode should be a short circuit. If the predominant failure mode is an open circuit, provisions need to be made to make sure the remainder of the LEDs in the same string are powered” or something along those lines.”

Comment 2: “Lumen maintenance reports and projections are covered by LM-80 (Lumen Maintenance Testing and Data Reporting) and TM-21 (Projecting based on LM-80 data). LM-80 states a minimum of 6000 h data but IDOT can require longer if desired. Requiring the report at the design drive current is not a good idea as LED manufacturer’s test a series of drive currents and luminaire designers may operate at points between or below one of the published LM-80 datasets. TM-21 provides guidance on how to use versus the In-Situ operating conditions.”

Comment 3: “LM-80 requires 6000 hours. The 10,000 hour requirement could eliminate products with newer generation, higher performance LEDs.”

Comment 4: “LM-80 requires minimum of 6000 hours. 10,000 hours could limit new LEDs with better performance characteristics from being included.”

“Thermal Testing. In Situ Temperature Measurement Testing (ISTMT) must be recognized through UL’s Data Acceptance Program. The LED light source(s) manufacturer must prescribe/indicate a temperature measurement point on the light source(s). The temperature measurement point must be accessible to allow temporary attachment of a thermocouple for measurement of In Situ Temperature. Access via a temporary hole in the housing, tightly resealed during testing with putty or other flexible sealant is allowable.”

Comment 1: “This is only one of the paths to a credentialed ISTMT report. Make sure you don’t exclude the others.”

Comment 2: “UL1598 defines how ISTMT testing is completed, so I would simplify this paragraph or not include. IDOT should have every right to review ISTMT reports and would emphasize this be part of the submittal package as opposed to describing the procedure.”

“…with bird-fouling appropriately simulated (and documented by photograph)…”

Comment 3: “This is not part of the standard test procedure.”

Comment 4: "'Bird fouling' should be eliminated. It is not recognized by UL1598. Therefore, there will be lack of uniformity among how manufacturers test their products and users evaluate the testing. In addition, I have not seen empirical data to suggest this will be an issue. Thermal footprint of LEDs have improved greatly, when this was an initial concern and little was known about SSL."

Comment 5: "This bird fouling is not required under UL1598 or likely to be representative of the majority of the installed population of fixtures. If IDOT wants this it will need to define the extent and means of fouling simulation so that it can be consistently applied to all suppliers."

"TM-21 Lumen Maintenance Projection. The luminaire shall have long term lumen maintenance documented according to the IESNA TM-21. The submitted calculations shall incorporate ISTMT and LM-80 data with TM-21 inputs and reports according to the Energy Star TM-21 calculator. Ambient temperature shall be 25°C, mean temperature shall be 12°C, and maximum temperature shall be 47°C."

Comment 1: "From the Minnesota DOT Specification, the call for LLF to be determined by each manufacturer based on their TM21 Report as a Specific Ambient Temperature and Specific Hours: We personally think that a Blanket LLF is a dis-service to the DOT, because the State loses the Lifetime, Wattage Savings, Lumen Output, Driver Life advantages from a company that does proper junction temperature Heat Management. (See the Power Point we presented when you came to visit Holophane /AEL last August.)"

Comment 2: "We perform thermal tests at 25, 40 and 50C ambient at a worst case scenario with the maximum amount of components and options. LED case temperatures are indicated on the thermal report along with the driver case temperatures. These temperatures are lower than the maximum indicated on the LED LM-80 report and driver specification sheet. Limiting LED case temperatures to a certain degree assumes that all LEDs are equal which is not true."

Comment 3: "Standard computations are at 25C. Not clear in this requirement if the information request is for all or some of the temperatures."

Comment 4: "I do not know what this means. There is no way to project lumen maintenance with TM-21 for temperatures other than 25 degrees that I am aware of."

Comment 5: "What do these temperatures refer to?"

7.4 SUBMITTAL REQUIREMENTS

"The Contractor shall also submit five (5) hard copies and one (1) digital copy."

Comment 1: "Hard copies are not very "green" and create time management issues. Recommend all submittals be handled electronically."

"2) Quantity of LEDs in the luminaire and the LED drive current."

Comment 1: "Quantity of LED has little bearing on what the end user experiences in the form of operating life. For example I could use 4 multi-chip LEDs with 4 die per part or one 24 die LED on COB form or 24 single LEDs. In each case my "LED" count would appear to be radically different but as the die level identical. Similar comments could be made about the drive current due to the internal wiring differences of the3 described approaches. But at the die level they would all be identical."

“3) Total luminaire input wattage and total luminaire current at the system operating voltage.”

Comment 1: “Most systems are multivolt 120-277VAC. You need to be specific about what information you want in a multi-volt system.”

“4) LED efficacy expressed in lumens per watt (lpw).”

Comment 1: “For the LED package itself, or luminaire efficacy? The latter is the more useful number.”

“7) Luminaire IESNA distribution classification and TM-15 BUG rating.”

Comment 1: “IESNA has deprecated the old cutoff classing. You need to be specific about what classing information you want. You also need to be aware that lateral classing (e.g. Type 2) does not ensure application interchangeability. We recommend IDOT consider application based approach and more generic descriptors. Or structure the specification to avoid making Typing an acceptance criteria.”

“9) Isocandela diagram”

Comment 1: “No generally used in daily practice. Suggest no requiring.”

“10) Documentation of manufacturers experience and verification that luminaires were made in the U.S.A. as specified in section III.”

Comment 1: “This wording really needs to change—“Made in the USA” means that virtually all components (including the driver and chips”) would need to be manufactured in the US.”

Comment 2: “Made in USA has strict FTC criteria not generally satisfied by most LED luminaire manufacturers. Suggest using Assembled in USA.”

“13) Thermal Test reports as specified in section III”

Comment 1: “It is not necessary to wade through hundreds of pages of submitted test reports (Thermal, LM79, LM80, TM21, etc.) when Lighting Facts is required. To get a LF label, manufacturers must submit all of this to DOE for independent validation and approval.”

“15) Salt spray test reports and certification as specified in section VI.”

Comment 1: “Proper terminology is Salt Fog.”

7.5 WARRANTY

“1) No light output from more than 10 percent of the luminaire’s discrete LEDs.”

Comment 1: “15%“

“2) The luminaire is operating below its original lumen maintenance curve supplied by the manufacturer.”

Comment 1: “There is not a practical way to test compliance. Similar to HID lamps, LED life ratings are based on 50% failure rate.”

Comment 2: “Lumen maintenance, like all performance parameters is a continuum of levels. Lxx values are typically published based on B50 (average) and product exhibit variation above and below this level. A single sample measurement is not enough to confirm. Also given variation all units would have to be tested for 0h outputs before installation to set an initial baseline for flux. None of this is workable.”

Comment 3: “Items 2, 4, and 5 are not a part of standard warranties. Complicated warranty negotiations will ensue, with these things needing to be defined much more clearly (how to measure and “prove” failure, etc.).”

“3) The power supplied by the driver(s) is not within the specified range.”

Comment 1: “Do you mean supplied to the LED array or consumed by the product?”

Comment 2: “Challenge is same as 2.”

“4) The surge protector fails to pass IEEE/ANSI C62.41.2 criteria.”

Comment 1: “SPD is sacrificial component. It will be difficult to prove failure is premature or due to surges that exceed rating, poor infrastructure, etc.”

Comment 2: “This doe no reference the proper standard. You either have to provide full definition or reference the MSSLC document or the draft version of ANSI C136.2-2014.”

“5) The color temperature has shifted by more than 300 K.”

Comment 1: “Same as 2, 3, and 4, not a practical method to test and enforce. Under IX LED Optical Assembly: The optical assembly shall utilize high brightness, long life, minimum 70 CRI, 4,000K color temperature (± 400K) LEDs binned in accordance with ANSI C78.377. Lenses shall be UV-stabilized polycarbonate or acrylic.”

Comment 2: “This allowance should be specific to the CCT and it should be consistent with the knowledge on CCT variation in the market which is generally covered by DOE LF Verification Testing tolerances of ± 8.4% of nominal CCT.”

“The warranty period shall begin on the date of project final acceptance for lighting as documented in the Resident Engineer’s project notes.”

Comment 1: “This is too open-ended. Product failures could be the result of other sources (drastic weather systems, poor infrastructure, installation practices, etc.) than the luminaire, but the luminaire manufacture would bear the brunt of the warranty costs. There needs to an absolute date to define when warranty period starts.”

Comment 2: “This could be problematic unless our warranty people have a way to determine the date of final acceptance. Once the fixtures are installed we have a date code but no order number to track that date code to—We would need to come up with a method to handle this.”

“The failure of individual luminaires during the warranty period shall be replaced by the LED luminaire manufacturer at no cost to the Department.”

Comment 1: “Due to defective material or workmanship. We really need to discuss this with our warranty group—both the extent of material and labor and the selection of the contractor.”

“Replacement luminaires shall be identical to the original luminaires unless they are no longer available in which case the replacement luminaires shall be selected by the Department on an equal to or better basis.”

Comment 1: “We will not honor custom warranties as stated. Too much risk and would merit a no quote.”

“Replacement costs shall include all material, equipment, labor, traffic control, etc. to replace all defective luminaires on the project plus the cost of independent testing of the replacement luminaires as described herein.”

Comment 1: “I think it may be difficult to find an LED luminaire manufacturer that would agree to pay for all labor and equipment costs related to warranty work. As I stated in my comments in the draft, most manufacturers would feel uncomfortable to agreeing to something they have absolutely no cost control over. They may end up paying $10,000 in labor to replace a $25 component, and this has always been the problem with requiring manufacturers to pay for labor. Have any manufacturer indicated that they would be willing to pay for labor? We have never come across one that would agree to this, because labor rates, local union rules, equipment expenses, etc. would vary greatly depending on location. A manufacturer could end up paying $10,000 or more to have a $25 power supply changed.”

“Near the end of the warranty period a luminaire shall be taken down and tested to verify it is still in compliance with this specification.”

Comment 1: “A single sample test can be anywhere in the tolerance range. Verification tolerance must account for variation and measurement uncertainty. This is extremely problematic and has not been addressed comprehensively by anyone in the industry. A manufacturer should not agree to this until the verification method and criteria are fully defined.”

Comment 2: “It would be Illinois DOT’s intention to remove one “representative” fixture at the end of the warranty period, have it photometrically tested, and use that as a representative sample for the entire population of fixtures. If the tested sample falls below the stated projected performance values, the entire population of fixtures would potentially need to be replaced. Very aggressive. Again, I’m not sure if this would get past any manufacturer’s legal team.”

Comment 3: “This reads to me like a warranty on lumen maintenance – which is very difficult since we will not be aware of all the conditions the fixture may be subjected to in the field.”

Comment 4: “We will not honor custom warranties as stated. Too much risk and would merit a no quote.”

“To satisfy this requirement IDOT will select and remove a working luminaire and ship this luminaire to an independent NVLAP certified laboratory.”

Comment 1: “Proper term is “accredited”. Can Manufacturer use an internal NVLAP accredited test facility if witnessed by an IDOT representative? This would be much more cost effective for IDOT.”

“At the request of the luminaire manufacturer, a second luminaire will be selected, removed from service, and shipped to the laboratory for testing to determine warranty compliance.”

Comment 1: “OK, but what happens if the second one passes? Need to define the decision protocol for test results that are acceptable.”

“The LED luminaire manufacturer’s liability for this end of warranty evaluation shall be limited to new replacement luminaires as deemed by the Department to be equal or better, Liability shall also include independent testing and shipment of all replacement luminaires to the project jobsite.”

Comment 1: “Not consistent with most Manufacturer’s limited warranty policies.”

“The warranty shall include all luminaire delivery and handling costs. Luminaires and accessories shall be securely packaged, labeled, and shipped to avoid damage or distortion. Luminaires and accessories shall be packaged for shipment in a secure manner to prevent soiling, physical damage, or moisture damage prior to installation. Provide for storage inspection by the Resident Engineer after luminaires and accessories have been delivered. This inspection is at no additional cost to the Department. All cartons shall be clearly marked with the proper identification of Manufacturer, catalogue number, luminaire designation, and proper storage/handling instructions.”

Comment 1: “Any modification to the standard warranty would have to be approved by the post sales department.”

Comment 2: “Please clarify storage item.”

7.6 HOUSING

“Material. The luminaire shall be a single, self-contained device, not requiring on-site assembly for installation. The power supply for the luminaire shall be integral to the unit.”

Comment 1: “Not sure this adds anything to the requirement. Suggest dropping “self-contained”.”

“The luminaire housing shall be fabricated from materials that are designed to withstand a 5000 hour salt spray test as specified in ASTM B117 with a minimum rating of six.”

Comment 1: “Recommend a minimum rating of 4 to qualify more products.”

Comment 2: “The standard finish on our outdoor LED will withstand over 3000 hours of salt spray which is sufficient for applications that are not on the coast. Our standard HID finish is tested to 1000 hours. We need to clarify this. The statement says “the luminaire housing”—not the “luminaire house paint finish” or “coating”. It could be that they are wanting to determine if the actual metal is designed to withstand the salt spray. They address the finish later on in the specification.”

Comment 3: “While this is definitely a robust finish durability rating, it exceeds the documented capability of ALL the HID luminaires IDOT currently purchases and is generally not necessary for 20 year durability in an in-land application condition.”

“The luminaire shall be provided with a leveling surface and shall be capable of being tilted by ±5 degrees in 1 degree increments and rotated to any degree with respect to the supporting arm.”

Comment 1: "Standard leveling steps are at 2.5 degrees each and will support adjustment of ± 5 degrees. This has been a standard on roadway lighting luminaires for over 60 years. I would suggest using the wording from ANSI C136.14—Permit leveling through no less than ± 3 degrees from the axis of the attachment."

Comment 2: "2.5 degree increments are most common among roadway luminaires."

"The housing shall be designed to prevent the accumulation of water, ice, dirt and debris and to ensure maximum heat dissipation."

Comment 1: "Need to define the ice testing protocol and accumulation criteria if you are going to make this statement."

"The effective projected area of the luminaire shall not exceed 1.4 sq. ft. The total weight of luminaire and accessories shall not exceed 70 lbs."

Comment 1: "Is this intended to capture weight and effective projected area of high mast or offset luminaires? If not weight of cobra head replacement should be less than 40lbs. This will be impactful for designing new construction with lighter weight poles."

Comment 2: "Seems excessively heavy. Consider lowering to 60 or 50 lbs. or setting a weight per watt rule since housing size and mass scale with watts for LED."

"A passive cooling method shall be employed to manage thermal output of the LED light engine and power supply."

Comment 1: "May be better to state what is not allowed (fans, heat pipes, etc.). Heat pipes without fans considered passive in computer world."

"The luminaire shall be designed to accommodate a 7-pin, twist-lock photo-control receptacle in accordance with ANSI C136.41."

Comment 1: "Not a 3-prong NEMA type?"

Comment 2: "Unless you have plans to use the additional 2 pins, you may be OK allowing a 5 pin version of the 7 pin standard with the dimming pins as mandatory."

Comment 3: "From the New MSSLC Roadway Specification released yesterday: ANSI C136.41 7-Pin Receptacle (You would use 1.1.3)."

"Vibration testing shall be run using the same luminaire in all three axes."

Comment 1: "OK … standard allows for new sample per axis, but OK to require."

"Hardware. All hardware shall be stainless steel. Captive screws are required on any components that require maintenance after installation."

Comment 1: "SS not standard construction in many assemblies, but possible at incremental cost. Keep in mind use of uncoated SS screws in aluminum results in galvanic action that eventually welds the SS to the aluminum and can prevent disassembly or repair. Consider the issue."

Comment 2: "All exterior hardware on our LED luminaires is stainless steel, interior hardware is zinc plated or galvanized. Should not be an issue to supply stainless steel—IDOT has this requirement on HID also."

7.7 DRIVER

"The driver shall be installed in a manner to keep it mechanically and thermally separated from the LED array heat sink. Driver shall have a typical self-rise temperature of 45°C at the maximum load in open air without a heat sink."

Comment 1: "This is a very loosely defined requirement. In all cases the driver is adjacent to the light source and received heat thru conduction, convection, or radiation. Suggest either defining an actual requirement or dropping. Not a useful requirement (temperature). What you want to ensure that when the driver is in the fixture at the expected fixture ambient that the drive case temperature is consistent with the life requirement."

Comment 2: "This "BTR" value was not specified on any of the vendor specification sheets—we would need to get that information from them."

"The driver shall tolerate sustained open and short circuit output conditions without damage."

Comment 1: "Might want to use indefinite vs sustained."

Comment 2: "What is the definition of "sustained"? If these conditions exist at the output of the driver, then luminaire needs to be replaced."

"Power supply shall have a Class A sound rating per ANSI Standard C62.41."

Comment 1: "C62.41 does not specify sound ratings; standard is centered on surge ratings."

Comment 2: "ANSI C62.41 has no relevance to sound … to our knowledge there is no standard for sound rating that can be referenced. You need to define in the specification or find a standard."

"Ingress Protection. The driver Ingress Protection (IP) rating as defined in the NEMA IEC 60529 standard shall have an IP66 rating."

Comment 1: "Recommend specifying UL registered component suitable for intended use instead of IP rating, to qualify more products."

"Input Voltage. The driver shall be suitable for operation over a range of 120 to 277 volts or 347 to 480 volts as required by the system operating voltage."

Comment 1: "Do you have a 347V operating condition? Might want to restate."

"Operating Temperature. The driver shall have an operating ambient temperature range of –40°C to 55°C."

Comment 1: "The upper temp limit needs to be higher based on self-rise and fixture ambient. Suggest 70C."

"Driver Life. The driver shall provide a life time of 100,000 hours at ≤ 65°C TC and 50,000 hours at ≤ 75°C TC with a minimum 90% survival."

Comment 1: "this is unique to one driver supplier. I would specify driver life for a given outside ambient temperature, e.g. driver 100,000 hours for maximum 25C ambient."

Comment 2: "The driver life listed is specific to Advance class 2 drivers which are limited to 100 watt output. We have upgraded to class 1 drivers (150 watt maximum output) in order to reduce components per customer requests. The class 1 full dimming driver from Advance shows a minimum of 65,000 hours at a Tcase temp of 100C and below to a maximum of 80,000 hours at a Tcase temperature of 35C. This would equate to a minimum operational like of 15.5 years on the driver which is consistent with the TM-21 life prediction on the LED which is limited to 60,000 hours."

Comment 3: "This requirement needs to be tailored to be consistent with differences in thermal management in suppliers. The goal is to ensure 100,000h life rating at whatever temp the driver runs at in the fixture at the desired average annual ambient. Lots of combinations would work. One specific requirement does not work on all supplier options."

"Power Factor. Drivers shall maintain a power factor of 0.9 or higher under all assigned loading conditions and total harmonic distortion of less than 20% and <15% of THD 3rd harmonic."

Comment 1: "Define assigned loading conditions. 3rd harmonic not typically reports in THD measurement … requires additional test documentation not normally present in photometric test apparatus used to collect this info. Instrumentation can collect it, but power meter must be programed to supply and sphere or gonio systems must collect and log for reporting."

"Driver efficiency. Efficiency of the driver is defined by the ratio of output power and input power. The driver shall deliver a maximum efficiency of >93% at maximum load and an efficiency of >90% for the driver operating at 50% power."

Comment 1: "Efficiency of the driver is determined by the voltage and percentage of output. Delivered lumens per watt from the luminaire is the best way to determine efficiency. The ratio they have requested is what codes and standards specify—and is noted on the driver suppliers specs sheets—although >than 93% may be a little high."

Comment 2: "Many commercial available drivers are 85% efficient when operating at 50% power. I would specify 90% efficiency at full load."

Comment 3: "Focusing on driver efficiency does no ensure the most efficient lighting solution. CU and Source efficacy can swamp minor differences in efficiency. Recommend setting the component level floor slightly lower and focusing on some kind of LPD metric for judging solution efficiency."

"End of Life Indication. The driver shall be configurable to indicate the end of the predicted lifetime of the LED module. The luminaire manufacturer shall define the time at which the end user is alerted to the end of life. When the end of life activation time is reached, the driver shall flash for 2.5 seconds and then continue normal operation. LED flashing shall occur every time at startup once the module's working end of life hours are exceeded."

Comment 1: "This is specific to only one type of driver on the market, and therefore limits product choice."

Comment 2: "With the calculated L70 numbers of our LED luminaires now exceeding 300,000 hours and end of life indicator on the driver appears to be an outdated option. The driver will fail long before the L70 number is reached. I suggest this be taken out of the specification until the standard is complete."

Comment 3: "This is limited to ONE driver supplier and the function could be emulated by a driver and control system with monitoring capability."

Comment 4: "This is not a good method for end-of-life indication because it requires a line crew to available when the product flashes. Flashing on-off is also not good for the electrical components. Potential for control system to log the hours of operation and send an email notification or turn unit off is better solution. However, the DOT may not want an email notification because of the liability should they not replace the luminaire in a timely manner."

"Electrical Interference. The driver shall meet the Electromagnetic Compatibility (EMC) requirements per Comité International Spécial des Perturbations Radioélectriques (CISPR) 15 Ed 7.2 and FCC Title 47 Code of Federal Regulations (CFR) Part 15 Class A."

Comment 1: "In US, only FCC is required. CISPR 15 would be for EU norm countries."

"LED drive current. Driver Output Current, Range and Tolerance. The driver shall be programmable to deliver any current between 200mA and 750mA with 10mA steps and shall deliver the current with a 5% tolerance from unit-to-unit over the complete temperature range of the driver (–40°C to 80°C TC). Rated lumens used shall be obtained at a 750mA drive current."

Comment 1: "This is specific to only one type of driver on the market, and therefore limits product choice. Specifying a particular attribute like this is not recommended, as it limits product choices and value"

Comment 2: "Any specification written that specifies output current limits the technology. Let manufacturer have flexibility to optimize the design."

Comment 3: "Rated lumens used shall be obtained at a 750mA drive current. We now deliver over 100 lumens per watt at a 1050mA drive current, lowering the drive current to 700mA will only increase the lumens per watt and increase the cost of the luminaires due to the additional material required for the same lumen output. The new LEDs are designed for the higher drive currents and maintain flux output better that the old LEDs at the lower drive currents. Due to this technology continuing to make strides forward at an unprecedented pace I suggest this phrase be modified to include future LED designs. The drive current of the LED cannot exceed the LED manufacturer's absolute maximum rating."

Comment 4: "Why? What benefit is this to IDOT versus selectable currents and desired flux levels? Recommend reviewing this criterion as it appears to be a supplier specific specification not based in application needs."

"Thermal Fold Back. The driver shall reduce the current to the LED module if the driver is overheating due to abnormal conditions. The driver shall cut-off or reduce the current when the driver case temperature is 5°C above its limit (80°C)."

Comment 1: "This statement is unique to 1 driver manufacturer."

Comment 2: "The limit may be specific to the driver supplier/design. The requirement should state 5°C over the drivers design case temperature limit rather than a specific temp."

“Dimming. The driver shall have dimming capability. The driver shall accept a dimming control signal that is compliant with the 0-10V protocol (as specified in IEC 60929 Annex E, as applicable) and the DALI protocol (as specified in IEC 62386-101/102/207).”

Comment 1: “The method of dimming LEDs is not prescribed. There are in general two ways to dim LEDs: using PWM or continuous change of drive current. If dimming to low light levels is required (<10% of maximum), I strongly recommend to specify PWM type dimming, as this guarantees consistency in flux and color point over the dimming range. LEDs tend to drift unpredictably from their nominal drive condition when driven at very low currents. This is not a reliability but a lit appearance issue.”

Comment 2: “Dali is the future; 0–10v is now. Limited offering on Dali drivers; even smaller offering on Dali compatible controls.”

Comment 3: “Our current 0–10V dimming drivers are not DALI. We will be able to supply DALI drivers when available from our suppliers.”

Comment 4: “This also limits driver choices. Is it certain that this is needed for a specific control system that will be specified?”

Comment 5: “Why does IDOT want Dali? 0-10V is a nearly universal control input for dimming function by many 3rd party control solutions. Why both? Again appears to be a supplier specific specification attempt”

“Surge Protection. The driver internal surge protection TVSS (transient voltage surge suppression) shall handle surges in the 2–3kV range for the 1.2/50usec combi-pulse (2ohm).”

Comment 1: “Each driver will differ in integral surge protection. The emphasis of specification should be system protection against electrical surges. This should be documented in SPD portion of specification.”

Comment 2: “The surge protection ration should be based on the luminaire product need not on the driver sub system.”

“Leakage current. The driver shall comply with safety standards in accordance with IEC 61347-1. In accordance to this standard, the following safety requirements shall be met…”

Comment 1: “This needs review for consistency with UL requirements. It appears an IEC standard was copied, but for North American products only UL requirements should be present.”

“Electrical testing. Electrical testing shall conform to NEMA and ANSI standards and as a minimum, shall yield a complete check of wiring connections, a dielectric test of the driver(s), total driver losses in watts and percent of input, a graph of the LED optical performance based on driver distortion, regulation data, LED current crest factor, power factor (minimum over the design range of input voltage at nominal voltage for the optical assembly), a table of driver characteristics showing input amperes, watts, and power factor, and the corresponding output volts, amperes, watts and LED crest factor as well as driver losses over the range of input power values from plus to minus 20 percent in 1 percent intervals. In addition, data shall show the peak temperature changes of the driver and the harmonic distortion associated with these power fluctuations.”

Comment 1: “Is this a submittal requirement? It is often not easy to obtain.”

Comment 2: "I would state the actual standard that product is to comply with. I am not familiar with the standard that is captured by the preceding paragraph or the purpose of the test. Input power should not vary more than ± 3% for any given load. Hence, I am not sure how you'd vary the input power from ± 20%. What would be considered nominal input power?"

Comment 3: "This needs review. None of this is normal production testing per UL requirements. If this is some form of design validation submission, then the relevant standards need to be identified for each test requirement so that the information supplied is consistent from manufacturer to manufacturer."

"Wiring. Wiring within the electrical enclosure shall be rated at 600v, 105°C or higher."

Comment 1: "Not all wiring needs to be 600V. Low voltage DC wiring from driver to LED could be."

7.8 SURGE PROTECTION DEVICE (SPD)

"This section describes the materials and installation requirements for surge protective devices for the protection of luminaire. SPD shall be UL 1449 labeled as Type 4 and integral part of the luminaire…"

Comment 1: "Suggest dropping this content and substituting ANSI C136.2-22014 Draft content at "Standard" or "Enhanced" specification levels to fully specify the system level surge performance criteria."

"Surge protection device features…"

Comment 1: "Do not specify device characteristics. Specify the system level surge performance requirement and the test standard. Use ANSI C136.2-2014 Draft."

"8) Green LED operational status indicator"

Comment 1: "The green indicator light is not an option or required on our SPD which will open the circuit upon failure of the MOVs. MCOV on our standard module is 420V on the 120–347 module and 510 on the 480V module."

7.9 LED OPTICAL ASSEMBLY

"The LED optical assembly shall be a scalable array consisting of discrete LED panels or modules. Each panel or module shall be rotatable by 90° and shall have a minimum IP rating of 66. The luminaire shall have an uplight BUG rating of U0."

Comment 1: "What is rationale or technical need for rotatable panels in roadway applications?"

"The optical assembly shall utilize high brightness, long life, minimum 70 CRI, 4,000K color temperature (± 400K). LEDs binned in accordance with ANSI C78.377. Lenses shall be UV-stabilized polycarbonate or acrylic."

Comment 1: "Specification calls out both 4000 K ± 400K and ANSI C78.377, which are not exactly the same. ANSI c78.377 is more complete as it specifies the color space in x/y coordinates. Specifying only a CCT range leaves the possibility of providing LEDs that are far off the black-body locus but still meet the CCT specification (excessively pinkish or greenish hues). If color consistency between luminaires is a major concern, you might even consider specifying LEDs with "center points of color distribution per ANSI C78.377 with a maximum of 5SDCM around that point."

Comment 2: “Under V. Warranty: The color temperature has shifted by more than 300K.”

Comment 3: “OK but exceeds DOE and disagrees with statement earlier in the document. Include glass as an option. Obviously more durable but currently excluded.”

“Lumen depreciation at 50,000 hours of operation shall not exceed 15% of initial lumen output at the specified LED drive current and an ambient temperature of 40°C”

Comment 1: “Industry standard testing used for lumen maintenance calculations is at 25C.”

Comment 2: “There is no climate rational to require 40C. 25C maximum as a convenient standard temp or suggest regional average annual night time temperatures.”

“The luminaire shall not utilize any type of external reflectors to direct the light from the LEDs. An external reflector is defined as any device outside of the LED panel, lens, or die.”

Comment 1: “This needs more clarification and structure to allow the full range of acceptable constructions. Alternate terminology might be better. For example reflector based systems enclosed with plate glass. Not obvious how what you’ve stated relates to that.”

7.10 INDEPENDENT TESTING AND ACCEPTANCE

“Luminaires shall be tested at an NVLAP certified laboratory approved for each of the required tests. All costs associated with luminaire testing shall be included in the bid price of the luminaire.”

Comment 1: “Change “certified” for “accredited”. Please provide list of specific testing that would be applied on a per luminaire basis for clarity.”

“The testing performed shall include mechanical, photometric, and electrical testing. Visual inspection shall be performed by the independent witness at the time the luminaires are randomly selected for testing.”

Comment 1: “Suggest an explicit list of specific tests that need witness testing rather than generic buckets of tests. This will help suppliers be consistent on planning and expense estimates for the required testing.”

“Should any of the tested luminaires of a given type, distribution, and wattage fail to satisfy the specifications and perform according to approved submittal information, the luminaire of that type, distribution, and wattage shall be unacceptable and shall be replaced.”

Comment 1: “We are cautions against the use of classic typing methods and recommends focusing on an application performance screening criteria as the photometric pass/fail. Electrical and ay photometric parameter tolerances should be clearly specified in this specification (flux, watts, PF, THD, CRI, CCT, etc.).”

7.11 EXHIBIT A

“Shipping Carton Undamaged”

Comment 1: “Shipping cartons are designed to absorb damage to protect the product. Some level of expected damage should be allowed.”

“Correct seal of the housing and individual LEDs”

Comment 1: “How will “correctness” be defined?”

“Surfaces are smooth and polished to prevent dirt accumulation.”

Comment 1: “Other than optical surfaces there are not many polished surfaces in a luminaire. In fact many surfaces are intentionally textured for cosmetic control purposes. Also die castings inherently have some flash. So this statement needs to be revised to reflect acceptable levels of known finish conditions.”

“Driver(s) correctly mounted to heat sink to maximize heat dissipation.”

Comment 1: “Drivers are not generally mounted to what is considered the heat sink in an LED fixture. The heat sink is generally considered the heat transfer body for the LEDs and earlier in the document the specification said to ensure the driver was thermally decoupled from the LEDs. Can’t have it both ways.”

“Electrical compartment properly gasketed and sealed.”

Comment 1: “Unless IDOT is requiring higher than UL Wet Location, then there may not be gasketing for the gear compartment.”

“All fasteners are stainless steel, tool-less, and captive.”

Comment 1: “No possible to have all fasteners to be tool-less … only specific ones.”

“Electrical components securely mounted on removable tray with quick-disconnect plugs for ease of maintenance.”

Comment 1: “Not all electrical components are on tray or power door … typically only the likely service items. For example PE, wiring, Terminal block, fusing, etc. are not on power door.”

7.11 EXHIBIT B

“I.E.S. Control of Distribution: Semicutoff”

Comment 1: “Cutoff no longer applies since IESNA implementation of TM-15 and deprecation of the legacy cutoff classing approach in 2007. We do not recommend continuing to include in new specifications.”

“I.E.S. Lateral Distribution: Type III”

Comment 1: “We caution against use of the classic lateral and vertical classing as a specification criteria and recommends application based performance requirements to avoid a specification conflict.”

“On Performance Requirements”

Comment 1: “IDOT needs to define either luminance or illuminance as the road design criteria and not both. The other specification serves as reference information to be used in field confirmation of the installation. Additionally, the assessment and planning for field verification and associated tolerances must be documented as a referenced document for this specification.”

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

A proposed specification for LED luminaires is one of the products of this study (the final draft version is included in Appendix A). It is recommended that IDOT use this specification with some modifications when needed.

The process used in developing this specification was unique, and that led to a very good specification. The preliminary version of the specification was drafted based on “best practices” and available technology. Then, the researchers worked with the project’s TRP to develop a draft version of the specification. Feedback from other DOTs, manufacturers, and lighting consultants was then obtained, and modifications were made based on that. It is recommended that this process be used by states or public agencies in developing lighting specifications.

The research team for this project also created a spreadsheet to use in performing life-cycle cost analysis (LCCA) for different lighting technologies, including HPS, LED, ceramic metal halide (CMH), and light-emitting plasma (LEP). This tool implements a net present value methodology in accordance with current IES guidelines contained in RP-31-14, and its use by IDOT is recommended.

Using the spreadsheet and different lighting design scenarios, LCCA was performed for different technologies for the following facilities: (1) a freeway segment, (2) an interchange, (3) an interchange using high mast, and (4) an intersection on an urban arterial. Each design had its own bill of materials for each technology.

Results showed that assuming a re-lamping and re-ballasting cycle of 4 years for HPS, and a cost of $845 per LED luminaire (half of the current unit cost provided by IDOT), HPS and LED produced the most economical lighting solutions in the four facilities with the exception of the conventional interchange project in which LED was 8.3% more expensive than HPS. If a less conservative re-lamping policy of a 6-year cycle is assumed, the above-mentioned figure changed to 12%.

Each technology may have different optimal spacings and mounting heights. An LCCA comparing different technologies should incorporate individual designs and bills of material for each. Energy costs, inflation, and interest rates also play an important role in LCCA, thus input values should be periodically updated to reflect current data.

In addition to LCCA, other factors may be considered in deciding which type of luminaires to use. Those factors may include glare, color rendering, visibility, safety benefits, future directions in lighting technology, preference of the public and other stakeholders, direction and level of encouragement from top managers and policy makers, aesthetics and appearance of the project, etc.

Current knowledge on dirt depreciation factors is evolving. The results of an ongoing dirt depreciation study at the Virginia Tech Transportation Institute should be monitored and applicable findings incorporated in the revised version of the specification.

Finally, it is recommended that IDOT continue monitoring new developments and trends in the lighting industry (light management, adaptive lighting, etc.) to take advantage of technological developments and ensure that the most qualified products are specified and purchased.

CHAPTER 9 REFERENCES

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APPENDIX A PROPOSED SPECIFICATIONS FOR LED LUMINAIRES

I. CONTENTS

DESCRIPTION

This work shall consist of furnishing and installing light-emitting diode (LED) luminaires as shown on the plans, as specified herein, and in accordance with the applicable requirements of Section 821 of the Illinois Department of Transportation (IDOT) Standard Specifications for Road and Bridge Construction (Standard Specs).

GENERAL

The luminaire shall be assembled in the continental United States and shall be assembled by and manufactured by the same Manufacturer. For easy removal, quick-connect/disconnect plugs shall be supplied between the discrete electrical components within the luminaire such as the driver, surge protection device, and optical assembly. The quick-connect/disconnect plugs shall be operable without the use of tools and while insulated gloves are worn. The luminaire shall be in compliance with ANSI C136.37 LED light source(s), and driver(s) shall be compliant with the Restriction of Hazardous Substances (RoHS) Directive 2011/65/EU.

Manufacturer Experience. The luminaire shall be designed to be incorporated into a lighting system with an expected 30-year lifetime. The luminaire Manufacturer shall have a minimum of 30 years' experience manufacturing high-intensity discharge (HID) roadway luminaires and shall have a minimum of 5 years' experience manufacturing LED roadway luminaires. The Manufacturer shall have a minimum of 5,000 total LED roadway luminaires installed on a minimum of 30 separate installations, all within the continental United States.

HOUSING

The housing shall be designed to ensure maximum heat dissipation and to prevent the accumulation of water, ice, dirt, and debris. A passive cooling method with no moving or rotating parts shall be employed for heat management. The effective projected area of the luminaire shall not exceed 1.4 sq. ft. The total weight of the luminaire(s) and accessories shall not exceed 75 lb. Wiring within the electrical enclosure shall be rated at 1000 V[1], 221°F (105°C) or higher.

Finish. Painted or finished luminaire surfaces exposed to the environment shall exceed a rating of six, according to ASTM D1654, after 1000 hours of ASTM B117 testing. The coating shall exhibit no greater than 30% reduction of gloss, according to ASTM D523, after 500 hours of ASTM G154 Cycle 6 QUV® accelerated weathering testing.

Attachment. The luminaire shall slip-fit on a mounting arm with a 2 in (5 cm) diameter tenon (2.375 in. [6 cm] outer diameter) and shall have a barrier to limit the amount of insertion. The luminaire shall be provided with a leveling surface and shall be capable of being tilted ±5 degrees from the axis of attachment in not more than 2.5-degree increments and rotated to any degree with respect to the supporting arm.

Receptacle. The luminaire shall include a fully prewired, 7-pin twist lock ANSI C136.41-compliant receptacle. Unused pins shall be connected as directed by the Manufacturer and as approved by the Engineer. A shorting cap shall be provided with the luminaire.

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[1] 2014 edition of the National Electrical Code change from 600 V to 1 kV.

Vibration Characteristics. All luminaires shall pass ANSI C136.31 requirements. Roadway luminaires mounted on a bridge and high-mast luminaires shall be rated for 3G peak acceleration. Vibration testing shall be run using the same luminaire in all three axes.

Labels and Decals. All luminaires shall have ANSI C136.15 external labels and ANSI C136.22 internal labels.

The luminaire shall be listed for wet locations by a nationally recognized testing laboratory (NRTL) as defined by OSHA and shall be in compliance with UL 8750 and UL 1598. It shall be identified as such by the holographic UL tag/sticker on the inside of the luminaire.

Hardware. All hardware shall be stainless steel. Captive screws are required on any component that requires maintenance after installation.

OPTICAL ASSEMBLY

The LED optical assembly, consisting of LED packages, shall have a minimum ingress protection rating of 66 (IP66) as defined in ANSI/IEC 60529. Circuiting shall be designed to minimize the impact of individual LED failures on the operation of the other LEDs.

The optical assembly shall utilize high-brightness, long-life LEDs with a minimum color rendering index (CRI) of 70, 4000 K color temperature (± 300 K), and binned according to ANSI C78.377. Lenses shall be UV-stabilized acrylic or glass. Provisions for house-side shielding shall be specified along with means of attachment.

Lumen depreciation at 50,000 hours of operation shall not exceed 15% of initial lumen output at the specified LED drive current and an ambient temperature of 77°F (25°C).

The assembly shall have individual serial numbers or other means for Manufacturer tracking.

PHOTOMETRIC PERFORMANCE

Testing. Luminaires shall be tested according to IES LM-79. The laboratory performing this test shall hold accreditation from the National Voluntary Laboratory Accreditation Program (NVLAP) under NIST. Submitted reports shall have a backlight, uplight, and glare (BUG) rating according to IESNA TM-15, including a luminaire classification system graph with both the recorded lumen value and percent lumens by zone.

Lumen maintenance shall be measured for the LEDs according to LM-80, or when available for the luminaires according to LM-84. The LM-80 report shall be based on a minimum of 6000 hours; however, 10,000-hour reports shall be provided for luminaires in cases in which tests have been completed.

Thermal testing shall be provided according to UL 1598. The luminaire shall start and operate in the ambient temperature range specified. The maximum rated case temperature of the driver, LEDs, and other internal components shall not be exceeded when the luminaire is operated in the ambient temperature range specified.

Mechanical design of protruding external surfaces such as heat sink fins shall facilitate hose-down cleaning and discourage debris accumulation. Testing shall be submitted when available to show that the maximum rated case temperature of the driver, LEDs, and other internal components are not exceeded when the luminaire is operated with the heat sink filled with debris.

Calculations. Complete point-by-point luminance and veiling luminance calculations as well as listings of all indicated averages and ratios as applicable shall be provided according to IES RP-8 recommendations. Lighting calculations shall be performed using AGi32 software with calculations performed to two decimal places (i.e., x.xx cd/m^2). Calculation results shall demonstrate that the submitted luminaire meets the lighting metrics specified in the project Luminaire Performance Tables (see Exhibit B). Scotopic or mesopic factors will not be allowed.

Lumen Maintenance Projection. The LEDs shall have long-term lumen maintenance documented according to IESNA TM-21, or when available for the luminaires according to IESNA TM-28. The submitted calculations shall incorporate an in situ temperature measurement test (ISTMT) and LM-80 data with TM-21 inputs and reports according to the TM-21 calculator, or when available an ISTMT and LM-84 data with TM-28 inputs and reports according to the TM-28 calculator. Ambient temperature shall be 77°F (25°C).

DRIVER

The driver for the luminaire shall be integral to the unit. It shall be mounted in the rear of the luminaire on the inside of a removable door or on a removable mounting pad. The removable door or pad shall be secure when fastened in place, and all individual components shall be secured upon the removable element. Each component shall be readily removable from the removable door or pad for replacement.

The driver shall be installed in a manner to keep it mechanically separated from the LED array heat sink.

Circuit Protection. The driver shall tolerate indefinitely open and short-circuit output conditions without damage.

Ingress Protection. The driver shall have an IP66 rating.

Input Voltage. The driver shall be suitable for operation over a range of 120 to 277 V or 347 to 480 V as required by the system operating voltage.

Operating Temperature. The driver shall have an operating ambient temperature range of 104°F to 158°F (40°C to 70°C).

Driver Life. The driver shall provide a lifetime of 100,000 hours at an ambient temperature of 77°F (25°C).

Safety/UL. The driver shall be listed under UL 1012.

Power Factor. The driver shall maintain a power factor of 0.9 or higher and total harmonic distortion of less than 20%.

Driver Efficiency. The driver shall have a minimum efficiency of 90% at maximum load and a minimum efficiency of 85% for the driver operating at 50% power, with driver efficiency defined as output power divided by input power.

Electrical Interference. The driver shall meet the electromagnetic compatibility (EMC) requirements for Class A digital devices included in the FCC Rules and Regulations, Title 47, Part 15.

Thermal Fold Back. The driver shall reduce the current to the LED module if the driver is overheating as a result of abnormal conditions.

Dimming. The driver shall have 0 to 10 V dimming capability.

Leakage Current. The driver shall comply with safety standards according to IEC 61347-1.

SURGE PROTECTION DEVICE (SPD)

SPD shall be labeled as Type 4 in accordance with UL 1449 and be an integral part of the luminaire. It shall provide a minimum system protection level of 10 kV, 10 kA. To protect for a 10 kV, 10 kA surge the required clamping voltage of the external metal oxide varistor (MOV) or other SPD shall be lower than 1 kV at 8 kA {(10 kV – 2 kV)/1 ohm = 8 kA}.

The SPD shall comply with the following standards:

1) IEEE C62.41.1, IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits,
2) IEEE C62.41.2, IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits,
3) IEEE C62.45, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits, and
4) ANSI C136.2, American National Standard for Roadway and Area Lighting Equipment — Luminaire Voltage Classification.

The SPD and performance parameters shall be posted at www.UL.com under category code VZCA2.

WARRANTY

The entire luminaire and all of its component parts shall be covered by a 10-year warranty. Failure is defined as when one or more of the following occur:

1) Negligible light output from more than 10% of the LED packages,
2) Moisture inside the optical assembly,
3) Driver that continues to operate at a reduced output, and/or
4) Other failed conditions that do not meet specifications.

The warranty period shall begin on the date of final acceptance of the lighting work as documented in the Resident Engineer’s project notes.

SUBMITTAL REQUIREMENTS

The Contractor shall submit, for approval, an electronic version of all associated luminaire IES files, AGi32 files, and the TM-21 or TM-28 calculator spreadsheet with inputs and reports associated with the project luminaires. The Contractor shall also provide an electronic version of each of the following Manufacturers’ product data sheets for each type of luminaire.

1) Descriptive literature and catalog cuts for luminaire, LED package, driver, and surge protection device;

2) LED drive current, total luminaire input wattage, and total luminaire current at the system operating voltage or voltage range and ambient temperature of 77°F (25°C);
3) Luminaire efficacy expressed in lumens per watt (lpw) per luminaire;
4) Initial delivered lumens at the specified color temperature, drive current, and ambient temperature;
5) Computer photometric calculation reports as specified in Sections III and VI, and in the luminaire performance table (Exhibit B);
6) TM-15 BUG rating report as specified in Section VI;
7) Documentation of Manufacturers' experience and certification that luminaires were assembled in the United States as specified in Section III;
8) Supporting documentation of compliance with ANSI standards, as well as listing requirements as specified in Sections III, VI, VII and VIII;
9) Supporting documentation of laboratory accreditations and certifications for specified testing as indicated in Section VI;
10) Thermal testing documents as specified in Section VI;
11) IES LM-79, LM-80 (or LM-84), and TM-21 (or TM-28) reports as specified in Section VI;
12) Salt spray (fog) test reports and certification as specified in Section IV;
13) Vibration characteristics test reports and certification as specified in Section IV;
14) IP test reports as specified in Sections V and VII;
15) Manufacturer written warranty as specified in Section IX; and
16) Luminaire installation, maintenance, and washing instructions.

BASIS OF PAYMENT

This work will be paid for at the contract unit price per each LED luminaire of the specified type, as indicated below (this is the current classification and it may change in the future), which shall be payment in full for all labor, equipment, and material necessary to perform the work specified herein.

LED luminaire classification shall be as follows:

Type A: Delivered Lumens ≤ 10,000, Max Wattage 110 W,

Type B: Delivered Lumens > 10,000, ≤ 20,000, Max Wattage 220 W,

Type C: Delivered Lumens > 20,000, ≤ 30,000, Max Wattage 330 W, and

Type D: Delivered Lumens > 30,000, ≤ 40,000, Max Wattage 440 W.

Note: Luminaires with wattages above the stated maximums will not be accepted.

EXHIBIT A

ILLINOIS DEPARTMENT OF TRANSPORTATION
LUMINAIRE PHYSICAL INSPECTION CHECKLIST

IDOT Contract No: ____________ Date: _________ Inspector: ______________________________

Luminaire Type:___________________ Wattage: ___________________ Distribution: ___________________

Packaging

Inspection Item	Sample:	Sample:	Sample:	Sample:
Shipping carton undamaged				
Shipping carton properly labeled				
Packaging adequately secures and protects luminaire				

Luminaire Housing

Inspection Item	Sample:	Sample:	Sample:	Sample:
Paint and coatings even and unblemished				
Correct 7-pin receptacle in place and adequately sealed				
No dents, cracks, or other malformations present				
Correct seal of the housing and individual LEDs				
Internal and external labels correct				
Pole or bracket mounting hardware correct				

Lamp Compartment

Inspection Item	Sample:	Sample:	Sample:	Sample:
Lens properly secured to each LED or door or housing				
Lenses not cracked or scratched				
Correct number of LEDs and LED array assemblies				
LEDs correctly installed and oriented				
Photocell receptacle operates correctly				
All fasteners are stainless steel				
Surfaces are smooth to prevent dirt accumulation				

Electrical Compartment

Inspection Item	Sample:	Sample:	Sample:	Sample:
Driver(s) is held securely in place				
Wiring is undamaged, protected from sharp edges, and neatly routed				
Terminations for incoming power wiring are clearly marked and correct for 10 AWG cables				
Driver has quick-disconnect plugs for power and lamp connections which cannot be misconnected				
Photocell socket is securely mounted and gasketed				
Electrical compartment door latch operates correctly				
All fasteners are stainless steel and captive				
Electrical components securely mounted on removable tray with quick-disconnect plugs for ease of maintenance				

Describe any deficiencies found:

EXHIBIT B

ILLINOIS DEPARTMENT OF TRANSPORTATION
LUMINAIRE PERFORMANCE TABLE

GIVEN CONDITIONS

ROADWAY DATA	Pavement Width (in one direction only)	ft.
	Pavement Width (in opposite direction)	ft.
	Number of Lanes (in one direction only)	
	Number of Lanes (in opposite direction)	
	Median Width	ft.
	I.E.S. Surface Classification	R3
	Q-Zero Value	.07
LIGHT POLE DATA	Mounting Height	ft.
	Mast Arm Length	ft.
	Pole Set-Back From Edge of Pavement	ft.
LUMINAIRE DATA	Luminaire Type	LED
	Luminaire Lumens	
	I.E.S. Vertical Distribution	Short
	Lamp Lumen Depreciation Factor	
	Luminaire BUG Rating (e.g., 3-0-3)	
	Dirt Depreciation Factor	
	Equipment Factor	
	Total Light Loss Factor	
LAYOUT DATA	Spacing	ft.
	Configuration	One Sided
	Luminaire Overhang over edge of pavement	ft.

NOTE: Variations from the above specified IES distribution pattern may be requested, and acceptance of variations will be subject to review by the engineer based on how well the performance requirements are met.

PERFORMANCE REQUIREMENTS

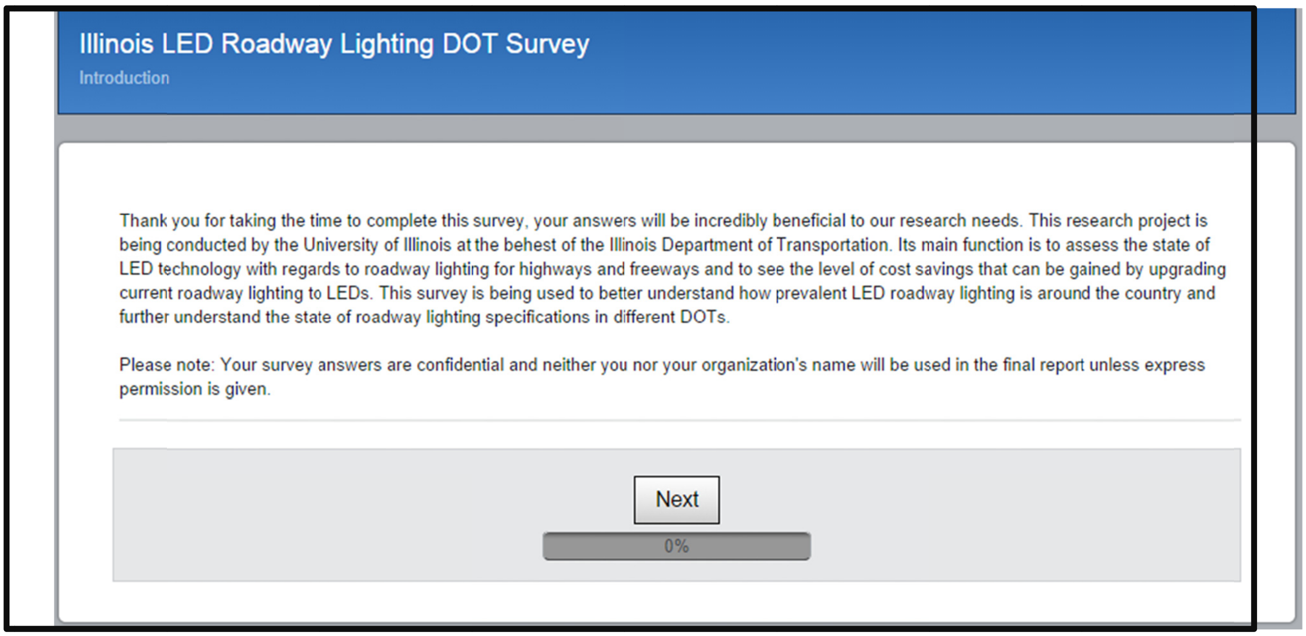
NOTE: These performance requirements shall be the minimum acceptable standards of photometric performance for the luminaire, based on the given conditions listed above. TM-21 and LM-80 reports, or TM-28 and LM-84 reports, must be attached and must support the Lamp Lumen Depreciation Factor given above.

ILLUMINATION	Average Horizontal Illumination, E_{AVE}	N/A
	Uniformity Ratio, E_{AVE}/E_{MIN}	N/A
LUMINANCE	Average Luminance, L_{AVE}	Cd/m^2
	Uniformity Ratio, L_{AVE}/L_{MIN}	:1
	Uniformity Ratio, L_{MAX}/L_{MIN}	:1
	Max. Veiling Luminance Ratio, L_V/L_{AVE}	:1

APPENDIX B ILLINOIS LED ROADWAY LIGHTING SURVEY OF DEPARTMENTS OF TRANSPORTATION

This survey was created on www.surveygizmo.com. the link for the Web-based version is http://edu.surveygizmo.com/s3/1086026/Illinois-LED-Street-Light-DOT-Survey.

Screenshots of the survey, as seen by the participants are is included below in case the survey link is removed.



Illinois LED Roadway Lighting DOT Survey

General Information

All questions marked with an asterisk (*) are required.

Section 1: Organization Information

1. Organization name *

2. Address *

Your city and state are required

Street

City/County

State

Zip

3. Website

Section 2: Contact Information

4. Contact Information (Person completing the survey) *

Last name and email are required

First name

Last name

Title

Department

E-mail address

Office phone

Back Next

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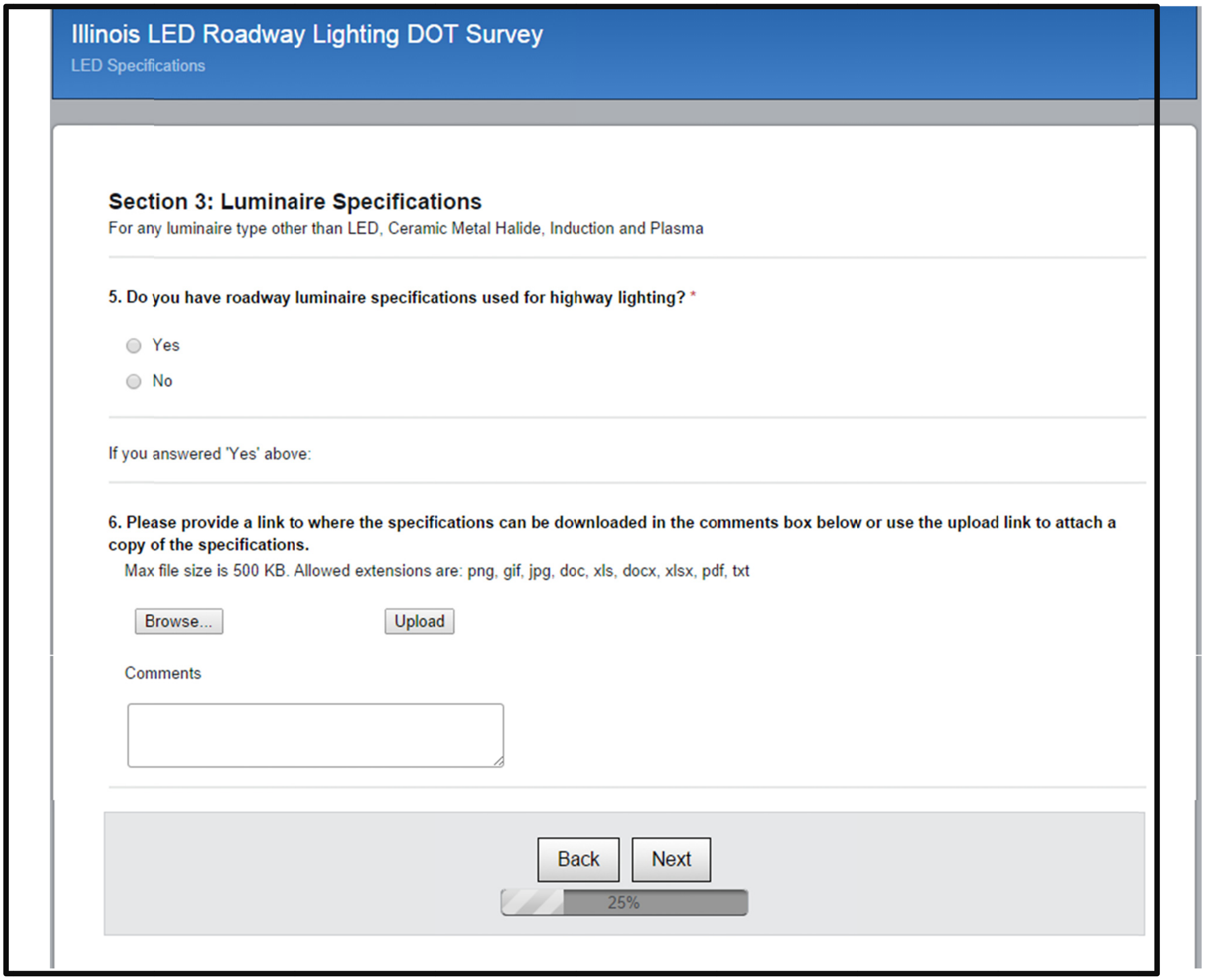

Illinois LED Roadway Lighting DOT Survey

LED Specifications

Section 3: Luminaire Specifications

For any luminaire type other than LED, Ceramic Metal Halide, Induction and Plasma

5. Do you have roadway luminaire specifications used for highway lighting? *

- Yes
- No

If you answered 'Yes' above:

6. Please provide a link to where the specifications can be downloaded in the comments box below or use the upload link to attach a copy of the specifications.

Max file size is 500 KB. Allowed extensions are: png, gif, jpg, doc, xls, docx, xlsx, pdf, txt

Browse... Upload

Comments

Back Next

25%

Illinois LED Roadway Lighting DOT Survey

General Specifications

Section 4: LED Specifications

7. Do you have LED luminaire specifications? *

- Yes
- No

If you answered 'Yes' above:

8. Please provide a link to where the specifications can be downloaded in the comments box below or use the upload link to attach a copy of the specifications.

Max file size is 500 KB. Allowed extensions are: png, gif, jpg, doc, xls, docx, xlsx, pdf, txt

Browse... Upload

Comments

Section 5: Other Lighting Technologies

9. Do you have luminaire specifications for any other technologies such as Ceramic Metal Halide, Induction or Plasma?

- Yes
- No

If you answered 'Yes' above:

10. Please provide a link to download the specifications in the comment box below and indicate which technology they are for. If you have specifications for more than one technology listed, please provide links for all specifications. If no link can be provided, please upload a copy of the specifications.

Max file size is 500 KB. Allowed extensions are: png, gif, jpg, doc, xls, docx, xlsx, pdf, txt

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Comments

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38%

Illinois LED Roadway Lighting DOT Survey

Specification Development

Section 6: Luminaire Specification Development

11. Are you currently revising or considering revising your luminaire specifications in the next year or so?

- Yes
- No

If you answered **'Yes'** above:

12. What are you developing specifications for? (i.e. new luminaire technology, location, etc.)

13. Please attach a draft of the new specifications, if possible.

Max file size is 500 KB. Allowed extensions are: png, gif, jpg, doc, xls, docx, xlsx, pdf, txt

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50%

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Light Loss Factors and Luminaire General Information

Section 7: Light Loss Factors

14. Please provide the values you are using now or plan to use in the future in the table below.

If you fill out the 'Other' row, please remember to indicate the luminaire type in the first column.

	Total Light Loss Factor (LLF)	Lamp Lumen Depreciation Factor (LLD)	Luminaire Dirt Depreciation Factor (LDD)	Equipment Factor (EF)
High Pressure Sodium				
LED				
Ceramic Metal Halide				
Induction				
Plasma				
Enter another option				
Enter another option				

15. How were these values determined? If you used supporting documents, please list the title.

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63%

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Luminaire General Knowledge

Section 8: Luminaire Type

16. Please note the percentage of luminaire type currently used for total highway lighting. If you fill in a percentage for 'Other', please indicate the luminaire type in the comments below.

For example: Enter '95' next to High Pressure Sodium if 95% of highway lighting fixtures are High Pressure Sodium.

	% of Highway Lighting
High Pressure Sodium	
LED	
Ceramic Metal Halide	
Induction	
Plasma	
Other	

Comments

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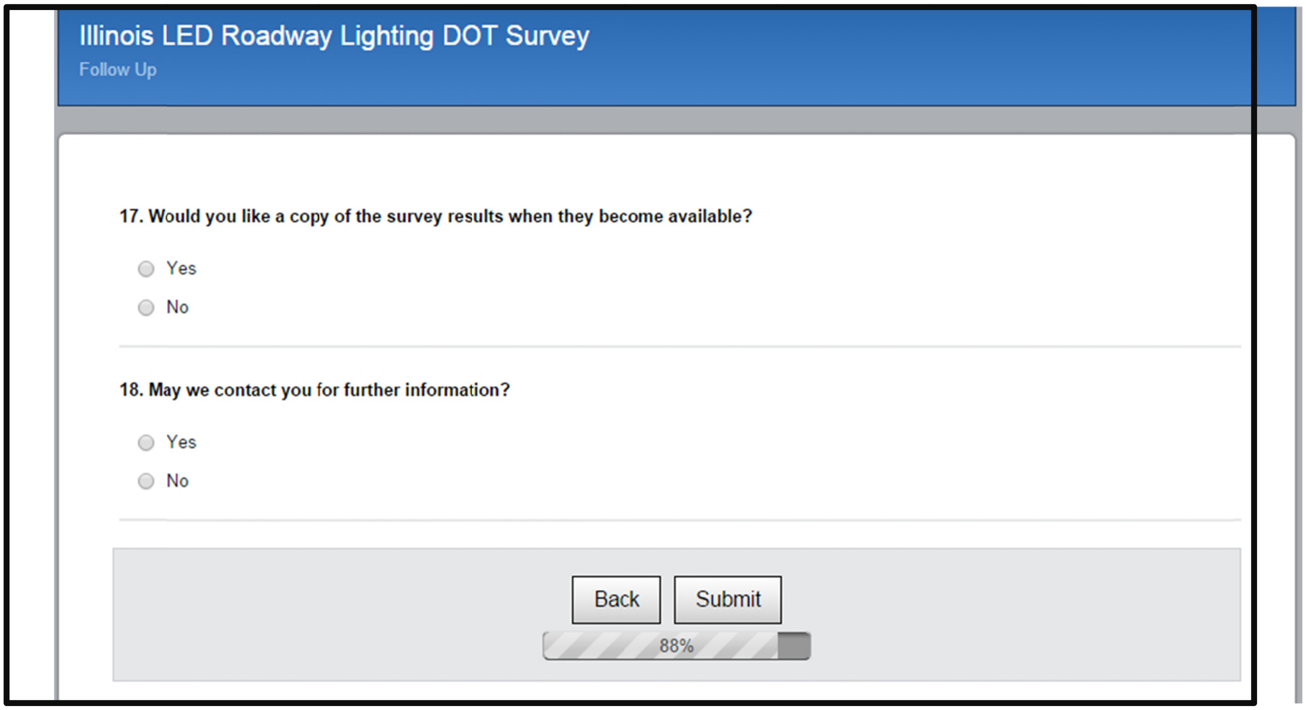
75%



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Follow Up

17. Would you like a copy of the survey results when they become available?

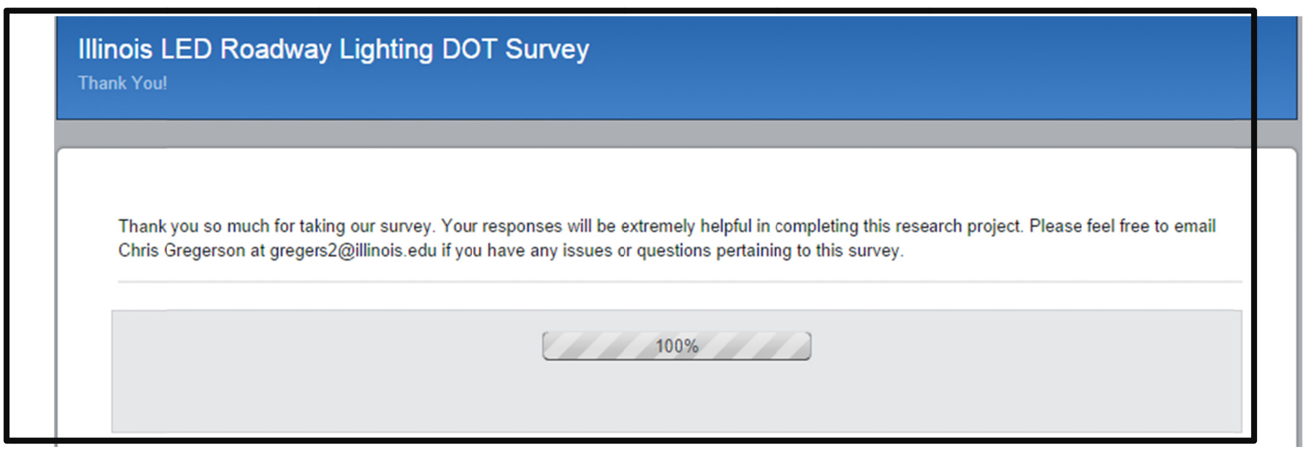
- Yes
- No

18. May we contact you for further information?

- Yes
- No

Back Submit

88%



Illinois LED Roadway Lighting DOT Survey

Thank You!

Thank you so much for taking our survey. Your responses will be extremely helpful in completing this research project. Please feel free to email Chris Gregerson at gregers2@illinois.edu if you have any issues or questions pertaining to this survey.

100%

Illinois Department of Transportation

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