
Publication of this Design Guide has been approved by IES.
Suggestions for revisions should be directed to IES.

Prepared by:
The Energy Management Subcommittee of the Roadway Lighting Committee of the Illuminating Engineering Society of North America
Copyright 2015 by the Illuminating Engineering Society of North America.

Approved by the IES Board of Directors, June 12, 2015, as a Transaction of the Illuminating Engineering Society of North America.


All rights reserved. No part of this publication may be reproduced in any form, in any electronic retrieval system or otherwise, without prior written permission of the IES.

Published by the Illuminating Engineering Society of North America, 120 Wall Street, New York, New York 10005.

IES Standards and Guides are developed through committee consensus and produced by the IES Office in New York. Careful attention is given to style and accuracy. If any errors are noted in this document, please forward them to the Director of Technology, at the above address for verification and correction. The IES welcomes and urges feedback and comments.

ISBN # 978-0-87995-314-0

Printed in the United States of America

DISCLAIMER

IES publications are developed through the consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on lighting recommendations. While the IES administers the process and establishes policies and procedures to promote fairness in the development of consensus, it makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

The IES disclaims liability for any injury to persons or property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document.

In issuing and making this document available, the IES is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the IES undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The IES has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the IES list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or statement of compliance with the requirements of this document shall not be attributable to the IES and is solely the responsibility of the certifier or maker of the statement.
AMERICAN NATIONAL STANDARD

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria have been met by the standards developer.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether that person has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation to any American National Standard. Moreover, no person shall have the right or authority to issue and interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

CAUTION NOTICE: This American National Standard may be revised at any time. The procedures of the American National Standards Institute require that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of approval. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.
# Contents

1.0 Introduction ......................................................................................... 1

2.0 Goals and Best Practices .................................................................... 1

2.1 Safety ................................................................................................. 1

2.2 Project Planning Introduction .......................................................... 1

2.2.1 The Systems Engineering Process .............................................. 2

2.2.1.1 What is a System? ............................................................. 2

2.2.1.2 What is Systems Engineering? ......................................... 2

2.2.1.3 Systems Engineering Principles ........................................ 2

2.2.1.3.1 Start with Your Eye on the Finish .................................. 2

2.2.1.3.2 Stakeholder Involvement is Key ...................................... 2

2.2.1.3.3 Define the Problem Before Implementing the Solution .... 2

2.2.1.3.4 Delay Technology Choices ........................................... 3

2.2.1.3.5 Divide and Conquer ...................................................... 3

2.2.1.3.6 Connecting the Dots - Traceability ................................. 3

2.2.1.3.7 The "V" Systems Engineering Model ............................. 3

2.2.1.3.8 Overview of the "V" Model ............................................. 3

2.2.1.3.9 Connecting the Left and Right Sides of the "V". ............... 4

2.2.1.3.10 Decision Points ........................................................... 5

2.2.2 User Needs ..................................................................................... 5

2.2.2.1 Who and What Can Generate User Needs? ....................... 5

2.2.3 Operational and Functional Requirements ................................... 6

2.2.4 Testing ........................................................................................... 8

2.4 Cost Benefit Analysis ....................................................................... 9

2.5 Procurement ....................................................................................... 9

3.0 Control Technologies .......................................................................... 9

3.1 Stand-alone Technologies .................................................................. 9

3.1.1 Background .................................................................................. 9

3.1.2 Dusk to Dawn Photo Controls (Photocells) ............................. 10

3.1.3 Time Switches .............................................................................. 10

3.1.4 Part Night Photo Controls (Photocell) ....................................... 10

3.1.5 Astronomical Time Clocks ......................................................... 11

3.1.6 Motion Detectors ......................................................................... 11

3.2 Networking and Communications Technologies ............................. 11

3.2.1 Background .................................................................................. 11

3.2.2 Management Station ................................................................. 12

3.2.3 Data Logger .................................................................................. 13

3.2.4 Streetlight Controllers ............................................................... 14

3.2.5 Data Logging ............................................................................... 14

3.2.6 Data Security ............................................................................... 14
4.0 Adaptive Lighting Design .......................................................... 14
  4.1 General Considerations .......................................................... 14
  4.2 Specific Design Considerations .............................................. 16
    4.2.1 Residential Streets ...................................................... 16
    4.2.2 Collector and Arterial (Major) Streets .............................. 17
    4.2.3 Freeways and Highways ............................................. 18
    4.2.4 Sidewalks, Walkways and Alleyways .............................. 18
    4.2.5 Tunnels ........................................................................ 18
  4.3 Inventory Assessment .......................................................... 18
  4.4 Deployment ........................................................................... 19

5.0 Adaptive Lighting Operations .................................................. 19
  5.1 Preventive Maintenance Analysis .......................................... 19
  5.2 Inventory Analysis .............................................................. 19
  5.3 Work Management Analysis ................................................. 19
  5.4 Asset Management .............................................................. 20
  5.5 Electrical System Maintenance ............................................. 20
  5.6 Other Considerations .......................................................... 20
    5.6.1 Asset Tracking ............................................................. 20
    5.6.2 Electrical Safety Equipment .......................................... 20
  5.7 Power Metering and Monitoring ........................................... 20
    5.7.1 Tariffs ......................................................................... 20
    5.7.2 Flat Rate Billing ............................................................ 20
    5.7.3 Metered Service ............................................................ 21
    5.7.4 Meter Accuracy ............................................................. 21

6.0 Integration and Commissioning ............................................... 21
  6.1 Interoperability ..................................................................... 21
  6.2 Interchangeability ................................................................. 22
  6.3 Compliance vs. Conformance ............................................... 22
  6.4 Integration with US DOE “Smart Grid” Compliant Systems ....... 22
  6.5 Integration with Intelligent Transportation Systems ................ 22
  6.6 Integration with Building Automation Systems ..................... 23

General References ...................................................................... 23

Annex A – U.S. DOT Intelligent Transportation Standards ................. 23
Annex C – U.S. Department of Commerce / National Institute of Standards and Technology - Smart Grid Interoperability Panel Standards .......................................................... 25
Annex E – TALQ Consortium .......................................................... 26
Annex F – BACnet ....................................................................... 27
Annex G – LonWorks® Technology .................................................. 27
Annex H – Zigbee ...................................................................... 27
Annex I – IMSA Roadway Lighting Technician Courses ..................... 27
Annex J – Interoperability and the OSI 7 Layer Model ....................... 28
Annex K – Glossary .................................................................... 30
Annex L – General Bibliography .................................................... 36
1.0 INTRODUCTION

Electric outdoor lights are generally controlled in groups via relays (contactors) and photocells, or controlled individually with photocells mounted on the luminaires. In some cases time clocks are used to control the lighting. Today’s digital technology, in both control systems and light sources, offers new potential to better control the lighting system and provide the right amount of lighting when required. These improved controls allow the lighting system to adapt the lighting levels to the ambient conditions. Better lighting controls can result in improved visibility and potential savings in both energy and maintenance costs. The purpose of this Design Guide is to educate the reader on control technologies, and to advise considerations for their implementation.

Before moving forward, it should be understood that these new systems, while bringing the potential to improve visibility as well as considerably reduce both energy and maintenance costs, also bring a significant and long-term investment. For that reason, the user/designer should understand the functionalities and consequences of the different technologies, each with its own cost/benefit analysis.

The drive to reduce energy consumption, and the related costs, has led to new strategies for lighting controls. In many cases, particularly in retail areas and parking lots, full light output is not required throughout the duration of the night, after business hours. In some cases street and roadway lighting can also be reduced as the level of activity is reduced, at specific times during the hours of darkness. New digital technologies in both controls and light sources now enable the user to turn specific individual or groups of lights on or off, or to adjust individual or group light levels up or down as needed. These new control systems enable full customization - from individual light points to complete lighting systems - in order to meet the specific needs of each user. Adaptive control systems can make adjustments due to changing ambient light levels, pedestrian activity, vehicular traffic and even weather conditions.

This Design Guide presents an overview of lighting control technologies, some of which are new and evolving, and others which have a proven history (for examples, refer to IES TM-23-11 Lighting Control Protocols).

2.0 GOALS AND BEST PRACTICES

2.1 Safety

This document does not cover safety in detail; however, it does list some specific design considerations which can relate to safety. Prior to undertaking any installation where lighting levels are reduced from their current values (or standards) it is recommended that a review and study be undertaken, as further discussed in the Design Section. Additionally, all potential system failures should be identified and tested to ensure that the system fails to a well-known/designed safe condition. When using a networked system, notice of failures should be sent to operators and maintenance personnel, in a near real-time basis.

2.2 Project Planning Introduction

Project planning typically includes determination of the user needs for the project, the subsequent refining of those user needs into project specific operational and functional requirements, and lastly the development of a project specific test plan, for verification and validation. Prior to selection and deployment it is recommended a project plan be developed and utilized. The USDOT (U.S. Department of Transportation) as well as many states and local agencies require the use of the Systems Engineering Process (SEP) as a project development tool. The SEP contains the following concepts which are examined in subsequent sections of this document:

- SEP is a structured process for arriving at a final design of a system
- Analysis determines needs of system
- Requirements of systems are traced back to user needs
- User needs and requirements are verified

SEP Benefits:

- Guides the development team and manages expectations
- Reduces significant uncertainties in the cost and schedule
- Reduces late changes that drive project costs
- Improves the success rate
- Unambiguously defines the problem before implementing the solution
All projects that are funded per the Code of Federal Regulations Title 23 Highways Section 940.11, shall be based on a systems engineering analysis on a scale commensurate with the project scope.

SEP Deliverables:

• Project Plan
• Systems Engineering Management Plan
• Concept of Operations Plan

A Concept of Operations Document is described by the IEEE (Institute of Electrical and Electronics Engineers) Std 1362 Guide for Information Technology as:

• A user requirement for a system that a user believes would solve a problem experienced by the user."

• “The user's set of qualitative and quantitative requirements in a particular problem domain”

• Requirements and Verification Plan

2.2.1 The Systems Engineering Process In true systems engineering fashion, knowledge of a few basic definitions is important before reviewing the details of the systems engineering discipline.

2.2.1.1 What is a System? Everyone uses the term and has an intuitive notion of what a system is, but there is a formal definition. INCOSE, the International Council on Systems Engineering, defines a system as: “A combination of interacting elements organized to achieve one or more stated purposes.” This general definition covers almost everything – household appliances, transportation management systems, the latest weapon system, for example – all of these are systems.

2.2.1.2 What is Systems Engineering? Since the term was coined in the 1950s, systems engineering has evolved from a process focused primarily on large-scale defense systems to a broader discipline that is used in all kinds of project development. Systems engineering can be applied to any system development, so whether you are developing a household appliance, building a house, or implementing a sophisticated transportation management system, systems engineering can be used. INCOSE1,2 defines systems engineering as:

“Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and

required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem.”

Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Note that this definition is very broad – it covers the project life cycle from “needs definition” to “system disposal”. It includes technical activities like requirements and design, as well as project activities like risk management and configuration management. Systems engineering provides a systematic process and tools that directly support project management.

2.2.1.3 Systems Engineering Principles

2.2.1.3.1 Start with Your Eye on the Finish Consensus should be reached at the very beginning of the project on what will constitute success at the end. This means that the stakeholders should start with an agreement of what the project should accomplish and the metrics that will be used to measure the success of the project. This initial focus on the finish line should be sustained by project management as project development progresses and competing interests and project complexities begin to dominate the day-to-day work.

2.2.1.3.2 Stakeholder Involvement is Key Successful projects involve the customer, users, operators, and other stakeholders in the project development. Systems engineering is a systematic process that includes reviews and decision points intended to provide visibility into the process and encourage stakeholder involvement. The systems engineering process includes stakeholders through all stages of the project, from initial needs definition through system verification and acceptance. The stakeholders who are involved in any particular step will vary, providing managers, operators, and technical personnel with an opportunity to contribute to the steps in the process where their input is needed.

2.2.1.3.3 Define the Problem Before Implementing the Solution Solutions may seem to be readily obvious at the start of a project, and subsequently, requirements are created that “match” that particular solution. Such an approach may not be comprehensive in its satisfaction of all stakeholders user needs. In using a systems engineering process to first define the problem, there may be multiple ways to
solve the problem. A study will help to determine the best solution on the basis of a clear understanding of the user needs and requirements.

2.2.1.3.4 Delay Technology Choices Technology is constantly changing; choices that are available when a project is initially conceived may well be replaced by better technology by the time the project is implemented. Specifying technology too early will result in outdated technology or constant baseline changes, in trying to keep up with technology advancements. It may be best to follow the systems engineering process by defining the needs, requirements, and high-level design without specifying technology. This will create a stable baseline, and the most appropriate technology choices can be made when it is time to implement them.

"Baseline" is a frequently used term in systems engineering. A baseline is a reference point against which everyone on the project team works, so you want to control the changes that are made to the baseline. The process of establishing and controlling project baselines is configuration management.

2.2.1.3.5 Divide and Conquer Many systems are large and complex. A key systems engineering strategy is the decomposition of such a system into smaller subsystems and then of the subsystems into more manageable hardware and software components. These simpler components are easier to understand and define and ultimately are easier to build. Much of the systems engineering process is built around this approach – breaking down a big problem into many smaller components that can be individually solved and then recombined.

2.2.1.3.6 Connecting the Dots – Traceability Moving through the systems engineering process, it is important to be able to relate the items in one step with those in another. The relationship between items is called traceability. For example, use traceability to relate a requirement to the subsystem that will implement the requirement. Traceability connects many items together. The requirement will be related to a user need as well as to a test that will be used to verify the requirement. Traceability is a powerful concept that allows you to be certain that the system that is implemented at the end of the project is directly connected with the user needs that were identified at the beginning.

2.2.1.3.7 The “V” Systems Engineering Model Many different process models have been developed over the years that specify a series of steps that make up the systems engineering approach. Among these models, the “V” model, shown in Figure 1 below, has emerged as the de facto standard way to represent systems engineering projects.

2.2.1.3.8 Overview of the “V” Model Since it was first developed in the 1980s, the “V” model has been refined and applied in many different industries. Wings have been recently added to the “V” to show how project development fits within the broader project life cycle. The left wing shows the regional architecture, feasibility studies, and concept exploration that support initial identification and scoping of a project based on regional needs. A gap follows the regional architecture(s) step because the regional architecture is a broader product of the planning process that support initial identification and scoping of a project based on regional needs. A gap follows the regional architecture(s) step because the regional architecture is a broader product of the planning process that covers all projects in the region. The
2.2.1.3.9 Connecting the Left and Right Sides of the “V” One of the first things that is significant about the “V” is the symmetry between the left and right sides of the model. This symmetry reflects the relationship between the steps on the left and the steps on the right. The system definition that is generated on the left is ultimately used to verify the system on the right. For example, the user needs and performance measures that are identified in the Concept of Operations are the basis for the System Validation Plan that is used to validate the system at the end of project development. Similarly, a System Verification Plan is developed with the System Requirements so that the engineers consider how to verify each requirement as the requirements are written.

The connections between the left and right are indicated by the arrows that cross the “V”, showing how plans developed on the left drive the process on the right. These connections provide continuity between the beginning and end of project development and ensure that the engineers are focused on the completion of the project from the beginning. The connections between the left and right sides of the model reflect one of the systems engineering principles – start with your eye on the finish line.

As displayed in Figure 3 below, it is vitally important to remember that requirements are dependent upon user needs, and user needs are dependent on the system users. These system users, also known as stakeholders, include vehicle operators, pedestrians, bicyclists as well as system operators and maintenance personnel.
2.2.1.3.10 Decision Points
Projects have been managed for years using Gantt charts that identify tasks and major milestones. Under this approach, the next task is not started until the previous supporting tasks have been completed, and passed the intervening milestone. The “V” diagram is similarly punctuated by a series of major milestones (labeled Document/Approval in the figure) where the output of the previous step is reviewed and the customer and project team determine whether the project is ready to move to the next step in the process. The project moves forward only if the criteria for the decision point have been satisfied. Decision points are important milestones that provide visibility into the project development and allow for issue identification and course correction during development.

For a comprehensive and unambiguous project specification, it is incumbent upon the project designer to examine the architecture and actual data flow levels. This granularity allows clear identification of which logical objects to implement.

2.2.2 User Needs
A user need describes the major capability provided by a system. A system should not be procured or built without first knowing what it is expected to do. User needs help to assess/validate if a system does what the user wants it to do.

It is recommended the designer (engineer) review and define stakeholders, and document the needs. These stakeholders may include city, county and state management personnel - including those from the respective managers, maintenance staff, system developers and the public.

An outdoor lighting systems user need, describes the major capability provided by the lighting system to satisfy operational needs. User needs describe the actual needs of the user, which the systems intend it to need. User needs are the basis of agreement from the design team on what the proposed system is intended to provide. A project team with no user needs to document most probably also lacks agreement on what the exact purpose of the product or project is. This is a major reason why projects and products fail. Put simply; whereas requirements analysis focuses on the elements needed to be represented in the system, user needs analysis focuses on the requirements related to the goals, aspirations and needs of the users and/or the user community and feeds them into the system requirement analysis process. The main purpose of user needs analysis is the user's satisfaction.

This process is represented by the left side of the “V” model, as shown in Figure 4, where user needs are decomposed and refined into functional requirements.

Figure 3: The Dependency of Requirements on User Needs, and the Dependency of User Needs on the Needs of the Actual Users (Graphic courtesy of Jim Frazer)

Figure 4: (Graphic courtesy of the U.S. Department of Transportation)
Subsequently these requirements can be refined into project specifications. It is important to document the user needs and requirements before the design and construction process begins as changes at this phase are much less costly to implement than at later phases of the project. The following image, Figure 5 is a representation of a comprehensive requirements table. Notice that each user need in the table has a numerical identifier, as well as a textual description. Similarly, Requirements derived from those user needs also have a numerical identifier, as well as a textual description.

Notice in Figure 5, 2.4.1.1 “Provide Live Data” is a user need. This user need is refined into the following four functional requirements:

- 3.3.1.1 Retrieve Data
- 3.3.1.2 Deliver Data
- 3.3.1.3 Data Retrieval and Data Delivery Action Performance
- 3.5.5.1 Live Data Response Time

System performance needs also drive functional requirements. Notice that in Figure 6 below, the project-specific user need defines the maximum response time.

Earlier, it was stated that “for a comprehensive and unambiguous project specification, the project designer is required to examine the architecture and actual data object levels”. This granularity allows clear identification of which logical objects to implement, as well as which objects to test after installation and commissioning.

Networks and the servers that use them have never been more interdependent. This, in large part, is because today’s complex and sophisticated lighting control systems rely on multiple components across many different systems. Networks should accommodate the critical functions of network based servers (such as DNS - domain naming system, or DHCP - dynamic host configuration protocol), as well as those of gateways, database servers, application servers, file servers, and terminal devices.

Optimization is a basic functional activity that is integrated into a system. There is little value in optimizing a system that doesn’t accomplish its essential goals. Therefore, all optimization efforts should be aimed at improving system performance to reach project goals beyond the minimum expectations.

The ability to monitor and proactively manage each of these systems and their applications is what differentiates a successful implementation from a poorly performing installation and allows tuning the system for peak performance.

### 2.2.3 Operational and Functional Requirements

Once a comprehensive list of user needs is established, then functional requirements can be defined.
In Figure 7 below, these objects are clearly defined in the Dialog, Object ID and Object columns within this sample logical object table. Notice these objects are refined from the requirements in columns one and two. Those requirements themselves were refined from the stakeholders’ user needs as described in Figure 4 above.

Valuable aids that provide guidance for development of the user needs, requirements and logical objects used in a project specific specification include:

- The DOE (Department of Energy) Municipal Solid State Lighting Consortium’s Model Specification for Adaptive Control and Remote Monitoring of LED Roadway Luminaires. The DOE MSSLC model specification describes hardware, software and communications interfaces. It provides both a suggested set of high-level requirements and a template for translating unique user needs into clear and consistent specification language. The tool allows users to determine what requirements should be mandatory; how best to support the breadth of system architectures and features available in the marketplace. It is available at http://www1.eere.energy.gov/buildings/ssl/control-specification.html

- The U.S. DOT (Department of Transportation) NTCIP 1213 Electrical and Lighting Management Systems standard describes the communications interface between the management station and field devices. This tool allows users to quickly develop an unambiguous project specific mandatory communications interface.

- The Transportation of Canada Roadway Lighting Efficiency and Power Reduction Guide reviews options and also provides guidelines for light reductions and energy efficiency practices. It provides information to road jurisdictions, designers, consultants, and suppliers on how to assess, evaluate, select, and deploy energy-efficient roadway lighting while reducing power

![Figure 6](Reprinted from NTCIP 1213 v0220r by permission of NEMA. Excerpt ©2002 AASHTO/ITE/NEMA)

![Figure 7](Reprinted from NTCIP 1213 v0220r by permission of NEMA. Excerpt ©2002 AASHTO/ITE/NEMA)
consumption and cost. The information presented in the Guide was gathered from international research and studies conducted by organizations such as the U.S. Department of Energy, the Illuminating Engineering Society of North America, the Commission Internationale de l’Eclairage (CIE), the U.S. Federal Highway Administration, and LightSavers Canada. The Roadway Lighting Efficiency and Power Reduction Guide is a supplement to the TAC Guide for the Design of Roadway Lighting (2006).

2.2.4 Testing The benefits of testing include:

- Validation: Making sure a system, when placed in operation, will support agency needs
- Verification: Making sure a design complies with requirements and that the systems (as proposed and delivered) comply with both design and requirements
- Traceability: A tool to help determine if the agency’s requirements are fulfilled by the design and that implementation was done correctly
- Reducing overall project risk

Use of the systems engineering process allows creation of an unambiguous testing plan. Well-defined and well-documented user needs allow the development of test plans to proceed in an orderly manner. Figure 8 below describes how test plans are dependent upon the requirements and user needs developed earlier in the process.

Unit device testing focuses on comparing an implementation against the standards and specified options; this may be performed by inspecting the code to use proven software to send test messages to the device. This software and hardware components are thoroughly tested to identify as many defects as possible. Additionally a series of test cases shall be devised that will exercise the hardware and software components. These test cases are documented in a unit verification plan after the software is complete and thoroughly debugged by the developer.

Identified defects are analyzed or corrected and testing is repeated until all known defects are either fixed or otherwise resolved.

Subsystem testing consists of connecting two or more devices together and exchanging data. A subsystem test assumes that the individual devices and subsystem components have previously passed a sufficiently designed unit test plan, and that the devices or subsystem components support the same operational, and/or functional features. This process ensures that every requirement is verified through use of the test system.

Finally an end to end system test should be used to verify that the lights do turn on, off, and dim in response to a command from the management center software. The fully integrated system should be verified at the vendor’s facility before it is installed at the customer’s site.

System verification testing is the highest test level. It is also usually the one with the fewest requirements remaining to be verified. Only those requirements relating to subsystem interactions, quantity of field devices, external interfaces or system performance should remain to be formally verified at this point. Subsystem acceptance testing is performed after all
lower level testing has been successfully completed. It is performed in the operational environment using all available and previously installed and tested system hardware and software. The system acceptance test should include an end to end or operational readiness test of sufficient duration to verify all operational aspects and functionality under actual operating conditions. Formal acceptance of the system, at the subsystem or system level may trigger the start of equipment warranty periods or software licenses agreements, as well as operational or maintenance agreements. The procurement documents should clearly specify which of these are applicable.

Additional testing guidance provided by the U.S. DOT Federal Highway Administration document: FHWA NTCIP 9012, "Testing Guide for NTCIP Center-to-Field Communications". This document helps deploying agencies define device testing processes and programs. The testing guide explains testing for compliance and conformance, where testing fits in the systems engineering model, how to develop good device specifications based on standards, and how to define a testing framework. NTCIP 9012 also discusses writing detailed test procedures, and the options for who should perform testing. While written for the NTCIP community, it is useful for agencies, vendors and consultants who develop, design, deploy and maintain streetlight control systems.

2.4 Cost Benefit Analysis

The cost savings received through use of lighting control systems can be substantial. These savings can be used to perform break-even and Return of Investment (ROI) calculations. These results can be valuable additions used to meet the project specifications for minimum break-even time, minimum ROI or lowest total cost of ownership.

Benefits that accrue to the project implementer include energy savings, as well as asset management, wire theft protection and reduced maintenance efforts. In order to reliably quantify these savings, a cost accounting study of all cost drivers involved in the project should be conducted.

2.5 Procurement

FHWA policy (and the policies of many other public agencies as well as private operators) prohibit contracting agencies from requiring the use of a patented or proprietary material, specification, or process, unless:

- The item is purchased or obtained through competitive bidding with equally suitable unpatented items, or

- The contracting agency certifies either that the proprietary or patented item is essential for synchronization with the existing highway facilities or that no equally suitable alternative exists, or

- The item is used for research or for a special type of construction on relatively short sections of road for experimental purposes.

- If there are other equally acceptable materials or products available, the contracting agency may require a specific material or product when the Division Administrator approves of its use as being in the public interest.

Materials and products that are determined to be equal may be bid under generic specifications. If only patented or proprietary products are acceptable, they should be bid as alternatives with all, or at least a reasonable number of, acceptable materials or products listed.

Additionally, FHWA funded roadway lighting projects shall conform to the National Intelligent Transportation Systems (ITS) Architecture and standards, including use of the SEP. Conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture. Development of the regional ITS architecture should be consistent with the transportation planning process for Statewide and Metropolitan Transportation Planning.

All projects that are funded in whole or in part with the highway trust fund, including those on the National Highway System (NHS) and on non-NHS facilities, are subject to these provisions.

3.0 CONTROL TECHNOLOGIES

3.1 Stand-alone Technologies

This section covers control solutions that are “stand-alone,” meaning that they do not require a network or other separate device to operate.

3.1.1 Background Historically, Cadmium Sulfide (CdS) light sensitive cells (actually light sensitive resistors) were used in series with the pickup coil of an AC relay. These were generally called electro-mechanical or magnetic photocontrols. Newer electronic photocontrols offer several advantages, including the ability to use a more stable photo-transistor (or photo-diode) and more accurate turn on and turn off control.
Cadmium Sulfide cells are still used on what is called a thermal photocell. The thermal photocontrols do not have the advantages of an electronic photo control, but they are still used because of their low price and because they are more compact and are used in the smaller “button” photo controls.

Filtered photodiodes (also known as phototransistors) are mostly modern photo controls which use silicon photo-transistors (or photo-diodes) to detect light levels. Due to their much higher response to the infrared (IR) spectrum than the visible spectrum, the presence of infrared wavelengths can shift the control points of silicon based photo controls that are calibrated with visible light sources. Hence, many lighting authorities are requiring IR filtered or IR blocking photo controls to allow operation based on visible light levels and not invisible levels.

Cadmium-sulfide (CdS) cells were used for detection of visible light levels because their response matches very well with that of the human eye, and is very insensitive to IR. However, their undesirable sensitivity changes with age, and their requirement for light conditioning has led most manufacturers to move away from them and embrace silicon detectors. In an effort to cope with the IR sensitivity of silicon, many manufacturers have turned to various methods of filtering in an effort to cancel the effect of IR on the control levels. Generally, this filtering might be accomplished optically or electronically. An optical filter might simply be a piece of plastic film placed in front of the silicon photo-transistor or it might be molded as part of the photo-transistor’s lens. The most common method of electronic IR filtering is to use an IR photo-transistor that is sensitive to only IR and subtract it from a photo-transistor that is sensitive to both IR and visible light, leaving only the visible light response.

3.1.2 Dusk to Dawn Photo Controls (Photocells) Dusk to dawn photo controls (photocells), as implied, turn on a light at dusk and off at dawn. They are generally packaged in a locking-type (NEMA, twist lock) 3 terminal device measuring about 7.6 cm (3”) in diameter and are compliant with ANSI C136.10.

The light levels that these photo controls turn on and turn off are important in determining the burn time of the light. If these levels are set high, it will cause the burn time to be excessive, causing increased energy usage. If these levels are too low the light might not turn on due to light from other artificial sources (such as other lights). They can be specified in various types, turn and off settings and voltages and typically mount onto the luminaire.

Filtering photodiodes (also known as phototransistors) are mostly modern photo controls which use silicon photo-transistors (or photo-diodes) to detect light levels. Due to their much higher response to the infrared (IR) spectrum than the visible spectrum, the presence of infrared wavelengths can shift the control points of silicon based photo controls that are calibrated with visible light sources. Hence, many lighting authorities are requiring IR filtered or IR blocking photo controls to allow operation based on visible light levels and not invisible levels.

Cadmium-sulfide (CdS) cells were used for detection of visible light levels because their response matches very well with that of the human eye, and is very insensitive to IR. However, their undesirable sensitivity changes with age, and their requirement for light conditioning has led most manufacturers to move away from them and embrace silicon detectors. In an effort to cope with the IR sensitivity of silicon, many manufacturers have turned to various methods of filtering in an effort to cancel the effect of IR on the control levels. Generally, this filtering might be accomplished optically or electronically. An optical filter might simply be a piece of plastic film placed in front of the silicon photo-transistor or it might be molded as part of the photo-transistor’s lens. The most common method of electronic IR filtering is to use an IR photo-transistor that is sensitive to only IR and subtract it from a photo-transistor that is sensitive to both IR and visible light, leaving only the visible light response.

3.1.3 Time Switches Time switches traditionally have been used to turn a light on and off at specific times; the device will need to be calibrated for the local time. Assuming the time switch is not connected to an outside information source (such as the Internet), the ability of the switch to maintain an accurate time could be a concern, particularly in the case of electro-mechanical timers. Many time switches also do not allow for time shifts due to daylight saving time.

A time switch can be put in series with a photo control (photocell) in such a way that the light load will come on at dusk and turn off at a chosen time. There are also part-night photo controls available that integrate a photo control (photocell) with an internal switch (see Section 3.1.4 below).

The function of a time switch is also generally included within the control functions of a networked system, which is discussed in the appropriate section within this design guide.

For stand-alone applications that do receive time updates from a master time reference, the parameters of “Global Time”, “Global Daylight Savings Time”, “Standard Time Zone”, “Local Time” and “Daylight Saving Time” are formatted according to the NTCIP 1201 V03 Global Object Definition Standard, a Joint Standard of the American Association of State Highway Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE) and the National Electrical Manufacturers Association (NEMA).

3.1.4 Part Night Photo Controls (Photocell) They are similar to the dawn to dusk photo-controls above however instead of using a time clock in series with a photo control, they can turn the lights on at dusk and shut the lights off at a specified time (or % of night)
allowing the designer to save energy. They measure the length of each night, and thereby adjust themselves each night as the seasons change. In this type of application, one or more fixtures with standard dusk to dawn photo controls may be used as a “night light” to supply minimal lighting, while the others save energy during the late night, after business hours.

A slightly different variation of a part night photo control receives a very precise time signal via radio from government maintained time standards. These give the added benefit of automatic time resynchronization after a power outage without the need of being connected to a network.

3.1.5 Astronomical Time Switch Astronomical time switches, also known as astronomical clocks, work much the way a typical time switch works, but additionally it knows the theoretical sunrise and sunset times for each particular day of the year at a particular coordinate (location). This is useful should one wish to turn on a light at sunset (and/or off at sunrise) without the use of a photo control (photocell). Because twilight generally follows sunset (and precedes sunrise), an offset time, say 10 minutes, can be used so that the light fixture is not turned on or off too early (or too late for sunrise).

Astronomical time switches have the potential disadvantage in that they do not compensate for cloudy days, or other variables that affect light levels around sunrise and sunset. Effects from mountains may also shift the actual sunrise and sunset.

Most astronomical time switches do allow for time shifts due to daylight saving time.

The function of an astronomical time switch may also be included within the control functions of a networked system, of which is discussed in the appropriate section within this design guide.

3.1.6 Motion Detectors Motion detectors can be used to change the state of a light (or multiple of lights) when motion is detected. This change of state might be to turn on a light or to change the light from a dimmed state to a full bright state. These are commonly used for indoor applications (often called occupancy sensors) where elements like blowing leaves and running animals are not particularly a problem. False detection caused by such issues as blowing leaves, animals and wind vibrating poles can make it more challenging to implement motion detection in outdoor environments. Motion detectors can also be adversely affected by changes in ambient temperature. Improved PIR (Passive Infrared) detectors, radar, hybrid and intelligent cameras that better prevent false detection may be considered and do help dealing with the outdoor environment. If the user determines that motion sensing functionality is needed, the designer/engineer can specify the appropriate detection pattern for that application. It is important to remember that outdoor application scenarios may present significant obstacles to successful design and operation, including missed and false detections. The designer should act judiciously when attempting to employ outdoor motion sensors in new or retrofit designs.

Motion detectors can also be used in conjunction with a networked system to provide on-demand lighting which can result in energy saving.

3.2 Networking and Communications Technologies

This section covers several technology elements that are essential parts of an integrated and interdependent system that comprise advanced street lighting controls. These include the management station, the data logger and street lighting controllers as well as other terminal devices. These are represented in Figure 10 below.

3.2.1 Background Whereas in the past it has not been practical to dim or instantly turn on or re-start HID light sources, LEDs have given us a practical way of doing so. Networking lighting systems now give the ability to monitor, control and even create systems that have the ability to react to changing environments – adaptive lighting. A thoughtful, well-informed approach to re-engineering street lighting systems is emerging to create cost-effective opportunities to reduce power consumption and maintenance costs.
3.2.2 Management Station

A management station (sometimes referred to as a Central Management System (CMS)) is defined as one or more host computing platforms that control(s) the field devices. They may be hosted by a third party provider or by the maintaining agency. Mobile management stations are devices that can be used at a fixture or electrical service cabinet.

For networked controls, the management station is located where the communications with the luminaires are collected and analyzed. Street lighting operators should consider a requirement that all manufacturers of lighting communications products transmit their data to their management center in a language that the management station can use. Designers should require that the communications interface between all devices should be detailed by an Interface Control Document (ICD). The ICD defines the “language” that the systems and subsystems should use.

These systems can be built using a variety of architectures, from hardware and software hosting at the management center, to hosting at an offsite location. To avoid the constrictions that often occur with operating proprietary systems, street lighting operators should consider insisting that the management station communicate in a standardized protocol with the field devices, This would allow interoperability between system components, allow exact interchangeability of system components and reduce the probability of product obsolescence.

Figure 12 below describes a roadway lighting management system that includes control and monitoring of electrical services and branch circuits.

Management center communications interfaces to either a data logger or the actual field device (streetlight controller) and can be grouped into two classifications. These are known as proprietary or standardized protocols. Proprietary protocols provide a single point of contact for initial system acquisition as well as maintenance. Alternatively, standardized solutions allow multiple vendors’ products to operate together. Support of these standardized devices and systems can range from interoperability for some (or all) features to complete interchangeability of differing vendors products.

Depicted in Figure 13 above, the standards continuum can be thought of as stretching from a single or two-party proprietary specification to a full international standard, across the dimension of development time measured in months to years. Further categorization can be applied regarding the \textit{de facto} or \textit{de jure} legal status. Specifications and requirements are defined by single or multiple persons, alliances or organizations. Often proprietary in nature, they are quickly developed to support interconnection and integration of various devices and systems, usually over a period of months.
behavior such as market division, pricing discussions and the like. Also, intellectual property is treated as a potential source for standards language, and requires disclosure by the holder. A clear distinction from an alliance or users group is that strict control is maintained of the candidate voter pool for balloting to ensure a measure of fairness and balance. As an example, the American National Standards Institute (ANSI) has three categories: producer, user and general interest, and for balloting purposes no single category can exceed one half of eligible voters (for non-safety related standards).

Formal standards (and many specifications) may actually begin as de facto “standards,” i.e., enough commonality among enough producers to call the product/approach/protocol “standard.” Beyond this, SDOs actually author de jure standards - those that are codified in a manner similar to laws. Given the careful attention to balloting balance, open rules and open participation, standards may be adopted in place of laws in certain jurisdictions.

Figure 13 summarizes the standards continuum with respect to the elements described above.

Standards meet the goal of creating a common basic understanding of a technology. Unless the scope of a standard includes interoperability tests or guidelines, a technology could only be stated to be in compliance with that standard. For confirmation of interoperability of the various system components, a comprehensive test plan should be developed.

Alliances, trade groups, and consortia are groups of entities (and individuals) that recognize the value of a particular technology, and form a formal “interest group” to promote aspects such as the codification of design and marketing of that technology. The difference between an alliance and a formal standards group lies within both the rules and the work products. Since any number and balance of interested parties can form an alliance, the rules under which they operate are very broad.

In contrast to alliances, Standards Development Organizations (SDOs) operate under similar rules and governance principles worldwide. In general terms, the members of the committees doing the actual development work are limited by anti-trust rules or laws from engaging in anti-competitive

Depending on the project-specific user needs that have been defined for a lighting control system, proprietary or standardized communications solutions may be selected.

3.2.3 Data Logger A data logger is a physical component that collects and stores information on the state and operation of electrical and lighting management system devices. Data logging is a functionality that may be included in various system components, not limited to the data logger. For a large scale system, such as for a large city, some temporary data logging may take place at the luminaire controller so as to not to require transmission of data on a constant basis. Similarly, the data logger field device may store temporary data before passing the data to the Management Station.
Examples of data than can be logged include:

- Luminaire Switch State Logging
- Luminaire Lamp Condition Logging
- Luminaire Burn Condition Logging
- Periodic Luminaire Burn Time Logging
- Luminaire Temperature Logging
- Luminaire Pole Condition Logging
- Relay Switch State Logging
- Power Meter Switch State Logging
- Periodic Power Meter Measurement Logging
- Power Meter Condition Logging
- Ground Fault Switch State Logging
- Periodic Ground Fault Measurement Logging

Additional logging functions can include:

- Luminaire Burn Time Log
- Power Meter Measurement Log
- Ground Fault Measurement Log
- Meter Switch State Log
- Meter Condition Log
- Off-line Log Data
- Luminaire Switch State Log
- Configuration of Logging Service
- Capabilities of Event Logging Services
- Number of Events Currently Logged

Attention should be paid to the protocols that may be used between these various components, since interoperability, interchangeability between various manufacturers may be an issue.

3.2.4 Streetlight Controllers Streetlight controllers (sometimes referred to as nodes if using a mesh topology) are terminal devices that communicate with the data logger over dedicated wires, via powerline carrier or wireless equipment. Each streetlight controller may have control, measurement, logging and communication features. Dedicated wires are a simple, reliable means of communicating with luminaires. Powerline carrier costs can rise when numerous transformers are present because additional hardware is required. These bridges are necessary to route the signal around transformers.

Wireless transmitters/receivers have limitations, including obstructions to radio signals such as trees, buildings and hills. Wireless systems can use different frequency bands such as the license free ISM bands (e.g., the 915 MHz and 2.45 GHz center bands) or privately licensed frequencies. Further, a type of topology such as mesh or star (point to multipoint), or a combination, will be used. It is good to understand the advantages and disadvantage of each of these in order to choose the best solution for a particular application.

3.2.5 Data Logging Depending on the needs of the user, both operational parameters and exceptional conditions may be recorded or logged. This function can occur physically within the streetlight controller or within the data logger.

3.2.6 Data Security Since roadway lighting systems rely on computer communication technology and may be linked via an Internet connection, data and system security should be addressed when the project-specific user needs are developed.

4.0 ADAPTIVE LIGHTING DESIGN

4.1 General Considerations

The design considerations noted are mainly related to energy savings. The quality of the lighting and
improved visibility should also be considered. The items listed should be considered as part of the planning and design phases of an outdoor lighting project. As a cautionary note, applying this information requires a very sound knowledge and understanding of lighting and road safety. Local conditions, (i.e., user needs from all stakeholder communities), including law enforcement shall be supported. Therefore, it is recommended that further research and review be undertaken prior to adopting these design considerations with respect to lighting and road safety, with a focus upon the specific application.

New energy efficient light technologies and controls are now changing the landscape by offering potential energy savings and performance benefits. However, with these advances there is an increased level of complexity, which requires increased expertise and understanding from owners and lighting designers. One major barrier to obtaining energy cost savings from an adaptive control system can be the flat rate power agreement from the utility provider which is typically based on a fixed luminaire wattage and usage over a monthly or yearly period. It is recommended that a custom rate schedule or metering system be agreed to with the local electrical utility prior to proceeding with energy saving adaptive lighting controls if cost reduction is a priority.

In terms of power savings, adaptive lighting involves varying lighting levels to suit activity levels during off-peak periods. Adaptive lighting is achieved via the use of lighting controls that allow luminaires to be dimmed or turned off at pre-defined times. Simply put, by varying the levels of lighting during non-peak periods, significant power can be saved. Occupancy based control can also be considered in applications where activity levels are varied. Adaptive lighting controls will typically have the highest benefit for continuous lighting systems in urban areas. They can be applied in rural areas. Typically they will have less energy saving benefits than in urban areas where light levels are higher and more lighting exists.

Three main techniques have the potential to save power and reduce light pollution with adaptive lighting controls:

- Reduce Initial Light Output to Maintained Levels - Light output from light sources depreciates over time. To maintain the minimum maintained lighting levels on the roads and sidewalks, lighting designs are based on maintained lamp life and, therefore, have a maintenance factor applied to the design to take into account this depreciation.

- Match Light Output to Pedestrian Activity Levels - The amount of light required for a roadway or sidewalk is based on two significant criteria: the classification of the roadway itself and the level of pedestrian activity. The classification of the roadway
Reducing lighting levels based on pedestrian activity levels is not recommended in all lighting scenarios. Listed below are scenarios where reducing lighting levels in off-peak periods is not recommended:

- **Signalized Intersections** - Signalized intersections typically include pedestrian crossings. Pedestrian conflicts with vehicles are very likely at signalized intersections. The lighting should not be reduced from design levels at intersections.

- **Mid-Block Crosswalks** - The decision not to dim mid-block crosswalks follows the same logic as stated for signalized intersections.

- **Roundabouts** - Due to the complex geometry in roundabouts and the ineffectiveness of fixed headlights within the tight roundabout circle, dimming should not be applied to these facilities. Roundabouts are an alternative to signalized intersections, thus lighting should not be reduced from design levels at roundabouts.

- **Rail Crossings** - Rail crossing lighting is provided for detection of the trains and not related to pedestrian conflict levels. Therefore, reducing lighting levels during off-peak periods is not recommended.

### 4.2 Specific Design Considerations

Each specific roadway lighting application listed includes suggestions and recommendations for light level reductions and energy savings.

#### 4.2.1 Residential Streets

Lighting on residential roads typically makes up a large percentage of a city or municipality lighting infrastructure. Lighting on residential roads serves the driver and provides a sense of security and guidance to pedestrians. The light level requirements on residential streets can vary based on pedestrian volume (activity). For example, it is recommended that a local street with high-pedestrian volume be illuminated at a higher level than a low-pedestrian volume local street. Pedestrian volumes on local streets are certainly time dependent. Peak pedestrian volumes will occur earlier in the evening and late night, whereas early morning volumes will be quite low or zero. There can, however, be a peak in early morning pedestrian to vehicle conflicts. This should be reviewed as it may be specific to a given area. Where there is a change in the volume of pedestrians, the local street lighting levels can also be reduced to take this into account. For example, a local high-pedestrian volume street can be dimmed to the lighting level of a local low-pedestrian volume street.

Vertical illumination is a key consideration for the detection of pedestrians and cyclists.

**Figure 15** above shows the vertical and horizontal illuminance produced by a motor vehicle low beam headlight, with the red area showing any value at or above 1 lux (.09 fc). The 1.5m (5 ft) high vertical objects were placed into the right of the model along the sidewalk area, providing a surface for determining the vertical light illumination on pedestrians. The first vertical rectangle is at 30m (98 ft) from the motor.
vehicle headlamps and each vertical rectangle is spaced at 15m (49 ft) from that point on. The vertical illumination (of varying heights along the face of the object) of 1 lux (.09 fc) from vehicle’s headlamps is significant in this model. Therefore, the recommended vertical illumination levels of 1 lux (.09 fc) are achieved via motor vehicle headlamps for an extended distance in front of the vehicle. Horizontal illuminance extends from 30-40m (98 – 131 ft) from the vehicle headlamps and would not meet the required horizontal light level requirements. Headlamp data was provided in 2007 by the Virginia Tech Transportation Institute and the modeling of the headlamps was undertaken in 2007 by Parsons Brinckerhoff for review by the IES Roadway Lighting Committee.

This modeling clearly shows significant illumination contribution from motor vehicle headlamps. Though motor vehicle headlamps provide a level of visibility in low speed applications, roadway lighting is still of value in providing visibility and a level of security and comfort to the local residents and pedestrians.

To provide some level of lighting, a reduction in roadway lighting levels in an off-peak period (i.e., midnight to 5 AM) could be considered based on the contribution of motor vehicle headlamps. The level of reduction could be in the 30-60 percent range, however, it should be reviewed and assessed by study and evaluation. It is up to jurisdiction who owns the lighting to accept the times and light level reductions for the off-peak period.

Several cities, including San Jose and others, have begun to adopt adaptive lighting guidelines based on local conditions. Designers should reference local adaptive lighting guidelines where available. Although a 20-30 per cent difference in light level is not easily visible, a sudden change in light level is visible. It is recommended that any changes in light levels take place over a period of time to accommodate eye adaptation.

Simply turning lights off during off-peak periods has been undertaken by some communities. This practice is, however, not recommended without extensive review, research, and public consultation.

With the advent of new roadway lighting sources, such as LEDs with their advanced optical control, the uniformity ratio (often the limiting design factor in the past for high pressure sodium lighting on local roads) is now more easily achieved, which allows roads to be lighted closer to the required maintained average lighting levels. To reduce power consumption, adaptive lighting controls and LED lighting should be strongly considered for local roads.

### 4.2.2 Collector and Arterial (Major) Streets

Lighting on arterial and collector roads should meet the required levels as defined by ANSI/IES RP-8-14 Roadway Lighting. There is no basis to reduce lighting levels below the lowest lighting criteria (i.e., low pedestrian activity level) for the classification of the road (i.e., arterial or collector). To reduce power consumption, adaptive lighting controls and LED lighting should be strong considerations for these lighting applications.

Adaptive controls can allow for significant energy saving in areas of high and medium pedestrian activity, as the level of activity can typically be reduced to low in off-peak periods.
4.2.3 Freeways and Highways Lighting on freeways and highways should meet levels required. Freeways and highways are typically high-speed facilities where pedestrians are not normally present. For this reason, adaptive lighting should not be applied to reduce levels below the required levels without undertaking further research and assessment. One factor which could allow for reduced levels is reduced speed. Though not yet fully researched, full level lighting may be of less benefit where freeway traffic is gridlocked at low speed during rush hour periods. Speed sensors could be used to sense low speeds and adjust and dim light levels during these low speed periods.

As driver guidance and vehicle collision reduction is the primary objective, freeways and highways provide a great opportunity to consider alternatives to lighting such as retro-reflective pavements markings and delineators. Further guidance can be obtained through the publications: Guidelines for the Implementation of Reduced Lighting on Roadways (Pub No. FHWA-HRT-14-050 JUNE 2014), as well as Design Criteria for Adaptive Roadway Lighting (Pub. No. FHWA-HRT-14-051 JULY 2014) both published by the U.S. DOT FHWA.

4.2.4 Sidewalks, Walkways and Alleyways Sidewalk lighting should meet illumination levels recommended or required by the Authority Having Jurisdiction (AHJ) (refer to ANSI/IES RP-8-14). To reduce power consumption, adaptive lighting controls and LED lighting should be strong considerations for these lighting applications.

Lighting of walkways and alleyways can be a challenge and a concern, as they provide a sense of comfort and security that may, in fact, be misleading. It has been noted by police that when entering an alleyway or remote walkway, the criminal generally has the upper hand. This is due to a lack of natural surveillance from the roadway as well as the number of concealed areas within an alleyway or on the walkway for which a criminal can hide. Designers should consult with local law enforcement authorities as well as other stakeholders in order to develop a comprehensive list of project-specific user needs.

Many commercial alleyways have low nighttime traffic with little natural surveillance from the city’s streets or windows. Pedestrians may walk into a well-lighted alleyway thinking they are safe when, in fact, there may be hidden areas that pose a risk. In a situation where the alleyway is a main route, it should be well lighted throughout. However, personal safety would typically be improved if pedestrians used the sidewalk adjacent to the roadway, rather than side alleys that typically have little natural surveillance.

Motion sensor activated lighting is being considered instead of lighting that remains on continuously at night. If alleyways or walkways are lighted, then all alcoves, landscaping, and hidden areas may also be lighted to reduce surprise attacks. The police often prefer motion sensitive lights in alleyways so that activity can be noticed by neighbors or from adjoining streets, as the lights turning on will indicate activity. Motion sensor activated lighting has the potential to save power while improving safety.

4.2.5 Tunnels Lighting in tunnels should meet the requirements defined in ANSI/IES RP-22-11 American National Standard for Tunnel Lighting.

The orientation, physical attributes, and surrounding environment of a tunnel portal significantly impact the amount of lighting needed. Visibility analysis takes these issues into account. A tunnel will have multiple lighting levels for maximum efficiency. This is achieved by lighting controls that measure the luminance level outside the tunnel and adjust lighting at the tunnel entrance (threshold).

4.3 Inventory Assessment

For new installations, an inventory is not required since the adaptive lighting system should be developed as part of the lighting design.

For conversions of existing installations in order to optimize savings and to ensure proper lighting levels are achieved, an inventory assessment of the existing lighting is recommended. Many roadways are over lighted and, as such, energy savings can result by simply reducing levels to the required standards. Design criteria (road classification and pedestrian activity), road information (widths, number of lanes, sidewalk info), pole locations (spacing), heights, and wattages should be obtained from the city’s GIS (geographic information system) database. If no database exists then a survey of existing lighting should be undertaken using aerial maps and existing electrical design drawings.

The makes and models of luminaires should be established via consultation with the maintenance personnel. From this, the photometric files should be obtained from the lighting suppliers. Lighting calculations using computer roadway lighting calculation software should be undertaken. Sidewalk and walkway lighting calculations should also be undertaken.

Once the calculations are completed, they should be compiled into a spreadsheet along with all relevant data for comparison with the recommended design criteria.
The length of roadway calculations shall be undertaken for non-uniform spacing, greatest spacing and most non-typical design scenarios. This analysis should also extend over the entire length of the road. Typical roadway sections should be considered in the analysis. This process will capture typical lighting levels that generally reflect the extent of the roadway’s existing lighting installation.

To verify the calculations, sample light level measurements could be undertaken on roadways and sidewalks. Designers should adhere to IES guidance regarding light measurements as found in ANSI/IES RP-8-14.

As part of the inventory, the system manager will need to detail all new and existing luminaires. Depending on the project scope the agency may also decide to inspect and document the condition of the pole, foundation and wiring. This will allow the adaptive lighting supplier to plan a pilot installation with testing so as to properly allow them to retrofit their equipment into the luminaires. If the city has numerous types of luminaires this aspect may prove to be a substantial challenge. It is important to note that some streetlight controls include GPS functionality within the streetlight controller along with an asset management tools at the management station. These features greatly reduce the resources required for a post-installation audit.

4.4 Deployment

The installer should install all equipment to the supplier’s specifications. The level of effort required for the installation of an adaptive lighting system will vary between the different manufacturers and whether a fixed or adjustable system is deployed.

The supplier shall provide technician(s) to execute the start-up of the adaptive lighting system, and test the system for proper operation.

The equipment supplier should provide the system management personnel training in the understanding of the system and its operation along with the maintenance requirements of every component. If the system has adjustable dimming capabilities, the supplier is to ensure that the system management personnel are fully aware of the ways to fully utilize the features of the system.

The supplier shall provide the system management personnel with operations and maintenance manuals after the installation is fully tested and in operation. These documents shall be provided to the operations department of the system manager.

5.0 ADAPTIVE LIGHTING OPERATIONS

Adaptive lighting systems can have significant impacts on the operation of lighting system: some these are listed below.

5.1 Preventive Maintenance Analysis

It is good practice for an agency to create charts and maps of malfunctions and failure rates by location and equipment type from work management system records. A control system that includes a computerized maintenance management system (CMMS) also can create component failure rate reports and the mean time between failures (MTBF) index by component type/model and age category. With some adaptive systems the mean time to repair (MTTR) for different types and models of components can created by the CMMS as well.

5.2 Inventory Analysis

Analysis of partial usage can be key to maintenance control. By identifying statistically the highest use parts and their relative costs, agencies can invest their improvement efforts on these areas of highest return. Pareto and root cause analysis can be applied to reduce the incidence of these failures. Pareto analysis is a formal technique useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one. Root cause analysis is a method of problem solving that attempts to identify the root causes of faults or problems. A root cause is a cause that once removed from the problem fault sequence, prevents the final undesirable event from recurring.

These analyses can result not only in considerable savings in material costs and inventory but also in the labor and associated equipment costs previously expended on these failures. Analysis can also be applied in reviewing part specifications and past failure and maintenance requirements history, responsiveness of vendors and manufacturers in meeting supply requirements and the total in-house processing time from the technicians request for a part to its issue.

5.3 Work Management Analysis

Analysis is typically conducted through the CMMS to ensure that all labor, parts, and equipment recorded for the agency has been accounted for properly on a regularly scheduled basis. Work order activity analysis is conducted to determine the accuracy of
5.6.1 Asset Tracking Digital radio vendors can often support real-time asset management through barcode scanning. By scanning parts and tools as they travel through the organization, users can maintain a documented "chain of custody" of assets; losses can be greatly reduced while confirming that the correct amount of parts is in stock, both at the parts depot and on each service truck. Additionally, at each scan, the GPS location data is recorded so managers know exactly where and when each component was physically deployed.

5.6.2 Electrical Safety Equipment Ground fault detectors and interrupters can in virtual real-time report dangerous system anomalies. Some adaptive systems offer ground fault detection.

5.7 Power Metering and Monitoring

As discussed earlier in this document the utility providing power should agree with energy savings operations in order to receive cost benefit from power savings. It is therefore imperative this be negotiated prior to deployment.

5.7.1 Tariffs Utility tariffs are the published collection of rules, rate schedules and terms and conditions for use of service. This allows for the analysis of cost savings of switching from one light source to another, reduction of burn hours, achieving equal light output, and adaptive lighting.

It is estimated there are over three thousand traditional electric utilities in the United States. Electric utilities include investor-owned, publicly-owned, cooperatives, and Federal utilities; regulated by local, State, and Federal authorities, and in the case of many electric cooperatives, by their Board of Directors.

5.7.2 Flat rate billing The great majority of street and roadway lighting is un-metered due to their fixed energy usage when operated by a photoelectrical control and the costs associated with providing a conventional watt-hour meter, meter socket, and electrical panel for each pole location.

The total monthly charge per lamp source is equal to the sum of the facility charge (utility or customer owned) and the energy charge. Monthly facility charges include the costs of owning, operating and maintaining the various lamp types and size. Monthly energy charges are based on the kWh usage of each lamp.

Monthly energy charges per lamp are calculated using the following formula:
(System wattage) x Total burn hours per year/12 months/1000 x streetlight energy rate per kilowatt hour (kWh).

5.7.3 Metered Service This type of service is provided to multiple lighting systems to which the utility delivers current at a secondary voltage and series street lighting systems for which the utility furnishes constant current regulating transformers. The total bundled service charges are calculated using the total customer charge and total energy rate.

5.7.4 Meter Accuracy Utilities maintain strict requirements for revenue-grade metering, such as accuracy of +/- 2.0 percent -- compliance with ANSI C12.20; C37.90.1 Surge Withstanding Test and other ANSI metering requirements C12.1 or C12.10. Some of these standards may not apply to metering chipset for streetlights and control systems. Similarly, there will need to be some standardization in terms of the frequency and accuracy of power measurements recorded by network control systems.

One key point of interest, and highly touted feature of network controls, is the ability to monitor streetlight energy usage. This is an improvement from the government and utility perspective because flat-rate (non-metered) loads are difficult to detect when not operating properly. Use of an incorrect ballast factor, lamp failures or day burning lights, is often not detected in a flat-rate scenario.

The collection and sharing of the energy data from these systems allows transfer data collected by the streetlight network for monitoring and billing purposes. Electronic Data Interchange, ANSI Standard X12, is already being used for Direct Access, additionally the Smart Grid Energy Services Interface (ESI) defined by the US Department of Commerce and the NIST (National Institute of Standards and Technology) could be used.

To realize cost savings associated with burn schedule changes, appropriate utility tariffs may be available that allows billing streetlights based on actual, rather than assumed, energy use. This will be especially important for adaptive lighting scenarios, where the fixture wattage is not a fixed point. It will take all parties involved – standards development organizations, design professionals, regulators, utilities, and streetlight system owners to implement these tariffs.

6.0 INTEGRATION AND COMMISSIONING

System integration is defined as the process of bringing together the component subsystems into one system and assuring that the subsystems function together as a system. The system integrator brings together discrete systems utilizing a variety of techniques such as computer networking, enterprise application integration, business process management or manual programming.

Commissioning can be defined as the process of assuring that all systems and components of a streetlight system are designed, installed, tested, operated, and maintained according to the operational user needs of the owner or final client (refer to IES DG-29-11 The Commissioning Process Applied to Lighting and Control Systems).

For large projects, this process usually comprises planning, execution, and control of many inspection and test activities on “commissionable objects”, such as management stations, data loggers, streetlight controllers, circuits, communications infrastructure, subsystems, and systems. A well planned project from the time of project inception greatly minimizes the time and cost of integration and commissioning. It is important that all stakeholders active in the integration and commissioning process communicate, as many interdependent project activities have the ability to slow the start-up activities.

6.1 Interoperability

Interoperability is defined as the ability of two or more systems or components to exchange information and use the information that has been exchanged (IEEE Std. 610.12-1990: IEEE Standard Glossary of Software Engineering Terminology). This ability of diverse systems and their components to work together—is vitally important to the performance of the streetlighting system at every level. It enables integration, effective cooperation, and two-way communication among the many interconnected elements of the streetlighting network. Effective interoperability is built on a unifying framework of interfaces, protocols, and the other consensus standards. These standards facilitate useful interactions so that, for example, “smart” streetlights tell users how much power they are using and at what cost, providing them with more control over their energy and maintenance resources.

For example, just because the management station and a field device support the same feature there is no guarantee that the two will interoperate or be interchangeable. They could support the same feature but speak different languages. To achieve interoperability, all seven layers of the OSI Model should be followed. To achieve this goal, designers need to examine the architecture and data flow levels and clearly identify which of them they are implementing and how.
Interoperability scenarios:

- If both the management station and the field device support a feature (that consists of an unambiguous data object), interoperability is provided.
- If the management station supports the feature, but the field device does not, the management station can still use other features and the management station can still interoperate that feature with other devices.
- If the terminal device supports the feature, but the management station does not, the feature could be used by another or a future management station.

6.2 Interchangeability

For interchangeability of components or systems, three scenarios exist:

- If both systems (and devices) support a feature that consists of an unambiguous data object, equipment is interchangeable for the feature.
- If new equipment supports a feature but the old one does not, the new equipment is interchangeable (meets or exceeds).
- If the old equipment supports a feature, but the new equipment does not, the feature will not be supported. In this scenario the user should reexamine if the feature is actually required.

6.3 Compliance vs. Conformance

The definition of “conformance” means:

- Meets a specified standard
- To claim "conformance" to a standard, the vendor shall at a minimum satisfy the mandatory requirements without violating any rules
- Vendors that provide additional features beyond the mandatory requirements are still conformant
- Vendors that replace conformant features with proprietary features are not conformant

The definition of “compliance”:

- Meets a specification (e.g., for a specific project)

6.4 Integration with U.S. DOE “Smart Grid” Compliant Systems

Under the Energy Independence and Security Act (EISA) of 2007, the National Institute of Standards and Technology (NIST) has the “primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…".

The Smart Grid will be key to national efforts to further energy independence and curb greenhouse gas emissions, and NIST is carrying out its responsibilities with a sense of urgency. With industry, government, and consumer stakeholders, NIST is expediting identification and development of standards critical to achieving a reliable and robust Smart Grid.

Integration of the street lighting system can be by a simple on/off signal to the utility. A significantly more substantial "Smart Grid" interface is defined by the National Institute of Standards and Technology (NIST) as an Energy Services Interface (ESI) which provides a forecast of bidirectional energy usage and its related cost.

6.5 Integration with Intelligent Transportation Systems

Integration with Intelligent Transportation Systems requires compliance with US DOT National Transportation Communications for Intelligent Transportation System, particularly NTCIP 1213, and other related standards. NTCIP and its dependence on the SEP process allows for the development of an unambiguous project specification.

In addition, NTCIP compliance includes unambiguous definition of communication interface objects. These objects can then be deployed to achieve interoperability and interchangeability with other devices, systems and applications resident on the national highway network.

The United States Federal Highway Administration (FHWA) and Federal Transportation Agency (FTA) provides funding for 13 standardized intelligent transportation systems applications, including street lighting applications. In order to be eligible for this funding, the project should comply with the city, county or state regional ITS architecture plan as approved by FHWA. All regional architectures are required to comply with the particular ITS standards for that application. For street lighting applications, the relevant standard is NTCIP 1213 Electrical and Lighting Management Systems. More information on NTCIP is located in Annexes B and C.
6.6 Integration with Building Automation Systems

Streets and roadways can often extend onto geographies managed by private third parties. These include shopping malls, office complexes and gated communities. In these instances, frequently the facility operator desires to monitor and control the lighting, and to integrate these functionalities with the facility's Building Automation Systems (BAS).

A variety of software, hardware and communications standards are used in the BAS domain. These include BACNet, LonWorks® technology and Zigbee technology. Each standard is described briefly in the Annexes (also refer to IES TM-23-11 Lighting Control Protocols).

GENERAL REFERENCES


ANNEX A – U.S. DOT INTELLIGENT TRANSPORTATION STANDARDS

A.1 History

The NTCIP is a joint standardization project of AASHTO, ITE, and NEMA, with funding from the RITA ITS JPO. Those new to the NTCIP should download The NTCIP Guide (NTCIP 9001) at www.ntcip.org.

The National Transportation Communications for ITS Protocol (NTCIP) family of standards defines protocols and profiles that are open, consensus-based data communications standards. When used for the remote control of roadside and other transportation management devices, the NTCIP-based devices and software can help achieve interoperability and interchangeability.

NTCIP is a family of communications standards for transmitting data and messages between microcomputer control devices used in Intelligent Transportation Systems (ITS).

An example of such a system is a computer at city hall monitoring and controlling the operation of microprocessor-based roadside controllers at streetlights within a city. The computer may send instructions to the streetlights to change light output levels as conditions warrant. The family of NTCIP standards is intended for use in all types of management systems dealing with the transportation environment, including those for freeways, traffic signals, transit, emergency management, traveler information and data archiving. NTCIP is intended for wire-line or some wireless communications between computers in different systems or different management centers, and between a computer and devices at the roadside.

Interoperability and interchangeability are two key goals of the NTCIP open-standards effort. Historically, one problem commonly encountered results from the use of proprietary communications protocols. These protocols are often specific to the given project, as well as to the specific manufacturers involved in the project. As a result, expansion of the system after initial deployment can generally only be done using equipment of the same type and usually the same brand as in the initial deployment, unless there are investments in major systems integration efforts. There is little to no opportunity for realistic competitive bidding as additional field devices are added to the system, due to the lack of interchangeability. Nor is there any opportunity to add additional types of field devices to the system, due to the lack of interoperability. The proper use of NTCIP open-standards in an ITS deployment will allow the future expansion of the system to benefit from true competitive bidding, as well as allow other types of field devices to be added.

A.2 NTCIP and the Systems Engineering Process

NTCIP (and its dependence on the SEP process) allows the development of an unambiguous project specification.

A.3 Benefits of NTCIP

NTCIP offers increased flexibility and choices for agencies operating transportation management systems. It removes barriers to interagency coordination and allows equipment of different types and manufacturers to be mixed on the same communications line. For these reasons, operating agencies will benefit from specifying NTCIP in future purchases and upgrades, even if NTCIP is not used initially.
1. Avoid Early Obsolescence - An operating agency can ensure that its equipment remains useful and compatible long into the future by requiring NTCIP support

2. Provide Choice of Manufacturer - Once an agency has a central computer system that includes support for NTCIP, it can purchase other systems, field devices, or software from any manufacturer offering NTCIP conformant products that will communicate with that system.

3. Interchangeability and Interoperability through well documented, precise user needs, requirements and object definitions reduce risk in instances of interchangeability and interoperability. Test plan development is also documented

4. Use One Communications Network for All Purposes. The communications network is usually one of the most expensive components of a transportation management system. NTCIP allows a management system to communicate with a mixture of device types on the same communications channel.

5. Assure Interoperability with External Systems

Including Vehicle to Infrastructure Communications (V2I) and Electrical distribution "Smart Grid" communication standard.

**ANNEX A – REFERENCES**


**RESOURCES**

US DOT Professional Engineer CEU Courses: All are eligible for Professional Engineer CEU credits.

A101 - Using ITS Standards: An Overview

---

**ANNEX B – U.S. DOT STANDARD NTCIP 1213 ELECTRICAL AND LIGHTING MANAGEMENT SYSTEMS**

**SCOPE**

Communication between an ITS Management Center or portable computer and an Electrical and Lighting Management System (ELMS) is accomplished by using the NTCIP Application Layer services to convey requests to access or modify values of ELMS data elements resident in the device via an NTCIP network.

An NTCIP message consists of a specific Application Layer service and a set of data elements. An NTCIP message may be conveyed using any NTCIP defined class of service that has been specified to be compatible with the Simple Transportation Management Framework (STMF). The scope of NTCIP 1213 v02 is limited to the functionality related to ELMS within a transportation environment.

The remainder of NTCIP 1213 v02 includes the following sections, and each section builds on the previous section(s):

a) Concept of Operations (Section 2)—providing a description of user needs (needs for features and needs related to the operational environment) applicable to ELMS devices

b) Requirements (Section 3)—defining the functional requirements that address the user needs as identified in the Concept of Operations, and including a Protocol Requirements List (PRL) that defines conformance requirements, thereby allowing users to select the desired options for a particular project