A **CANADIAN URBAN INSTITUTE** PROGRAM

LIGHTSAVERS CANADA

ADAPTIVE CONTROLS FOR ROADWAY AND PARKING LIGHTING:

A LIGHTSAVERS PRIMER

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EXECUTIVE SUMMARY

Adaptive controls are used to adjust lighting output, and therefore energy consumption, to suit needs and reduce waste. With 20% annual growth in global adoption of light-emitting diode (LED) lighting, which are well suited to adaptive controls, the transition to adaptive technologies is more accessible now than ever in the continuing search for energy/cost savings and improved safety. As a result, government organizations and lighting asset managers are increasingly including controls or luminaires with control compatibility.

As with any new technology, adoption can be difficult at first, but for adaptive lighting controls, resources are now available for successful and reliable implementation leading to significant energy and cost savings.

The Canadian Urban Institute (CUI) has produced this LightSavers Primer as a tool for street and parking lighting managers who are considering adaptive controls for their lighting systems. This guide includes relevant industry resources, as well as applicable guidelines and standards.

This Primer addresses the value proposition for adaptive controls including the potential for: reduction in energy consumption and greenhouse gas (GHG) emissions; remote monitoring with real time data collection; improved asset management; and improved public safety. The Primer outlines current challenges relating to control procurement and installation, and discusses possible solutions. It also describes the lighting requirements, control triggers, methods of control and methods of light reduction that asset managers should consider when procuring adaptive control systems.

LightSavers Canada is a market transformation initiative established in 2008 to accelerate the adoption and deployment of LED lighting and adaptive control technologies across Canada. This primer is made possible by a financial contribution from Natural Resources Canada (NRCan).

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I. INTRODUCTION

1. PURPOSE

This primer is designed to introduce lighting managers to the issues relating to integrating adaptive controls into parking and roadway lighting systems in order to reduce energy consumption, while ensuring safety for vehicles and pedestrians.

2. SCOPE

This document outlines what adaptive controls do, factors to consider in making an implementation decision, system configurations, functions of the components and examples of existing installations. Although the content has been primarily derived from information applied to roads and streets, the concepts apply equally to parking lots and garages. This document does not attempt to prescribe procurement processes or particular solutions for specific applications; lighting asset managers are recommended to reference additional resources including those listed in the Industry Resources and Applicable Guidelines and Standards sections of this document.

3. WHAT ARE ADAPTIVE CONTROLS FOR LIGHTING

The term adaptive controls is used to refer to the technical solutions for adjusting light output to the amount actually required to achieve the design parameters on a roadway or parking facility. Street and parking lights have traditionally been powered at a constant level throughout the hours of darkness, despite the changing ambient light levels or traffic and pedestrian levels. Changes in light levels emitted from a fixture usually only occur as decreases resulting from luminaire age, failure or dirt accumulation. This can often result in more power being provided and more illumination generated than required for safety much or all of the time.

Adaptive controls reduce the power supplied to lighting systems so that the illumination levels are matched to the need. This can be to suit pedestrian and traffic activity, and/or to reduce the power supplied in the early years of an installation until required by the age or dirt related decrease. This control also reduces the overall impact of the lighting system on the environment.

Light emitting-diode (LED) lighting is particularly well suited to adaptive control compared to other lighting technologies in common use. Unlike high intensity discharge (HID) and fluorescent lighting, LEDs are often dimmable and do not decrease in service life with frequent ON/OFF functionality. Rapid improvements to technology and pricing have meant that more than 50% of global luminaire shipments are now LEDs, and this market is growing by about 20% annually. The platform for applying adaptive controls is therefore growing rapidly as well. Additionally, with the development of ANSI 136.41, control installation has become increasingly accessible. This ANSI document establishes mechanical, electrical and marking requirements for adaptive controls of street and area lighting. Appendix A highlights international case studies of past and ongoing lighting control implementation.

4. INDUSTRY RESOURCES

The following key industry resource groups provide technical support for the adoption of adaptive lighting control systems:

4.1 Canadian

a) ***Transportation Association of Canada (TAC)***
A national association of the full cross section of stakeholders in delivering transportation infrastructure, TAC funds research and has technical committees to produce guidance documents to members.

b) ***Canadian Smart Sustainable Lighting Network (SSL-Net)***
A network of researchers, industries, end-users and agencies, which was started by the Impact Centre at the University of Toronto to accelerate adoption of LEDs and other sustainable lighting across Canada.

4.2 US and International

a) ***AllSeen Alliance and AllJoyn***
A resource for accelerating widespread adoption, development and evolution of an interoperable peer connectivity and communications framework.

b) ***American National Standards Institute (ANSI)***
This is a standards organization that has Committee C136 for street and outdoor lighting products. It is made up of users and manufacturers, and handles about 50 standards.

c) ***Illuminating Engineering Society (IES or IESNA)***
A North American professional association with a chapter structure for members across Canada and the US. They prepare design standards through committees.

d) ***International Commission on Illumination***
This is a United Nations body based in the UK with international representation to develop and/or contribute to standards development.

e) ***LonMark International***
A non-profit vendor association with 14 streetlighting members, standards development based on ISO 14908 series, compliance testing and certification.

f) ***Municipal Solid-State Street Lighting Consortium (MSSLC)***
This is a North American consortium established by the US Department of Energy (DOE) as a user's group (owners and power utilities) to allow members to share technical information and experiences related to LED street and area lighting demonstrations and evaluate new products on the market intended for those applications.

g) ***National Transportation Communications for ITS Protocol (NTCIP)***
A family of standards that provides both rules for communicating and vocabulary necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system.

h) ***TALQ Consortium***
Aims to establish a globally accepted standard for management software interfaces to control and monitor heterogeneous outdoor lighting networks to enable interoperability between Central management systems and outdoor lighting networks.

i) ***3rd Generation Partnership Project (3GPP)***
This initiative unites seven telecommunications standard development organizations to produce the Reports and Specifications that define 3GPP technologies.

j) ***U.S. Department of Transportation Federal Highway Administration (FHWA)***
An agency that provides financial and technical assistance to ensure America's roads and highways are safe and technologically sound. Many of the information documents developed by the FHWA are applicable to roadways outside of America.

k) ***Wi-SUN Alliance***
A global industry association that promotes certified standards that coordinate various wireless systems and standardize power levels, data rates, modulations and frequency bands. It offers free consultations, awareness programs and contribution towards standards.

5. APPLICABLE GUIDELINES AND STANDARDS

The following documents provide guidelines and standards used in the implementation of adaptive controls:

5.1 Canadian

a) ***TAC Roadway Lighting Efficiency & Power Reduction Guide 2013***
A research document and guide for owners and designers to use in reducing roadway lighting consumption. Available at http://tac-atc.ca/en/bookstore-and-resources/bookstore

5.2 US and International

a) ***ANSI 136.41-2013 American National Standard for Roadway and Area Lighting Equipment – Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver***
Describes light control between an external locking type photocontrol and dimmable ballast or driver for street and area lighting equipment. It outlines requirements for dimming, locking type photocontrols and mating receptacles that purchasers should reference when reviewing product specifications.
Available at: https://www.nema.org/Standards/Pages/For-Roadway-and-Area-Lighting-Equipment-Dimming-Control-Between-an-External-Locking-Type-Photocontrol-and-Ballast-or-Driver.aspx

b) ***ANSI/IES RP-8-14 Recommended Practice for Roadway Lighting***
This update of a version from 2000 has introduced a new section that includes 5.4 Adaptive Lighting. It addresses changing light levels to suit changing pedestrian volumes and street or roadway classifications, which can vary between night and day in some jurisdictions. The IES method specifies roadway lighting by road type and the potential for pedestrian conflict. This method adjusts the lighting levels based on changes in the pedestrian conflict level, rather than by reclassifying the roadway.
Available at https://www.ies.org/store/product/roadway-lighting-ansiies-rp814-1350.cfm

b) ***CIE 115:2010 - Lighting of Roads for Motor and Pedestrian Traffic***
In the CIE (International Commission on Illumination) method for adapting roadway lighting, roadways are classified as M for motorway, C for conflict areas, and P for roadway with pedestrians. Risks are weighted by factors to create lighting class, for which different illumination criteria are given. If traffic volume, intersection density, or ambient luminance fluctuates nightly or even hourly, an adaptive control system can monitor the changes and illuminate accordingly.
Available at http://www.techstreet.com/cie/searches/9298549

c) ***FHWA-HRT-14-051 - USDOT design Criteria for Adaptive Roadway Lighting, July 2014***
This document provides a design methodology for adaptive lighting and is based on the CIE roadway lighting criteria. It is meant to be used as a tool for determining if adaptive lighting is appropriate for a given roadway.
http://www.fhwa.dot.gov/publications/research/safety/14051/14051.pdf

d) ***FHWA-RD-86-018 - USDOT Guidelines for The Implementation of Reduced Lighting on Roadways, June 2014 (PUBLICATION NO. FHWA-HRT-14-050 - JUNE 2014)***

This document outlines the process for a lighting asset manager to determine required lighting levels for roadways and to install adaptive controls for both new and retrofit lighting. It supplements other lighting guidelines and details where and when to adapt lighting, the legal implications, and how to perform a cost benefit analysis.
http://www.fhwa.dot.gov/publications/research/safety/14050/14050.pdf

e) ***IES RP-31-14 Recommended Practice for Economic Analysis of Lighting***
Provides first- and second-level analysis methods used for determining the business case for controls.
http://www.ies.org/store/product/recommended-practice-for-the-economic-analysis-of-lighting-rp3114-1351.cfm

f) ***IES TM-23-11 – Lighting Control Protocols***
A technical resource for lighting designers and mangers, specifically outlining methods for integrating controls into their projects and providing information on new technologies.
http://www.ies.org/PDF/Store/TM-23-11_FINAL.pdf

g) ***Institution of Lighting Engineers in the UK – Technical Report 27: Code of Practice for variable Lighting Levels for Highways***
This gives defined recommendations for applying adaptive control technologies to roadway lighting systems for all types of highways. It provides information on dimming and enhancement of road lighting levels.
https://www.theilp.org.uk/resources/ilp-technical-reports/tr27/

h) ***ISO/IEC—14908 Protocol standards suite (with ANSI/CEA)***
This International Standard defines communication capabilities for local area control networks and was prepared for vendors to exchange information. It provides information on peer-to-peer communication for networked controls and can be used to implement peer-to-peer and master-slave strategies.
Available at: http://webstore.ansi.org/RecordDetail.aspx?sku=ISO%2FIEC%2014908-3:2012&sourcekeyword=_inurl%3Awebstore.ansi.org%23inurl%3Asku%3Diso&source=google&adgroup=iso27002&gclid=CK7i8fKe3cYCFQoPaQodZpsJxw

i) ***MSSLC - Model Specification for Networked Outdoor Lighting Control Systems V2 2014***
This is a guide for owners to help in their adoption of systems to further reduce the energy and maintenance costs of operating their streetlights. It provides both suggested high-level requirements and a template for translating user needs into specification language.
http://www1.eere.energy.gov/buildings/ssl/control-specification.html

j) ***NEMA/ANSI C136 Series – Standards for Roadway and Area Lighting Equipment***
This set of standards has been established to standardize material and methods used for smart lighting controls for metering e.g.:

- C136.10 describes physical and electrical interchangeability and testing for locking-type photocontrol devices and mating receptacles
- C136.41 describes light level control connections between photocontrol (or similar device) and a dimmable ballast or driver for street and area lighting equipment
- C136.48 (Remote Monitoring and Control) and C136.50 (Revenue Grade Energy Measurement) are being developed

Available at http://www.nema.org/Technical/Pages/ANSI-C136-Series-Standards-for-Roadway-and-Area-Lighting-Equipment.aspx

II. ADAPTIVE CONTROLS DESIGN

1. DESIGN PROCESS

Lighting system design starts with determining the required illumination levels to be provided by the lighting system. This requires predicting the pedestrian and vehicle use and the possible impacts on adjacent uses and eco-systems. Then the factors that affect safety, such as illumination intensity levels, colours and variation across the surfaces to be lit are defined. If there is no adaptive control, these parameters are selected for the worst case scenario, which defines the minimum light output that will be delivered consistently when the lights are on.

To incorporate adaptive controls, the range of illumination required over time, for different ambient light at different times of day, and different levels of pedestrian or vehicle use, needs to be defined. Then the criteria used to determine appropriate light levels timing, and the method of changing those light levels need to be developed.

A key consideration for applying adaptive controls is that standard lighting technologies are usually designed with reference to standardized design practices. For lighting systems that integrate adaptive controls, a higher level of design input should be applied to reliably achieve the desired outcomes.

Adaptive lighting controls also create an opportunity to rethink lighting design by questioning standard practices that were relevant before controls were available. For example, vehicles traveling at slow speeds in gridlock do not require the light levels required for vehicles traveling at highway speed limits.

It is worth noting that traditional roadway lighting design has not factored colour contrast into the standard metrics. However, testing has shown that different light sources create significantly different visibility for objects with different colours. Therefore, the impact of changing light levels on light colour should be considered. Refer to the Transportation Association Canada (TAC) Lighting Efficiency and Power Reduction Guide for further information.

2. DEVELOPING THE ADAPTIVE CONTROL STRATEGY

2.1 TRIGGERS FOR ADAPTIVE CONTROLS

Adaptive controls are used to change light output levels to account for one or more of:

a) **Vehicle and/or pedestrian activity level** –The illumination required for safety changes with volume and speed of traffic and the presence of pedestrians. For roadways, the activity information is determined by road classification and "pedestrian activity," or "pedestrian conflict". Standard design assumes a "worst case" scenario and provides the required lighting all the time the lighting system is on. Adaptive controls can be used to change the power supplied to match prescribed patterns (e.g. weekend or weekday use) to respond to actual conditions.

b) **Decreased luminance as lamps age** – Standard practice requires lighting systems to be designed based on the luminance delivered at the end of life. This causes the luminance, and power consumption, to be higher than required for most of the life of the luminaire. Adaptive controls can reduce the power supplied at the beginning of the lamp life and increase it over time to maintain the required luminance. This practice avoids exceeding the design levels early in the life of the luminaire. The light depreciation with age associated with particular luminaires can be predicted through testing but more accurate information can be obtained through monitoring in use.

c) **Dirt depreciation levels** – The increasing level of dirt on a lens over time decreases the light level achieved. Standard design increases the light level provided to account for this. It is independent of the actual dirt accumulation or the time between cleanings. Adaptive controls can be provided to adjust light levels in response to these factors.

d) **Ambient light levels** – Standard design is based on illumination requirements at the darkest times. Adaptive controls can reduce the power demand by adapting to time of day or weather. It should be noted however that for roadway lighting, the impact of exposure of a vehicle's driver to weather conditions cannot be calculated. Studies that have considered crashes on wet roads found that they significantly affected object visibility in the presence of adaptive lighting (FHWA July 2014). At present, it is recommended that during periods of adverse weather, the lighting level should be at the design level. However, as experience with adaptive controls grows, this may change.

2.2 MATCHING LIGHT LEVELS TO ACTIVITY LEVELS

One of two approaches is typically used for adapting the light levels to activity:

a) **Curfews** (or "method of time")
Curfews refer to changing the lighting system at predetermined times. Times are selected based upon site measurement or modelling from formulae. The times selected depend upon which criteria are deemed to be of most importance to safety. Examples include:

- Changes in vehicular traffic level sampled over a period of time;
- Typical hours of operation of surrounding businesses;
- Changes in transportation schedules;
- Changes in parking regulations; and
- Sampled pedestrian activity.

For traffic levels, an average of the traffic and pedestrian volumes can be evaluated on an hourly basis and used to determine the timing of the adaptive changes.

It is important that exceptions to the curfew (e.g. for sporting or entertainment events) be considered, for example, by providing an agency with the ability to override the adaptive lighting program on demand.

Using curfew settings avoids the need to network controls at the luminaires, leading to lower initial costs, but also lower energy savings. For roadways, curfew settings can be used by the utility to develop a fixed rate for the lighting, which is simpler to include in municipal budgets. This solution is typically attractive for smaller customers.

b) **Active Monitoring** (or "occupancy based" control)
An active monitoring system can be designed with integrated sensors to respond to usage variation through active monitoring or scheduled usage patterns based on predictive algorithms. This strategy involves active monitoring with detectors or video monitoring to provide real time information about the traffic and pedestrian levels, the current condition of the lighting system and any other desired criteria that would then drive the light level selection. A network is required to link the monitoring system to the control system. These types of control systems allow control of the lighting level to maximize the asset value.

Active monitoring has the potential to be much more accurate, and therefore capable of achieving more energy savings, but will generally be more costly to implement. Evaluation of the viability of active monitoring requires an analysis of the potential benefits relative to the costs.

2.3 LIGHT LEVEL REDUCTION METHODS

For a given configuration of lighting fixtures, light levels and energy consumption can be reduced by "light extinguishing" (turning off luminaires in various arrangements) or dimming (reducing the lighting output from individual luminaires).

Adaptive controls can be applied to either solution. However, extinguishing methods are generally unsuccessful unless the original lighting configuration was designed specifically to accommodate the strategy. Light extinguishing methods will generally not meet design criteria for uniformity and glare control. However, this may be possible if there is more than one luminaire per location or relatively close spacing of luminaires.

The recommended technological approach to adaptive lighting is dimming. Dimming a luminaire allows the light level to be adjusted without upsetting the other design criteria. Dimming luminaires are typically capable of dimming from 100-percent output to anywhere between 50 and 10 percent of maximum output, depending on the light source technology. Dimming solutions are particularly appropriate for LED lighting and are able to achieve acceptable distribution with reduced light levels as long as the configuration can meet the maximum lighting demands.

The dimming methods can be applied with or without networked controls. Details on the components of networked adaptive controls are found in Appendix B.

III. THE VALUE PROPOSITION

The ultimate purpose for installing controls on lighting is to increase the value proposition for the capital and operating costs required for lighting infrastructure through reduced energy consumption and maintenance requirements. This is a short summary of the various benefits that can be achieved for roadways and parking facilities.

1. ENERGY AND GHG SAVINGS

The first motivation for exploring lighting controls is usually the energy (and cost and GHG) reductions to be achieved through matching light output to needs. In 2014, ICF Marbek estimated there are approximately 3.5 Million streetlights in Canada[1], consuming over 2.7 TWh of electricity, costing close to $300 million each year. In Washington State, US, the Department of Transportation (DOT) reported that of the $126M spent over 12 years on highway signaling, illumination and ITS; $46M, or about 35%, was for electricity. As reported by the Federal Highway Administration (FHWA) in July 2014, the current recommended lighting levels for roadways may be as much as twice that required for safety.

The TAC Roadway Lighting Efficiency & Power Reduction Guide 2013 provides an estimated range of energy reduction for the three main outcomes that can be achieved by using adaptive controls:

a) **Reduced lighting output to maintained levels** (expected 5 to 10% energy reduction, given the end of life factors vary from 10 to 30%):
Roadway lighting systems illumination levels are designed to meet the design levels at the end of the lamp service life. This means that for most of the life, the lamp is providing much more light, with associated wasted power consumption, than necessary. To maintain required illuminance throughout the lamp's service life, controls can be used to reduce levels by the difference between the initial lumen output and that provided at the design life.

b) **Dimmed areas that are overlit** (expect 5 to 30% energy savings):
Some roadways are also overlit to meet uniformity criteria, which is often the driving factor in the luminaire spacing. Standardizing on a uniform luminaire/pole/wattage configuration for maintenance or procurement reasons also results in having over illumination in some areas where lighting level requirements are lower than the local standard. With adaptive controls, each luminaire can be controlled individually to match requirements and ensure energy is not wasted on over illumination.

With 50% dimming, 50% of the time there is the potential to reduce energy usage by 25%, which presents an opportunity for about $70 million ($20 per luminaire) in annual savings for Canada. (For systems with LED lighting, the incremental saving would be 25% of the lower energy use).

c) **Matched light levels to usage** (expect 20 to 30% savings):
Throughout North America, the predominant standard used is the Illuminating Engineering Society of North America (IESNA) RP-8, American National Standard Practice for Roadway Lighting. In the updated RP-8-14, streetlighting levels are established by applying criteria based on road classification (i.e. major, local, and collector), type of pavement and pedestrian conflict levels (i.e. high, medium or low).

The higher the level of pedestrian conflict, the higher the level of lighting recommended. Pedestrian conflict levels do not necessarily remain constant throughout the hours of darkness. In most instances, the

[1] *Evaluation of the Market Transformation Impacts of MRCan's Contributions to LED Roadway Initiatives (2014).* ICF Marbek. National Resources Canada. www.marbek.ca

numbers of pedestrians present in a given area will be dramatically reduced in the late night and early morning hours when businesses are closed. Numbers of nighttime pedestrians may also be reduced based on the days of the week (weekday vs. weekend), seasonal factors, and other predictable dynamics. During hours of reduced pedestrian conflict, the level of lighting provided can be reduced, while maintaining the recommended criteria for the actual level of pedestrians present. This is significant as illumination levels vary from a high to low pedestrian activity by approximately 50%.

2. IMPROVED ASSET MANAGEMENT

a) *Improved Operations & Maintenance Ability*
Adaptive Control systems are typically designed with software to allow an owner to build a database of the asset and monitor performance on an area-wide basis. Additionally, combining luminaire locations can be identified by global positioning satellite (GPS) coordinates for easy identification, tracking and locating. The use of mapping software enables identifying and optimizing maintenance requirements.

b) *Outage Detection*
A relatively simple monitoring system provides the potential to identify luminaire outages and optimize maintenance over the lighting system.

c) *Enhance Customer Satisfaction*
Better outage management has been shown to result in improved public perception of the lighting standards, neighbourhood safety levels and drivers report improved visibility.

d) *Prolonged Service Life*
Dimming luminaires during reduced levels of vehicular or pedestrian activity/conflict will reduce the rate of performance depreciation, thus prolonging expected service lives.

e) *Improved Inventory Management*
Dimming controls allow one luminaire model to be used for different wattage specifications, which reduces the number of fixture models the lighting manager needs to keep in inventory.

3. PUBLIC SAFETY

With any new technology, public safety is of key importance. Adaptive controls can optimize public safety in a variety of ways:

a) *Constant Light Output*
With a constant power supply level, lumen output per watt (efficacy) of the luminaire decreases over time. Adaptive controls can adjust the power delivered to the luminaire to keep the light level constant over time. This maintains the perception of a constant condition, rather than one that appears to deteriorate, even though the starting point is above that deemed necessary.

b) *Dimming Based on Risk*
Collision or crime risk varies with visual acuity levels provided by lighting, combined with traffic or pedestrian volume and speed, as well as weather conditions. For roadways, there is extensive research done by or reported on by the US FHWA to evaluate the frequency and severity of crashes related to illumination levels. (FHWA July 2014)

Dimming the light level, while maintaining the lighting configuration, does not affect the uniformity of the lighting or an object's contrast. Test results tend to suggest that reducing the power of the luminaires (dimming) while maintaining the illumination Uniformity Ratio (UR) might be the best solution for conserving energy without negatively affecting driver or pedestrian safety. However, contrast thresholds will increase with lower light levels, resulting in longer detection times.

For routes with pedestrian activity, including local roads, collector and arterial streets, and sidewalks, TAC (2013) recommends that adaptive lighting controls and LED lighting are appropriate for reducing power consumption. For highways, reducing light levels below the design level is not considered to be an option, although slower speeds would likely require lower lighting levels. In cases where traffic congestion is common, speed sensors could be a viable control input. Areas of critical visibility, such as roadways that have a significant number of curves with short visibility distances or locations where traffic and pedestrian volume are consistent throughout the night (e.g., a hospital or other service facility), are also not good candidates for adaptive controls.

For sidewalks, LED lighting is capable of providing more optical control, so more detailed design than has been done in the past is required to achieve the desired safety levels. Motion sensor activation on sidewalks or alleys is considered to be a useful method for alerting neighbours to activity.

c) *Light Control Based on Traffic*
In areas of expanding development, pedestrian and/or vehicle traffic are expected to increase requiring higher light levels. Using controls allows operators to make these changes to match the varying traffic patterns without additional maintenance/operational costs.

d) *Results Monitoring*
Several studies are being undertaken to record safety parameters before and after adaptive controls have been installed. After Suffolk County UK installed controls on their streetlights, a report by Suffolk County's Police Authority in March 2012 concluded that 'there is no discernible evidence that crime has increased by the strategy to reduce streetlighting between midnight and 6 AM'.

4. EMERGING OPPORTUNITIES

Some of the benefits that are currently known to be realistic, but that would not typically be incorporated into a business case to support installing controls into a lighting system are:

a) *New Municipal Services Using Sensors on Streetlamps*
Nodes distributed on poles throughout a city can serve as a backbone for many applications using the associated access to the power and communications networks. Remote monitoring and control could be applied to traffic systems, charging stations, environmental health impact tracking, emergency response, etc. With the exponential growth in the Internet of Things (i.e. the connectivity between objects or 'things' allowing for the exchange of information), owning a network of controls and sensors creates the potential to integrate information across a variety of applications, many of which will not be considered at the time of implementation. As the population becomes more used to having control over devices, it becomes an expectation that services like lighting represent a similar standard of control.

b) *Revenue Opportunities from Lighting Infrastructure*
Lighting infrastructure incorporating adaptive lighting controls could be used for advertising or pay-per use applications. Some of the ideas that have been presented as revenue opportunities include:

- Mini-Cell Tower Deployments: small Cells are low-powered radio access nodes that operate in licensed and unlicensed spectrums that have a range of 10 meters to 1 or 2 kilometers, and provide a wireless or 4G backhaul;

- Parking Availability Service: used to guide drivers to the nearest empty parking space;
- Interactive LCD Billboards: generate advertising revenue from miniature displays on light standards related to local services;
- Weather Reporting: charge for highly local weather information that could be posted to alert pedestrian and drivers to potential watches and warnings;
- Air Quality Reporting: compliance tracking that would be a public benefit, but could also generate revenue from offender fines; and
- Parking Metering: integrated parking fee collection.

IV. CHALLENGES

1. UTILITY RATE STRUCTURE ISSUES

The flat rate utility tariff necessitated by unmetered streetlighting is a major hurdle for realizing the financial benefits of adaptive controls to recover the implementation cost.

The flat rate structure is typically based on an assumed and fixed luminaire energy consumption and usage. It can be based on either a flat rate or time of use. Flat rate tariffs are typically based on the maximum rated power consumption. Time of Use (TOU) tariffs are based on measured or assumed kWh usage and the cost rate for energy during specific time periods.

The cost reductions associated with changing the usage of the luminaires can only be achieved by agreeing to a billing process that reflects the reduced usage. This can be metering or an algorithm developed to suit the particular situation. Various US jurisdictions without individual pole meters have implemented algorithms, but Measurement Canada has yet to accept alternatives to individual meters for calculating usage by luminaires with adaptive controls.

CSA Group is currently developing, with industry, an express document presenting national guidelines and industry references for users of energy efficient lighting and/or adaptive lighting controls. It will address utility rate issues and recommend pricing practices for Utilities with customers using lighting controls. The express working group (CSA X05) includes representatives from Measurement Canada, CSA Group, control manufacturers, Utilities and end users. The document is expected to be published by the end of 2015 under the title: *Methodology for Evaluating Energy Savings from Use of Adaptive Controls in Street Lighting Applications*.

2. INTEROPERABILITY—HARDWARE AND SOFTWARE

Interoperability enables components from different suppliers to be integrated into a system over time as a technology user's needs change, and to manage the risk of component, manufacturer obsolescence. It facilitates ability to integrate best-of-breed components (e.g. controllers, sensors, software) into a system. It facilitates the ability to modify and improve an existing system as the needs become better defined.

The levels of interoperability to consider include:

- Between a Controller and a Luminaire;
- Between a Central Management System and Field Device Network;
- Between a Field Device and Communication Network; and
- Between Field Devices.

Sharing of application data requires a common application definition (sometimes referred to as a protocol or profile) or an up-to-date "translator". The lighting control and the network infrastructure are typically proprietary, while the data transmission elements are typically standards based.

Resources and standards relating to interoperability can be found in sections I.4.and I.5.

3. LOW UTILITY PRICES

In jurisdictions with relatively low electricity prices, the cost savings achieved by saving energy become less of a driver than in higher cost jurisdictions. This may be offset somewhat by GHG emission reduction drivers where the electricity is produced by high emitters.

4. THE WAITING GAME

As with all technological advancements, purchasers often fear that a system just acquired will become obsolete as soon as it is installed. With energy saving technologies however, the trade-off is that the longer you wait to take action, the more energy you will waste. Between 2010 and 2015, there were major changes in LED streetlight technology in terms of increased energy efficiency and decreased cost. However, the market is beginning to stabilize and significant changes, as previously seen, are less likely to occur. In addition, the risk that price for electricity will drop and reduce the benefit is relatively low in most jurisdictions.

5. TECHNOLOGICAL COMFORT

Although there can be a tendency to fear the novelty of any new technology, the increasing prevalence of the Internet of Things in planning for public assets has increased the level of comfort with newer controls technologies. There are many suppliers with many variables affecting cost, performance and reliability. There are many inferior products on the market, but there is also a growing body of knowledge that has developed from standards bodies and owners who have been through the qualification process that makes it less onerous to identify high quality providers.

6. POTENTIAL LEGAL ISSUES RELATED TO SAFETY

Any solution must address legal issues associated with whether the resulting lighting meets accepted design criteria after the lighting is reduced and whether changes to the design criteria might affect safety of the roadway or parking facility users. The legal concerns range from questioning an agency's justification for implementing adaptive controls to the legal liability of the owners and designers in the event of a personal injury lawsuit attributed to the adaptive lighting system.

For justifying the implementation on roadways, the extensive research done by or reported on by the US FHWA to evaluate the frequency and severity of crashes related to illumination levels provides a good basis for supporting a decision. (FHWA July 2014). For information on adaptive lighting applications as it related to specific road types refer to the TAC Light Reduction and Energy Efficiency Guide. For further information on adaptive lighting controls and applications refer to the FHWA study titled Guidelines for the Implementation of Reduced Lighting on Roadways

As outlined by the FHWA, tort law in the US has established precedent that, in designing an adaptive lighting system, an agency or engineer does not breach this duty of care if the agency or engineer performs according to industry-accepted guidelines (e.g., published analysis and/or design procedures). That is, if the engineer does what reasonable engineers would do in the same situation, a plaintiff will be hard pressed to argue that the engineer was negligent. It is therefore prudent for communities that adopt adaptive lighting controls to publish a lighting policy specific to the controls they implement. This way, the new risks from dimming luminaires during reduced pedestrian activity/conflict are addressed. (The policy should also address areas that have little or no lighting as well as those that meet industry standards for lighting.). [2]

The size of the area of the lighting controls system can occur broadly over all the surfaces within a given area, or selectively within the network, based on an analysis of needs. In general, dimming a large area will maintain a constant lighting level throughout, eliminating experiencing different lighting conditions that would require significant eye adaptation transition. Dimming a large area may also cause some areas to be too dark.

[2] Federal Highway Administration (FHWA). *Guidelines for the Implementation of Reduced Lighting on Roadways (2014).* U.S. Department of Transportation. http://www.fhwa.dot.gov/publications/research/safety/14050/14050.pdf

7. IT SECURITY

The communication network required for controlling distributing lighting assets creates the risk that the data being transmitted becomes a target for theft, and the system provides a portal into the home network of the owner.

To address these risks, Georgia Power has listed the following lessons from their evaluation[3]:

- Require IPSec Site-to-Site VPN tunnel from the gateway to the corporate perimeter;
- Require secure key management, user and device authentication and AES-256 bit encryption of data (in transit and at rest);
- Perform IP port/service minimization to close unneeded services and ports;
  and reduce the number of access points available to potential attackers;
- Require separation of the customer-side GUI front end from the company side database with a firewall;
- Secure deployment and commissioning, to prevent the addition of malicious devices in the system;
- Authentication, to prevent unauthorized people or devices from gaining access to the network to control or disrupt it;
- Data encryption, to prevent eavesdropping of network data;
- Secure software updates, to prevent hackers from loading non-functional or malicious software; and
- Ongoing maintenance of the system to ensure the security parameters are being maintained.

[3] Hutto, S. *LED Lighting & Smart Controls (2013).* Outdoor Lighting from Georgia Power. PowerPoint.

V. BUILDING THE ECONOMIC BUSINESS CASE

A business case is typically based on cost savings and sometimes on the associated reduction in greenhouse gases. The highest return is typically going to be achieved in locations with continuous lighting, usually found in urban areas where potential energy savings are significant.

Large-scale LED replacement projects are being conducted at a time when features of networked controls are becoming compelling. With LED drivers, there is a low marginal cost of incorporating dimming and wireless control. However, energy savings from LEDs minimize the energy available to be saved by networked control.

To determine the financial benefits to be expected from an adaptive lighting system, a lifecycle cost (LCC) analysis should be considered. This can be total cost of ownership or total value of ownership. A simple payback method of analysis could be used, but this method ignores operating and maintenance expenses, which are key components in evaluating lighting control systems and their expected benefits. The non-energy benefits are rarely considered in the business case, and it will take some time for the experience to develop to monetize safety or comfort benefits. An LCC considers the energy savings, equipment costs and maintenance or replacement costs and timing required for the implementation of adaptive lighting. It does not consider the cost of a crash or a vehicle-caused fatality, and it assumes that the safety level of the roadway is not affected by the changes to the lighting level.

The typical factors associated with an LCC of a lighting system include::

- Installation cost of the system;
- Expected reductions in energy costs (or change in rate structure offered by the electricity utility);
- Expected reduction or increase in maintenance costs for the lighting system, as well as the control equipment and support network;
- Expected life of the equipment; and
- Any energy incentives that may be available for the installation.

The resulting benefits of lighting determined by an LCC will vary depending on the roadway, land use and pedestrian activity. Assume that an adaptive control system is being added to a LED streetlighting system already equipped with dimming drivers and an acceptable photocell receptacle with sufficient pins for control and power connections. The assumed equipment life is 15 years, and the simple LCC analysis is set to that time frame. An example using these assumptions from the FHWA[4] is shown in Table 1 and Figure 1.

Table 1: Example cost information for an adaptive lighting system (FHWA, 2014)

Type of Cost	Existing System Without Adaptive Control	Adaptive Control System Costs
Installed Cost	$0	$600,000
Annual Energy Cost	$841,000	$589,000
Annual Maintenance Cost	$100,000	$90,000
15-year Total Cost	**$14,115,000**	**$10,785,000**

[4] Federal Highway Administration (FHWA). *Guidelines for the Implementation of Reduced Lighting on Roadways (2014).* U.S. Department of Transportation. http://www.fhwa.dot.gov/publications/research/safety/14050/14050.pdf

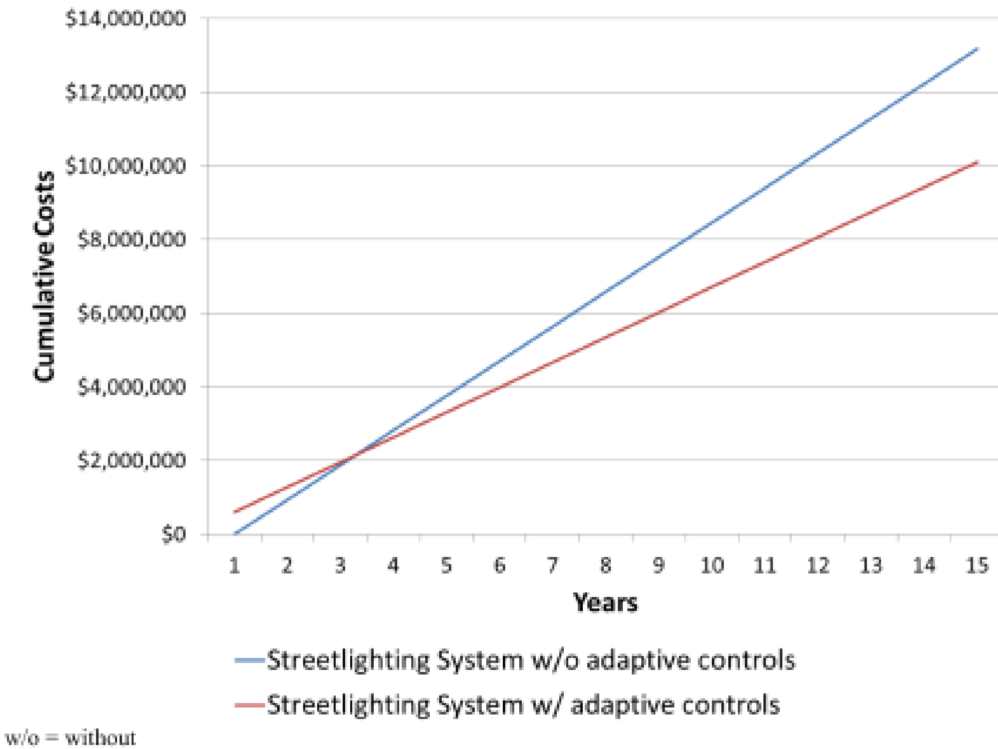


Figure 1: Example system costs by year for standard and adaptive lighting systems (FHWA, 2014)

To obtain a better picture of the actual costs, the cost of capital and future costs should be brought into the present day by converting them to the present value based on the assumed discount rate.

$Present = cost \cdot 1/(1 + discount\ rate)^n$

An example of a net present value (NPV) calculation is shown in Figure 2, also from FHWA (2014). The results show that the return on investment for this example is less than 3 years.

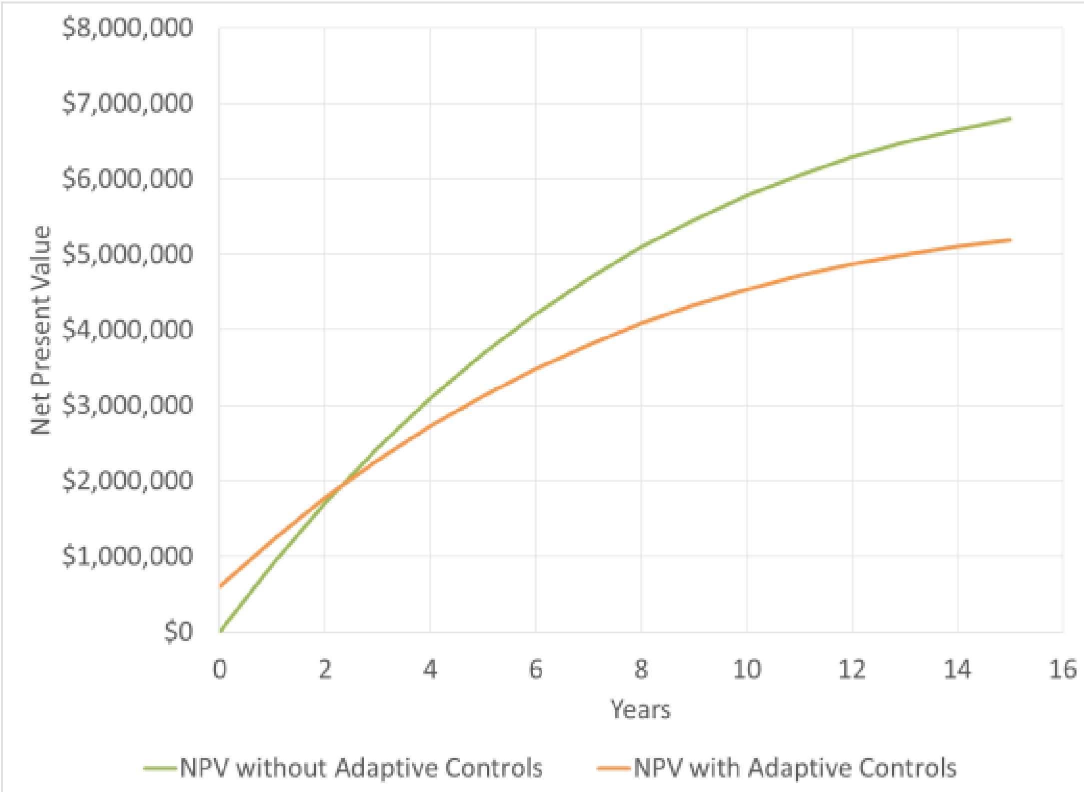


Figure 2: Example NPV for standard and adaptive lighting systems (FHWA, 2014)

VI. APPENDICES

APPENDIX A: CASE STUDIES OF TRIALS AND USERS

1. INITIAL APPLICATIONS FOR HPS STREETLAMPS

Since 1995, Netherlands has installed and operated a dynamically lighted roadway that can be adjusted to any of three lighting levels, depending on the amount of traffic, time of day and weather conditions. The low level is 0.2 cd/m2, the normal level is 1 cd/m2 and the high level is 2.0 cd/m^2. The different light levels are obtained through the use of electronically controlled, dimmable HPS ballasts.

The M65 was the first motorway in the UK to incorporate traffic controlled dimming, as a pilot and research opportunity in 2000 (see http://trilight.fi/dimming.pdf).

A central dimming technology supported by the University of Hong Kong has been successfully tested on road lighting systems in China since 2004, registering an average electricity savings of 30%. In the Guangdong Province of China, the county of Heshan is having 7,000 units installed.

In 2005, BC Hydro installed adaptive controls in the City of Prince George, British Columbia to determine the viability of this technology. The controls (STI Lumen IQ) were retrofitted into existing and new cobra head streetlight housings. The system was designed to vary lighting output, monitor lamp depreciation, sense and report outages and measure power usage. The streetlighting control is provided from a central location over the Internet. Signals are sent from the Internet through wireless links to each luminaire. The software provides data analysis and information integration.

Glendale, Arizona completed installation of 18,500 ROAM smart photocontrols on all streetlights in 2008. The City was previously experiencing excessive outages and customer complaints and was looking for an accountable system to monitor and report on streetlight performance. With ROAM adaptive controls, the City can access the coordinates, ON/OFF schedule of each light, wattage and electric supply voltage of each fixture. Since implementation of controls, Glendale has less than half a percent of malfunctioning streetlights, significantly increased efficiency of operations and improved public safety.

Suffolk County, UK installed Smart controls between 2011-2012 on 60,000, mostly HPS, lights over 1500 square meters. It was a $5 million project, completed in 18 months with an outsourced contractor and network monitoring. There were 44 base stations used to cover the 60,000 nodes. Available mapping information was uploaded from the Asset Management System to the Central Management System. The achieved savings are $1.2 million, versus the $1.1 million projected, with a $250,000 annual management cost. The LED rollout started in 2014.

2. MISSISSAUGA STREETLIGHT CONVERSION

City of Mississauga has converted their 50,000 streetlights to LEDs with adaptive controls in all luminaires in the largest full scale, city-wide LED-control project in the North America at the time of installation. The $28.5 million ($570 per luminaire) project started in November 2012 and is due for completion in 2015. The City Inspectors collected asset data during installation to create the streetlighting database.

3. WASHINGTON STATE HIGHWAY INTERCHANGE PILOT PROJECT

In 2013, 158 lights were installed at interchanges on the US101 highway. Some are on all the time and some are off overnight. Many lessons learned about the higher than expected commissioning level required and the calculated versus field luminance measurements show the use of adaptive controls is not an exact science. New investments in lighting need to prove a benefit-cost ratio greater than one for crash reduction. Many deeply held beliefs about safety are not supported by evidence.

4. LOS ANGELES, CALIFORNIA

Los Angeles has undertaken 160,000 LED streetlighting conversions from 2009 to 2014. They have installed 50,000 streetlight on/off controls with photoelectric cells and mesh networks, which will eventually have the ability to brighten, dim, blink and collect environmental information. They are planning another 110,000 controls in phase II with meter grade accuracy and remote activation. It is interesting to note that by 2014, the average price dropped to about 30% of the 2009 cost, efficacy and lifespan more than doubled, repair frequency dropped to about one half and crime statistics dropped by about 10%. They estimate about 60% energy savings. Their evaluation process approved 20 units out of 244 requests for evaluation, although 84 met the minimum requirements.

5. SAN DIEGO, CALIFORNIA

The city of San Diego retrofitted 3,000 fixtures with LED luminaires and adaptive controls. Annual maintenance savings are $352,000 annually which equals to annual energy savings of 2.5 million kWh. Smart City-testing and verification was completed with San Diego Gas and Electric to meter streetlights. There was initial public perception that dimming meant less light on the ground, however, once the LEDs and controls were installed, the general perception was of an improved light source.

6. ATLANTA, GEORGIA

Georgia Power Company, which has $245M annual revenue from lighting power, installed more than 23,000 LEDs in area lights in 2013, and is planning 120,000 conversions per year until 2018. They are currently evaluating lighting controls for implementation.

7. BUENOS AIRES, ARGENTINA

The city is replacing 91,000 streetlights with LEDs and adding a networking platform to enable remote monitoring of all lights as well as ON/OFF and dimming control.

8. RIYADH AND MECCA, SAUDI ARABIA

Riyadh (25,750 lights) and Mecca (27,000 lights) are installing adaptive controls to enable light level changes based on traffic sensors and user feedback. Monitoring outages was key motivator for the installation.

APPENDIX B: COMPONENTS OF NETWORKED ADAPTIVE CONTROLS

1. BASICS

Networked control systems connect sensors at the luminaire locations with a control system that adjusts the light levels. The sensor network and computational capability of networked controls provide the opportunity for real time data collection for a variety of uses:

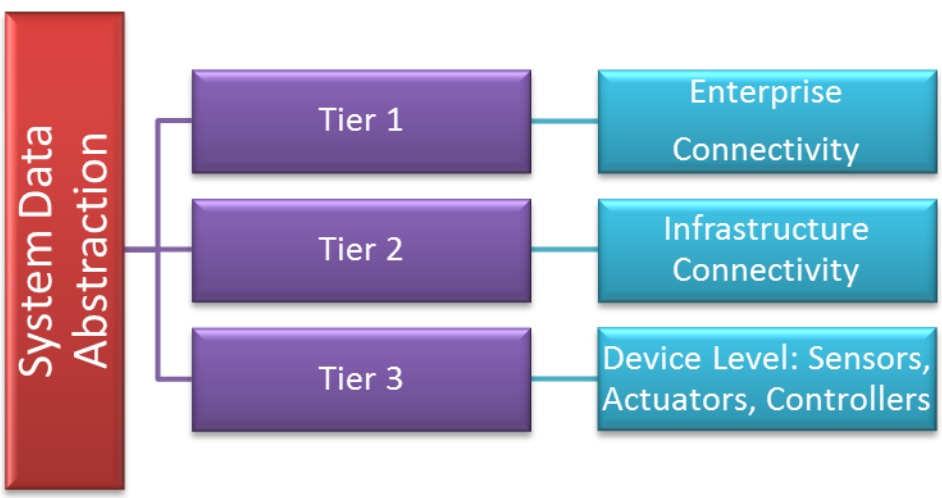
a) Accurate metering per light fixture to pay only for electricity consumed;
b) Built-in monitoring to know location and performance of every fixture;
c) Potential to monitor and facilitate adjustments to traffic patterns and support emergency response; and
d) Accurate time of use (TOU) lighting tariffs, specifically with Smart controls.

2. CONTROL BASICS

2.1 NETWORK ARCHITECTURE

A network is a group of systems that function cooperatively and/or interdependently to provide a chain of command for lighting control (from IES TM-23-11). The components of a network can be linked together by cables, wireless communication devices or other means forming an intricately connected system of devices.

Enterprise control systems are modeled on a three-tier architecture as shown below[5]:



Tier 1: Enterprise Infrastructure – Backhaul to server
The Backhaul Network is typically a Wide Area Network (WAN) that connects and facilitates communication between one or more Field Device networks with a Central Management System. It can be wired or fibre A (highest speed and cost); wireless cellular; or other wireless such as WiMax or 60Ghz line of sight.

Tier 2: Field Infrastructure – Pole to backhaul

[5] *Chart is based on:* Ron Bernstein. *Fundamentals of Open Adaptive Streetlighting Controls (2014).* https://static1.squarespace.com/static/546bbd2ae4b077803c592197/t/54b7f142e4b0c2c1fade9c38/1421340994653/LIGHTSAVERS+ADAPTIVE+CONTROLS+-+PRESENTATION+MATERIAL+Part2.pdf

This includes controllers, gateways, interfaces, panel networks, repeaters and routers that transmit information (wired or wirelessly) from the pole to the Backhaul Network.

Tier 3: Device Infrastructure – At the pole
At the pole are drivers, lamps, fixtures and sensors, which monitor conditions in the field.

2.2 FIELD DEVICES

a) Overall
The field devices are the set of networked Components (hardware and embedded software installed in the field) that, following installation, start-up and commissioning, function together to adaptively control and remotely monitor luminaires. Poles act as the platform for devices. The Field Device Network is typically a Local Area Network (LAN) that connects and enables communication between Field Devices

b) Controllers
The Controller is a device that originates a command to execute a lighting change. A Controller physically monitors and controls luminaires, reacts and responds to logical and physical inputs, makes control decisions using internal algorithmic and logic functions and communicates via a network protocol

c) Gateways
A Gateway is a device designed for interfacing between two communication networks that use different protocols. It serves (at a minimum) as the interface between one or more Field Devices and a Central Management System (CMS). It aggregates data packets (typically from a wireless system protocol) and connects to an external (typically WAN) network, such as WiFi, Ethernet or Cellular.

2.3 SENSORS

The range of conditions that can be monitored by sensors is ever expanding, but the general categories relevant to lighting controls are:

- Environmental: Temperature, Humidity, Pressure, Ambient Light, UVA/UVB, Radiation, Rainfall, Wind, O2 & CO2, Particulate Matter;
- Energy Monitoring; and
- Activity Monitors: inductive loop, Motion, Audio, Video

The output can be raw data (e.g. video stream) or locally processed/analyzed data (e.g. number of parked cars, traffic volume)

For energy monitoring used for billing, smart controls with "meter grade" accuracy are needed to accurately measure the fixture usage (annual random sample testing is needed to verify accuracy). Each smart control collects hourly usage data and transmits it to a base station (Gateway) or directly to a CMS. The hourly usage data from all smart controls are aggregated into one "virtual meter" data file by the CMS.

2.4 CENTRAL MANAGEMENT SYSTEM (CMS)

The CMS is a computer that functions as the user interface to the System by providing all shared System services, and consolidating and storing (or managing the storage of) all System data. This can be vendor hosted or user hosted. It is the point of control for commissioning, asset management, remote monitoring and reporting, and manual control. The most appropriate format will vary between users.

3. COMMUNICATION CONNECTIVITY OPTIONS

The communication network of an adaptive controls system connects the intelligent nodes throughout the area lights to the Gateway either wirelessly or wired. An effective network will automatically establish the correct system state and react appropriately to any changes through secure data transmission and minimal delays.

3.1 POWER LINE COMMUNICATION (PLC) CONFIGURATION

PLC configurations use the existing powerline as a conductor to carry data between nodes (on streetlamps, for example) and the remote terminal unit (as shown in Figure 3). The powerline is simultaneously used for AC electric power transmission. This two-way communication system has the following benefits over a wireless configuration:

- Maintained communication through walls, corners and underground;
- No line-of-sight limitation;
- Not affected by weather; and
- Detects any line breaks and their approximate location.

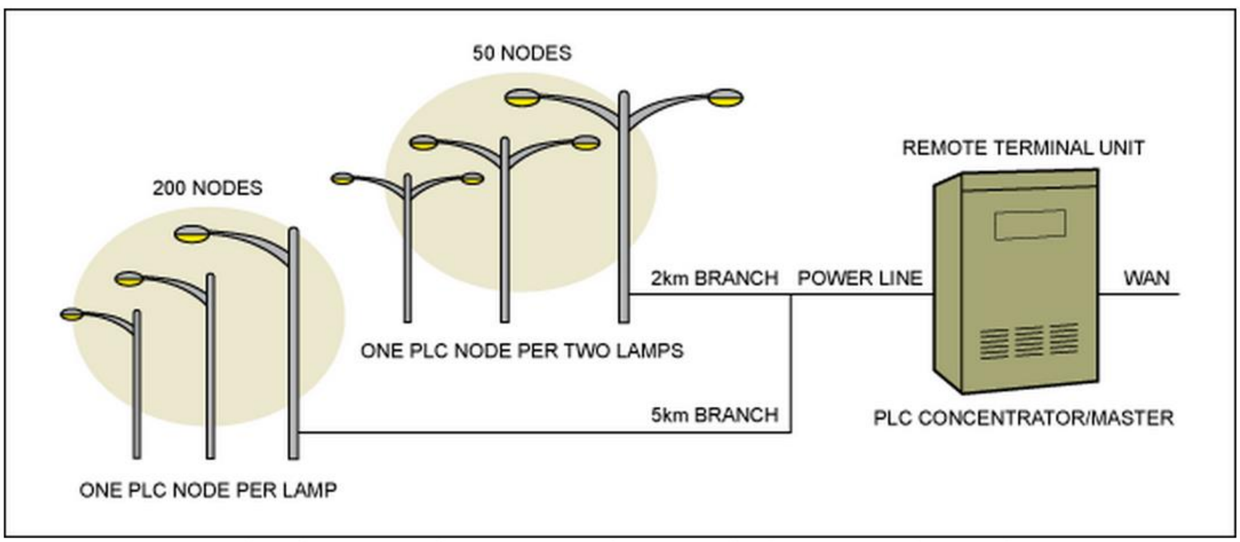


Figure 3: Example of a typical streetlight PLC communication configuration[6]

3.2 CONFIGURATION – WIRELESS LOCAL-AREA NETWORK (STAR OR MESH)

A LAN network connects control nodes through serial or Ethernet communication or a combination of both. Ethernet networks typically incorporate routable protocols, high bandwidth and interfaces that can simultaneously support multiple sessions, and are most common for LAN networks. As shown in Figure 4, wireless networks are either Star or Mesh topology. In a wireless Star, the gateway communicates individually with each node. In a wireless Mesh, the nodes communicate within each other as well as the gateway.

[6] *Powerline Communications or Street Lighting Automation (2012)*. Maxim Integrated Products Inc. https://www.maximintegrated.com/en/app-notes/index.mvp/id/5347

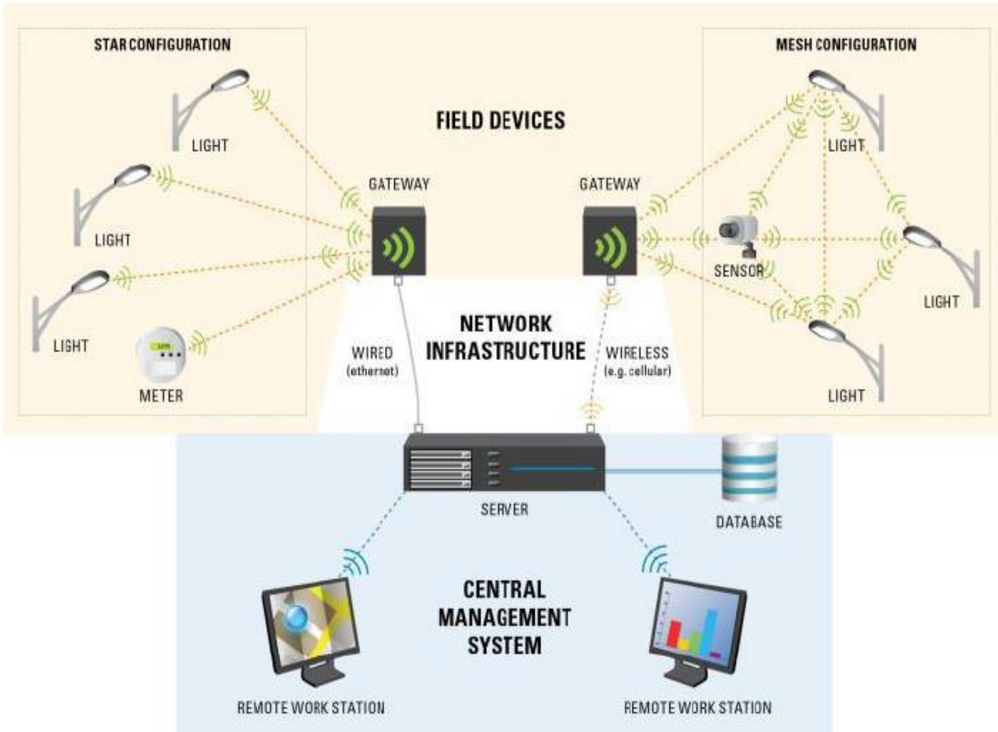


Figure 4: Major components of a wireless outdoor lighting control system[7]

3.3 RADIO FREQUENCY (RF) COMMUNICATION

Another wireless configuration is RF communication that uses radio frequency to transmit data. Typically, each user (or streetlight, for example) is equipped with a fixed superheterodyne transceiver for conversion between RF and baseband signals. As shown in Figure 5, the users receive RF signals from a single radio base station in a point-multipoint (P2MP) system. Connections between the streetlights and base station can be either line-of-sight or non-line-of-sights in lower frequency systems; the latter having higher capital costs.

[7] *Image created by the California Lighting Technology Center, UC Davis for the U.S. DOE Municipal Solid-State Street Lighting Consortium (MSSLC)*

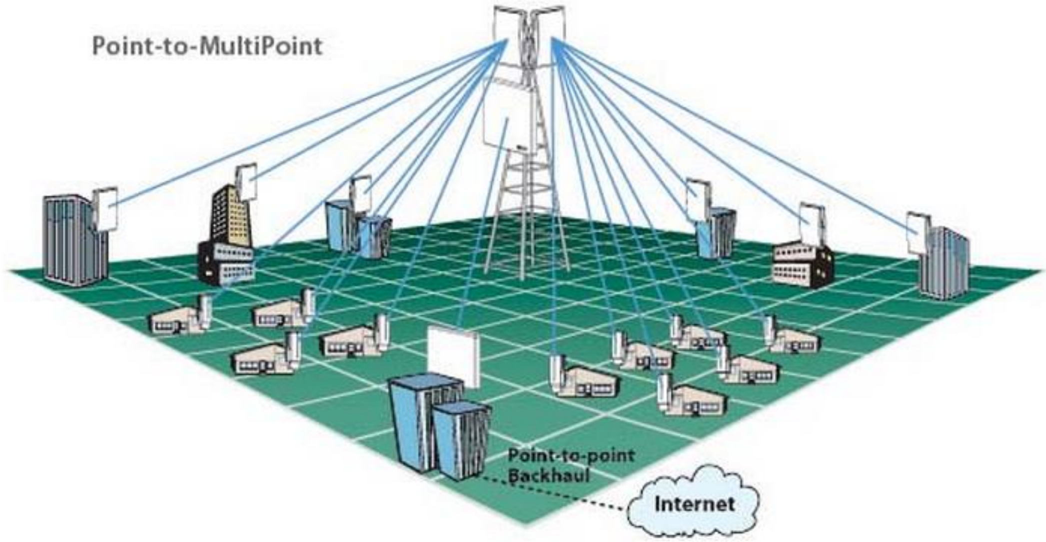


Figure 5: Example of a P2MP RF communication system with buildings as the users[8]

3.4 CELLULAR CONFIGURATION

Wireless cellular communication systems operate across land areas (or cells), which each use different frequencies to its neighbouring areas. As shown in Figure 6, every cell contains at least one base transceiver station which allows the network to cover a large geographical area (more than a system with only one transmitter).

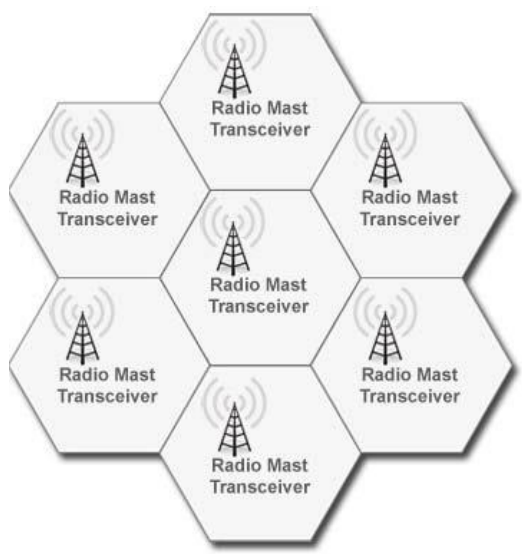
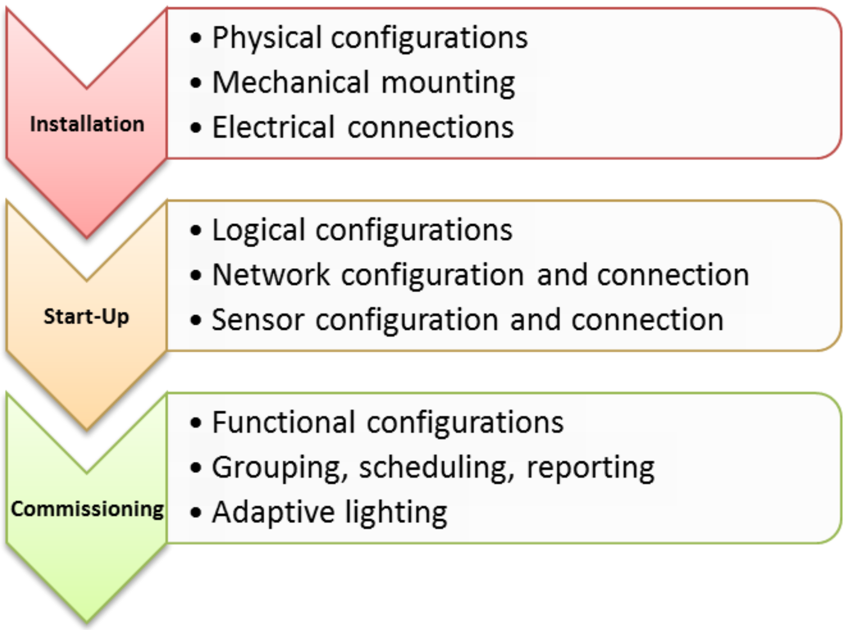


Figure 6: Depiction of a cellular network structure

[8] *Images sources from Airlinx Communications Inc. Access5830 Dual-Band Wireless Ethernet System (1997).* *http://www.airlinx.com/products.cfm/product/1-20-233.htm*

4. SYSTEM COMMISSIONING

Performance commissioning is a process that verifies that the system delivers the performance that it is specified to achieve. It is typically an iterative process, with problem identification leading to solution generation, implementation and testing repeated until the performance is achieved. The general outline of the process is as follows[9]:



Location commissioning involves identifying the coordinates of the unit. This can be from an existing database, from a onetime survey or with integrated GPS in the controller. There are differences in accuracy and cost that factor into the decision for this.

For guidelines on commissioning adaptive controls systems, asset managers should refer to IES-DG-29-11. The Commissioning Process Applied to Lighting and Controls Systems. This Illuminating Engineering Society (IES) document outlines requirements for commissioning procedures, methods and documentation of newly constructed lighting and control systems to achieve performance expectations.

[9] *Chart based on image from:* Michael Poplawski. *What to Look for Today in Control Systems (2014)*. IES Street and Area Lighting Conference. PowerPoint. http://energy.gov/sites/prod/files/2014/10/f18/poplawski_salc2014_1.pdf