Business Case for Smart Roadway and Area Lighting

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The Case for Smart Roadway and Area Lighting Controls

Overview

In order to make effective spending decisions, cities need dependable information on the costs and benefits of any given project.

Although ANSI/IEC RP-8 provides a simplified cost-benefit analysis framework for assessing the cost-benefit of LED retrofit projects, there is no provision for the analysis of "Smart Roadway Lighting" controls, and none that represent the current capabilities of controls such as those offered by Tondo.

In addition, Tondo's Smart Lighting controls include relatively new technologies such as artificial intellgience that are not considered within existing cost-benefit frameworks due to the significant recent advances in these technologies and standards.

This paper describes the current state-of-the-art for Smart Lighting control and describes a comprehensive cost-benefit analysis for cities to assess Smart Lighting costs and benefits.

Tondo maintains an economic model for assisting cities with their own cost-benefit analysis, and this model forms the basis for this paper. **If you are interested in having Tondo provide a customized cost-benefit model for a controls project at your city, please contact us at marketing@tondo-iot.com.**

Tondo Smart Lighting Overview

Networked lighting controls (NLCs) for roadway and area lighting, aka, "Smart Roadway and Area Lighting Controls or more simply, "Smart Lighting controls") have been governed as an established ANSI standard (ANSI C136.48) since 2016.

The key benefits of Tondo's Smart Lighting for a city's streetlight operations and management team focused on the delivery of consistent, safe, standards-based lighting for drivers, pedestrians, and cyclists, include:

1. **Consistent Lighting**: Tondo's Smart Lighting solution ensures consistent lighting levels across the city, providing a safe and comfortable environment where drivers, pedestrians, and cyclists are present.

   Tondo's controls use standards-based lighting control protocols 0-10V and DALI-2™, delivering reliable and uniform illumination.

2. **Energy Efficiency**: Tondo's Smart Lighting solution utilizes advanced energy management features, including daylight harvesting and AI-adaptive dimming.

   These capabilities optimize energy usage by adjusting lighting levels based on natural light conditions and traffic patterns, resulting in significant energy savings without compromising safety.

3. **Reduced Maintenance Costs: Tondo's Smart Lighting solution incorporates advanced monitoring and diagnostics capabilities.**

   It can detect faulty lamps or drivers, enabling proactive maintenance and reducing downtime. This proactive approach minimizes maintenance costs and ensures that lighting is consistently operational.

4. **Remote Control and Monitoring: Tondo's Smart Lighting solution enables remote control and monitoring of streetlights.**

   The operations and management team can easily adjust lighting levels, schedule on/off times, and monitor the status of individual fixtures from a centralized platform. This remote access streamlines operations and reduces the need for physical site visits.

5. **Improved Efficiency in Fault Detection: Tondo's Smart Lighting solution provides real-time alerts and notifications for any lighting system faults or anomalies.**

   This proactive fault detection enables the operations and management team to quickly identify and address issues, minimizing disruptions and ensuring continuous, reliable lighting.

6. **Automation, Alerts, and Notifications:** Tondo's Smart Lighting solution incorporates deep learning AI technology to automate various aspects of streetlight operations.

   Instead of burying cities in an avalanche of data, Tondo's AI-powered central management system generates real-time alerts and notifications for critical events, such as faulty fixtures or abnormal energy consumption. The proactive nature of the system enhances operational efficiency, reduces maintenance costs, and reduces the workload on city lighting operations teams.

7. **Smart City Sensor and Meter Connectivity**: Tondo's Smart Lighting solution supports seamless integration with a wide range of sensors and meters via DALI-2™ and D4i™ standard protocols using socketed and Bluetooth Mesh™ connections.

   This allows the operations and management team to gather valuable data on factors such as traffic flow, environmental conditions, and energy consumption. By combining lighting controls with sensor and meter data, the team can make informed decisions, optimize operations, and enhance the safety and efficiency of the city's critical infrastructure and operating environment.

8. **Enhanced Safety:** Tondo's Smart Lighting solution can use unique deep learning AI technology to monitor and adjust lighting levels based on real-time conditions.

   This ensures optimal visibility on roadways, sidewalks, and bike lanes, reducing the risk of accidents and enhancing safety for all road users.

9. **Compliance with Standards**: Tondo's Smart Lighting solution enables cities to deliver lighting according to industry standards such as ANSI RP-8 and IEC EN13201, ensuring that lighting levels meet the recommended best-practices for different road types and areas.

   Standards compliance ensures that the lighting provided is suitable and safe for drivers, pedestrians, and cyclists.

10. **Zero-Management Technology Platform**: Tondo's network technology platform is fully managed by Tondo for its customers.
    This eliminates the need for cities to worry about gateways, network protocols, cybersecurity, device provisioning, managing cellular plans, licenses, and other non-operational issues. This enables city operations teams to focus on their primary responsibilities and not learn how to "manage technology".

11. **Seamless Integration with Existing Operations Software: Tondo's Smart Lighting solution can seamlessly integrate with existing infrastructure and systems, such as maintenance dispatch, traffic management systems, and other city operations management systems.**

    This integration enables the operations and management team to have a unified view of the city's lighting infrastructure, enhancing coordination and efficiency.

Tondo's Smart Lighting solutions offers a range of benefits for a city's streetlight operations and management team, focusing on the delivery of consistent, safe, standards-based lighting for drivers, pedestrians, and cyclists.

Smart Lighting Costs and Benefits: A California City with 10,000 Fixtures

This paper considers a city with 10,000 lighting fixtures on three different Lighting Service (LS) rate plans available from Southern California Edison as of January 2024, and assumes operating of lighting from dusk-to-dawn at 100% of rated fixture power:

- Utility-owned streetlight service (SCE rate plan LS-1)
- City-owned streetlights on an unmetered rate plan (LS-2)
- City-owned streetlights on a metered rate plan (LS-3)
- Wireless Technology Rate unmetered rate plan (WTR)

The total annual cost of streetlighting operations for this city before installing Smart Lighting is estimated at $1,408,289 (not including the amortized cost of LED retrofit):

Current electricity costs	$911,630
Asset lifecycle & maintenance costs	$369,879
Non-maintenance operations	$162,876
Carbon credit offset costs	$8,951
Current cost of streetlight operations	**$1,083,457**

Table 1: Estimated current cost of streetlight operations

There are many critical variables unique to each city that significantly affect the costs and benefits of a Smart Lighting controls solution:

- Number of fixtures
- Utility streetlight rate plans
- Roadway inventory and classifications
- Intersections, crosswalks, and roundabouts
- Fixture wattage load and lamp types
- Cost of Smart Lighting controls installation
- Cost of lamp replacement
- Dusk-to-dawn periods
- Adjacent pedestrian traffic classifications
- Installation during or after LED retrofit

The combination of each of these factors creates a significant complexity in accurately modeling Smart Lighting costs and benefits that are addressed in this analysis.

Smart Lighting Economic Benefits

There are six components of the economic benefits to city operating budgets that decrease streetlight operating costs:

Sources of Savings - Post Deployment (%)	TCO Savings
Lower cost of metered streetlighting rate plans	45.0%
Correction of over-lighting to standards	3%
Adaptive roadway and area lighting control	14.5%
Fixture lifecycles & maintenance costs	7.3%
Non-maintenance operational efficiencies	3.7%
Carbon credit offset savings	0.3%
Reduced cost of streetlight operations	56.3%

Table 2: Sources of savings (%) from Tondo Smart Lighting on metered rate plan

Sources of Savings - Post Deployment ($)	TCO Savings
Lower cost of metered streetlighting rate plans	$398,793
Correction of over-lighting to standards	$44,215
Adaptive roadway and area lighting control	$211,380
Fixture lifecycles & maintenance costs	$106,123
Non-maintenance operational efficiencies	$53,749
Carbon credit offset savings	$4,490
Reduced cost of streetlight operations	**$818,751**

Table 3: Sources of savings ($) from Tondo Smart Lighting on metered rate plan

Tondo Smart Lighting provides a 56.3% or $818,751 decrease in costs for an SCE customer in California deploying Tondo's Smart Lighting controls on a metered rate plan:

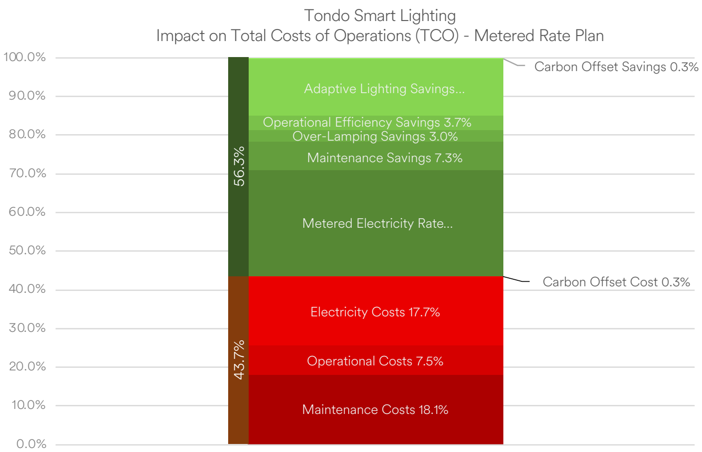

Figure 1: Sources of Costs and Benefits on metered rate plans

Sources of Costs - Post-Deployment ($)	Net TCO
Electricity costs	$257,241
Fixture lifecycles & maintenance costs	$263,665
Non-maintenance operational costs	$109,127
Carbon credit offset costs	$4,461
Post-deployment cost of streetlight operations	**$634,495**

Table 4: Net cost of streetlight operations after deployment metered rate plan

A Tondo Smart Lighting project provides a faster ROI with a full cost recovery in 3.59 years and a 20-year value of $10.6m for a city on a metered streetlighting rate plan, exceeding the $6.6 20-year value of an LED retrofit project.

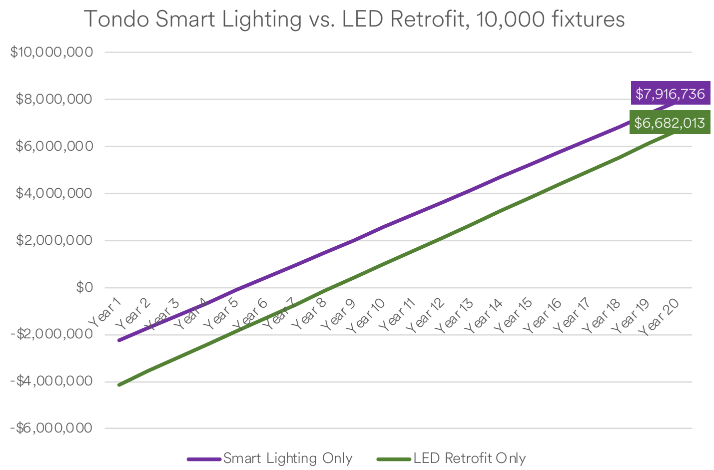

Figure 2: Fully-costed ROI on a metered rate plan

Tondo Smart Lighting Project Costs

The costs of Tondo's solution in this analysis are based on its list pricing, that would be subject to open public tendering processes and may result in a lower cost for cities. The figures below are only provided for modeling the ROI / project payback in this analysis.

Tondo Annual Project Costs			
Item	Quantity	Unit Price	Subtotals
Tondo Edge IQ Controller	10,000	$100.00	$1,000,000
Tondo Cloud IQ CMS SaaS License	10,000	$24.00/yr	$240,000
Adaptive Roadway Sensor	1,815	$70.00	$127,050
Sensor Mounting Kit	1,815	$20.00	$36,300
Adaptive Roadway Sensor SaaS License	1,815	$24.00/yr	$43,560
Estimated Installation Cost (Contractor)	13,630	$42.00	$570,813
Tondo On-Site Project Management	303 person-days	$234,165	$234,165
Totals			**$2,251,888**

Table 5: Fully costed Tondo Smart Lighting project, 10,000 fixtures

Detailed Benefits and Methodologies

To have confidence in a Smart Lighting costs and benefits, a detailed analysis is provided here, describing the assumptions and methodology for calculating each of the benefits in this analysis.

A Note on Utility Rate Plan Complexity

In most, if not all cities in the U.S., streetlighting energy is provided under a specific rate plan unique to streetlighting, separate from non-streetlighting rate plans for other city operations. These rate plans are highly complex and require careful analysis.

It is important to work with your utility and energy retailer to understand the specifics of your city rate plan and how they will be affected by the deployment of Smart Lighting. Tondo would be happy to help you work with your energy providers to validate your costs and benefits for Smart Lighting.

Most cities are either operating on a Utility-owned streetlighting-as-a-service plan such as SCE's LS-1 or WTR, or on a city-owned fixture/pole unmetered service such as SCE's LS-2 plan. In rare instances, cities may be operating City-owned fixture/pole metered services such as SCE's LS-3 plan.

Most streetlight rate plans are comprised of up to seven key components:

- Transmission & Distribution Demand Charges
- Generation Energy Charges
- Customer Account Charges
- Regulated Special Charges/Rate Riders
- Metering Charges
- Streetlighting Maintenance Charges (Optional Service)
- Streetlighting as a Service (Utility Owned Assets)

In de-regulated energy markets, utilities providing Transmission & Delivery may be different than the provider of your Energy/Generation supply. Utilities providing Streetlighting-as-a-Service with utility-owned assets will typically (but not always) also be your Energy/Generation provider. As in the SCE case described here, cities may have the option of purchasing metered energy from a third-party energy retailer.

It is worth noting that each utility will allocate their costs differently to each of these different key cost components.

Since these costs respond differently to Smart Lighting controls, particularly the number of fixtures, the wattage, time-of-use, energy savings from dimming, the savings from Smart Lighting can vary significantly for each city, utility, and energy retailer.

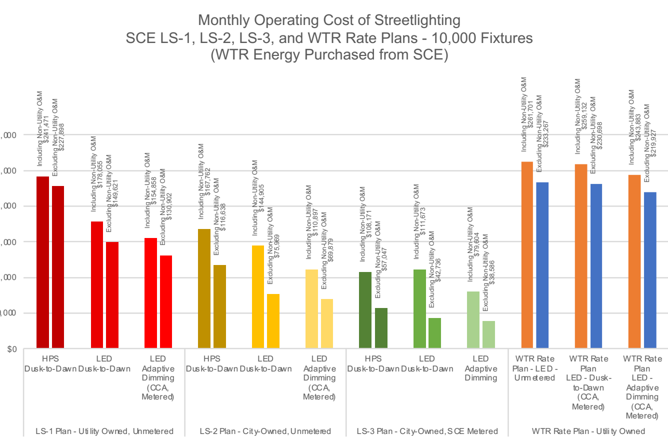

Figure 3: Total cost of streetlight operations - SCE rate plans

Tondo has developed a detailed model for several energy utility rate plans, including the SCE rate plans LS-1, LS-2, LS-3, and WTR used for this paper.

Dimming value for utility-owned assets (LS-1) would require purchasing energy from a Community Choice Aggregator / third-party energy retailer where de-regulated energy is available in a given state.

Metered Streetlighting

Metered streetlighting is typically offered in a rate plan such as SCE's LS-3 plan or via a third-party energy retailer, where electricity services are charged according to the precise consumption of electricity.

In cases where a city's utility does not offer metered streetlight rate plans or where city lighting assets are owned by their utility and electricity is bundled in a streetlight service, a city would need to be able to purchase their energy from a third-party retailer.

43% of electricity sold in the U.S. is in "de-regulated" states, enabling cities to purchase electricity from an electricity "retailer" and have it delivered by their current "transmission and delivery utility" partner.

As of June 2024, U.S. de-regulated electricity states are:

California	New Jersey
Connecticut	New York
Delaware	Ohio
Illinois	Oregon
Maine	Pennsylvania
Maryland	Rhode Island
Massachusetts	Texas
Michigan	Virginia
New Hampshire	District of Columbia

Typically, a utility and city will agree on the service points to be metered, and the city will pay the utility an additional per-meter cost that will include the meter and the services provided to monitor the meter and bill accordingly.

Meters must comply to the ANSI C12.1 (formerly C12.20) standard with an accuracy class of 0.5% or better, and typically must be tested and approved by the utility for accuracy.

In 2021, the ANSI standard C136.50 was published to recognize new technologies for socketed controls such as Tondo's Edge IQ controller that support ANSI C12.1 accuracy class 0.5 metering on each fixture. Also released was the related ANSI C136.52 standard for driver-based energy metering internal to a fixture.

Many utilities have not yet proceeded with or completed their testing and approvals process for ANSI C136.50. However, it can be expected that this will happen in due course.

Tondo also provides a lighting cabinet-based metering solution that is C12.1 accuracy class 0.5 compliant, in addition to providing advanced energy analytics capabilities and SCADA analog and digital control capabilities for a wide range of Smart Infrastructure applications.

For either socketed fixtures or lighting control cabinets, Tondo provides advanced electrical metering capabilities with secured energy logging that, *subject to utility approval*, can be used to migrate cities from unmetered rate plans such as SCE LS-1 or LS-2, to metered rate plans such as in SCE LS-3 or a similar plan from a third-party electricity retailer where available.

The savings for metered electricity are applied before all other savings calculations are performed, to ensure that savings for dimming control are exclusive to a metered rate plan.

These calculations include $114,771 in annual costs for SCE metering currently required to migrate from an unmetered SCE LS-2 plan to a metered SCE LS-3 plan.

To calculate the savings for Metered Electricity, the calculation is simply:

Metered Rate Plan Electricity Savings (LS-2 to LS-3)	
Current Cost of Dusk-to-Dawn Electricity	$911,630
Net Electricity Costs after Metering	$512,837
Electricity savings from metering	**$398,793**

Table 6: Calculation of metered rate plan electricity savings

Over-Lighting

Over-lighting occurs when luminaires are purchased and commissioned at 100% luminance that exceed the levels required to deliver illumination at the maximum levels required by ANSI/IES RP-8 for a given roadway classification and surface classification.

From ANS/IES RP-8-22:

"To maintain the minimum light 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. Designers may provide an initial level of lighting higher than the minimum maintained level. In effect, roads and sidewalks are over-lighted up until the end of assumed lamp life."

There are two classification methodologies under ANSI/IES RP-8 – the standard classification and the alternative classification under RP-8 Annex K. For this analysis, the standard classification system is used.

Cities often purchase fixtures with rated wattages that are close to but exceed the requirements for a given roadway segment. However, without Smart Lighting controls, cities have the capabilities to commission lamps dimmed to the levels appropriate for a specific roadway segment.

For the calculations used in this analysis, Tondo has analyzed the rated fixture wattage and compared that wattage with that of the commissioned wattage for the City of San Jose, California as available May 31, 2024 in the City's public Open Data portal at https://data.sanjoseca.gov/dataset/streetlight-fixture.

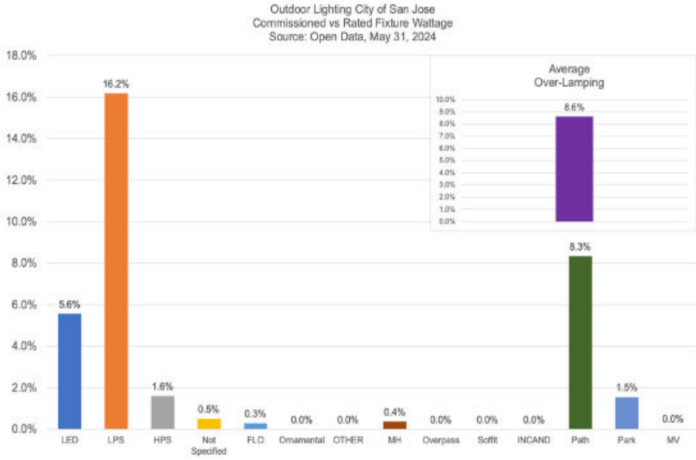

Figure 4: Over-lighting of City of San Jose lighting assets, May 2024

> *This analysis of the City of San Jose shows an 8.6% variance between the rated wattage and commissioned wattage dimmed to the level appropriate for their roadway segments.*

In this case, only 33.6% of San Jose's fixtures appear to have been dimmed to correct for over-lighting. **In this case, we might expect over-lamping to be as high as 25.4%.**

Here, over-lighting savings are calculated by applying the 8.6% factor to the dusk-to-dawn energy calculated for each fixture type for the 10,000-fixture scenario in this analysis.

Over-Lighting Savings - Metered Rate Plan	
Pre-dimming electricity cost	$911,630
Metered electricity savings	$398,793
Net cost of electricity before correction	$512,837
Electricity cost after over-lighting correction	$468,621
Savings from corrected over-lighting (8.6%)	**$44,215**

Table 7: Over-lighting savings on metered rate plan

This 8.6% correction for over-lighting provides for a 3.0% decrease in total operating costs.

Adaptive Roadway Lighting

Adaptive roadway lighting should not be confused with occupancy-based adaptive dimming common for pedestrian walkways and parking facilities that respond in real-time.

Real-time responsiveness on roadways would be disruptive and unsafe for drivers. **Instead, Tondo considers automation of adaptive roadway lighting to be automated adjustments to lighting profiles based on sustained traffic and pedestrian volume trends identified by Tondo's Deep Learning AI.**

From ANSI/IES RP-8-22, Section 6.10:

"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 types of controls allow the lighting system to adapt the light levels to the ambient conditions. Better lighting controls can result in improved visibility and potential savings in both energy and maintenance costs."

The barrier for manufacturers to implement Adaptive Roadway Lighting are rooted in the complexity of the ANSI/IES RP-8 standard, combined with the variety of deployed fixture models and their capabilities.

Example: the City of San Jose – at the time of this analysis – has deployed 229 different models of fixtures.

When we also consider that under ANSI/IES RP-8-22 there are six roadway classifications, four roadway surface classifications with three different vehicle traffic volumes, three different pedestrian traffic volumes, and consider intersections, roundabouts, and these are combined with numerous fixture models deployed in each city, the complexity of configuring dimming control for their fixtures becomes impossible to manage manually.

Example:

> 6 roadway classifications x 4 roadway surface classifications x 3 vehicle traffic volumes x 3 pedestrian traffic volumes = 216 lighting profile combinations.
>
> **216 profile combinations**
> **<u>x 229 fixture models</u>**
> **= 49,464 profiles**

With a *manually-managed* CMS, there might be thousands of distinct configurations for a city operations team to manage in order to implement Adaptive Roadway Lighting.

Further, the dynamic nature of vehicle and pedestrian traffic volumes also means that these factors can change over time, that without AI automation, would create an impossible management burden for city lighting operations.

Lamp Type	All Fixtures	Fixtures with Data	Average Watts/ Fixture	Watts (Rated)	Watts (Commissioned)	Watts Over-lighted
LED	40,877	39,191	59.6	2,334,911	2,211,946	122,965
LPS	21,866	21,276	77.5	1,647,856	1,418,503	229,353
HPS	4,177	3,953	102.3	404,315	397,962	6,353
Unspecified	453	318	94.1	29,917	29,771	146
FLO	467	414	96.2	39,838	39,726	112
Ornamental	77	71	98.1	6,965	6,965	0
OTHER	33	13	69.7	906	906	0
MH	217	215	95.0	20,418	20,344	74
Overpass	64	57	86.4	4,923	4,923	0
Soffit	39	3	70.0	210	210	0
INCAND	30	28	116.3	3,255	3,255	0
Path	179	116	81.3	9,430	8,705	725
Park	25	15	96.5	1,448	1,426	22
MV	279	198	141.9	28,095	28,086	9
Totals	**68,783**	**65,868**	68.8	4,532,487	4,172,727	359,760
	100.0%	**95.8%**				**8.6%**

Table 8: Over-lighting of City of San Jose lighting assets, May 2024

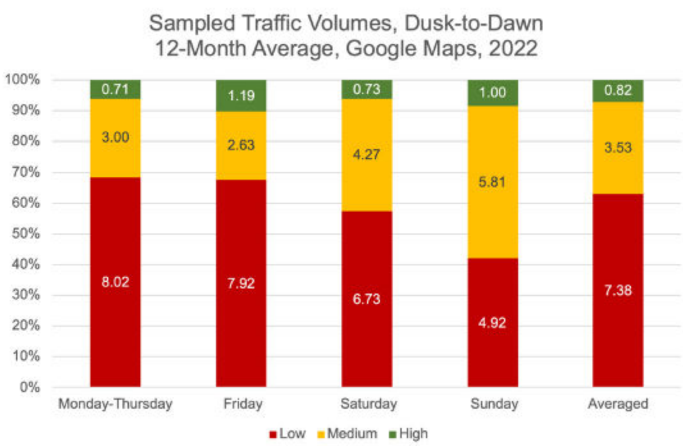

Figure 5: Average traffic volumes, sampled from Google Maps, 2022

Tondo's Cloud IQ CMS with its deep learning AI can automate the process of configuring and monitoring lighting levels compliant with ANSI/IES RP-8 so that the city's lighting operations team can ensure safe, standards-based lighting levels are aligned with the demand at any time.

Unlike adaptive lighting for pedestrian and cyclist pathways and parking facilities, Tondo's deep learning AI can identify trends in traffic patterns and adjust lighting profiles instead of responding to presence of vehicles and pedestrians in real-time. This avoids the numerous intensive dimming cycles that would distract drivers and create unsafe conditions.

The savings from Adaptive Roadway Lighting are based on a sampling of traffic volumes over a one-year period using Google Maps data and applied to ANSI/IES RP-8.

Pedestrian traffic is assumed to be relative to vehicle traffic volumes, where high vehicle volumes also correspond to high pedestrian traffic volumes.

Savings available from Adaptive Roadway Lighting are calculated on the difference for each roadway classification, surface classification, vehicle and pedestrian traffic volumes, and calculated as a ratio of the maximum average luminance (L*avg*) value.

Dimming values are then applied to roadway characteristics found in city Open Data sets, with the City of San Jose used as an example.

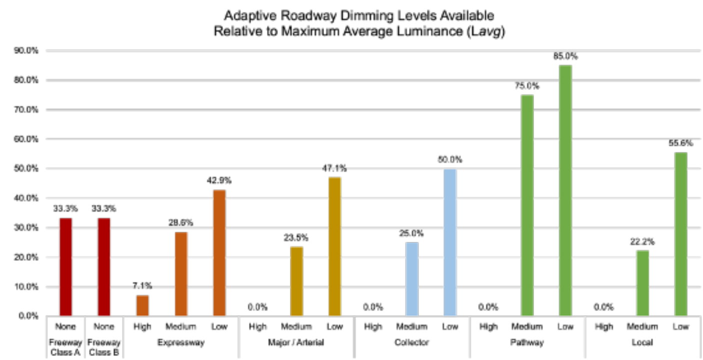

Figure 6: Available dimming levels from Tondo AI-Adaptive Roadway Lighting control

As a result, we can expect that for a city with roadway composition similar to the City of San Jose can reduce lighting levels by 45.1% from dusk-to-dawn control.

These 45.1% savings are applied to the dusk-to-dawn energy values net of the savings from correcting for over-lighting.

Adaptive Lighting Costs & Benefits - Metered Rate Plan	
Cost of unmetered electricity before dimming	$911,630
Metered electricity savings	$398,793
Over-lighting Correction Savings	$44,215
Cost of electricity before Adaptive Lighting	$468,621
Electricity cost after Tondo Smart Lighting	$257,241
Adaptive Roadway Lighting savings	**$211,380**

Table 9: Calculation of electricity savings on metered rate plan

Extended LED Lamp Lifecycles and Maintenance Costs

Since 2010, "modular" LED fixtures have become available, enabling maintenance crews to replace the LED driver independently of the LED light panel. This can offer significant savings, as the lifecycles of LED light panels may be extended via dimming.

In this case, we assume that a driver may be replaced, but that the entire fixture would be replaced at the end of lamp life.

Temperature via electrical current across an LED is the primary cause of lamp failure[1], while over-voltage, ripple current, charge-discharge, and temperature are the key causes of driver failure[2].

"Intensive" dimming such as that used in parking facility and pedestrian roadway applications has been shown to decrease the lifecycle of the driver by 2% when tested at 60 dimming cycles per hour[3].

The correction for over-lighting and Adaptive Roadway Dimming used in the Tondo model (long-cycle dimming) does not propose "intensive" dimming. As such, we assume that there is no significant positive or negative effect on the driver lifecycle[1].

However, for LED lamp lifecycles, we know that the operating temperature and ambient temperatures have a significant effect on LED lamp lifecycles.

1 K. -Z. Tan, S. -K. Lee and H. -C. Low, "LED Lifetime Prediction Under Thermal-Electrical Stress," in IEEE Transactions on Device and Materials Reliability, vol. 21, no. 3, pp. 310-319, Sept. 2021

2 The Impact of Output Capacitor Aging under Constant and Cycled Temperature Conditions on LED Driver Lifetime,
A.P. Sachintha, G. De Vas Gunawardena, N. Narendran; Lighting Research Center, Rensselaer Polytechnic Institute

3 Askola J, Kärhä P, Baumgartner H, Porrasmaa S, Ikonen E. Effect of adaptive control on the LED street luminaire lifetime and on the lifecycle costs of a lighting installation. Lighting Research & Technology. 2022;54(1):75-89.

Using the referenced study in "LED Lifetime Prediction Under Thermal-Electric Stress"[1], we predict the effects of dimming on lamp lifecycles using the Eyring equation:

$$L_p = AT^B \exp\left(\frac{E_a}{k_B T_j} + \left(C + \frac{D}{T_j}\right) I\right)$$

where for a 60,000 hour L70-rated 70W luminaire:

- Rated Input Current = 1A
- Drive Current = 700mA
- Rated Power = 70W at 120V
- L_p is the lumen maintenance life (60,000 hours)
- T is the ambient operating temperature (25°C)
- T_j is the LED junction temperature assumed to rise 2°C with each 10% decrease in output current (input current assumption = 1A)
- I is the drive current (700mA)
- A is a constant; a scaling factor that adjusts overall time to failure ($1x10^8$)
- B is a constant; a temperature factor (-1.5)
- C is a constant; an electrical stress factor (0.5)
- D is a constant; representing the relationship between B and C (0.05)
- E_a is a constant; representing the thermal threshold for degradation to begin occurring (0.65)

The impact on LED panel lifecycle is shown in the following chart:

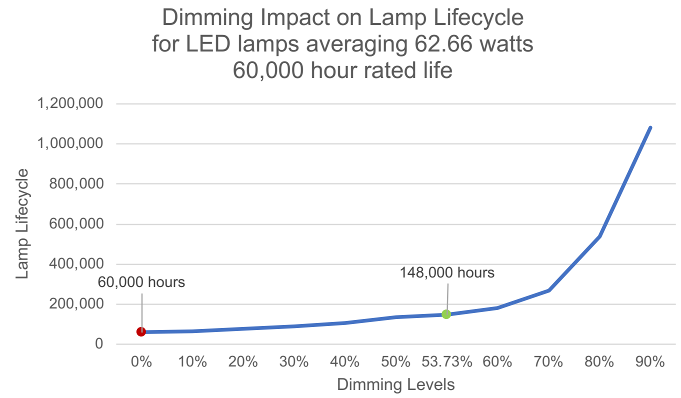

Figure 7: Dimming impact on lamp lifecycle

As such, we can expect the lifecycle of LED lamps that average 62.66 watts (City of San Jose data set) with correction for over-lighting (8.6%) and Adaptive Roadway Dimming (45.1%) totalling 53.73%, to be 148,000 hours - an extended life of 146%.

Lamp Lifecycle Maintenance Costs & Benefits	
Annualized cost of lamp replacement	$369,789
Annualized cost of lamp replacement - dimmed	$263,665
Extended Lamp Lifecycle Savings	**$106,123**

Table 10: Lamp Lifecycle Maintenance Costs & Benefits

Lifecycle Analysis (per fixture, annual)	
D2D Operating hours (per SCE rate plan)	4,284 hours per year
Sodium lifespan (Not Dimmable, 15,000 hour lifecycle)	3.50 years
Sodium Maintenance Cost (Municipal)	$45.06 per fixture
Sodium Maintenance Cost (SCE)	$133.51 per fixture
Induction lifespan (Pre-Dimming, 36,000 hour lifecycle)	8.4 years
Induction lifespan (Post-Dimming)	13.2 years
Induction Maintenance Cost (Municipal, Pre-Dimming)	$45.55 per fixture
Induction Maintenance Cost (SCE, Post-Dimming)	$45.55 per fixture
Induction Maintenance Cost (Municipal, Post-Dimming)	$28.90 per fixture
LED Lifespan (Pre-Dimming, 60,000 hour lifecycle)	14.01 years
LED Lifespan (Post-Dimming)	34.55 years
LED Fixture Lifecycle Cost (Municipal, Pre-Dimming)	$36.98 per fixture
LED Fixture Lifecycle Cost (Municipal, Post-Dimming)	$26.37 per fixture
LED Fixture Maintenance Cost (SCE, Pre-Dimming)	$88.38 per fixture
LED vs HPS maintenance savings, Utility-Owned, Metered	**$45.13 per fixture, annually**
LED vs HPS maintenance savings, Municipal-Owned, Metered	**$8.08 per fixture, annually**

Table 11: Fixture lifecycle analysis

Improved Operational Efficiencies

The use of Tondo's Cloud IQ central management system (CMS), with its deep learning AI automation and analytics, is expected to significantly improve city lighting operational efficiencies.

ANSI/IES RP-8-22, Section 9.8.3 describes a number of expected efficiencies from the use of a CMS :

- Preventive maintenance analysis
- Inventory analysis
- Work management analysis
- Asset management
- Electrical system maintenance
- Asset tracking
- Electrical safety equipment
- Power metering and monitoring
- Tariffs
- Flat rate billing
- Metered service
- Meter accuracy

In addition to these basic capabilities, Tondo can provide actionable insights such as:

- Electrical wiring fault detection
- Advanced electricity quality monitoring
- Integration with maintenance dispatch systems
- Identification of electricity theft
- Identification of wire theft
- Automation of lighting profile management for standards-based lighting delivery

A CMS generally consists of a "front-end" dashboard that city operations teams use in their daily work, and a "back-end" system that manages device authorization and provisioning, cybersecurity, network performance, cellular and wireless connectivity.

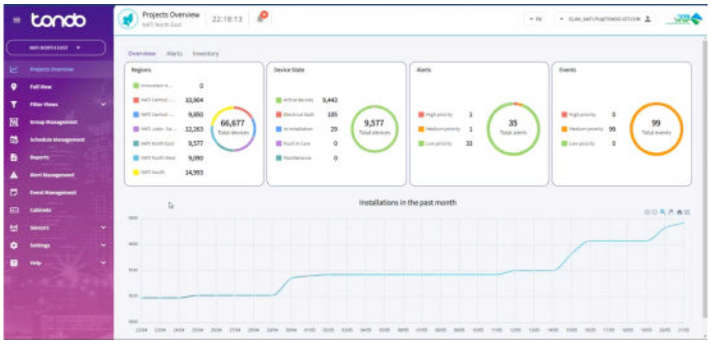

Figure 8: Tondo Cloud IQ CMS Dashboard Project Summary View

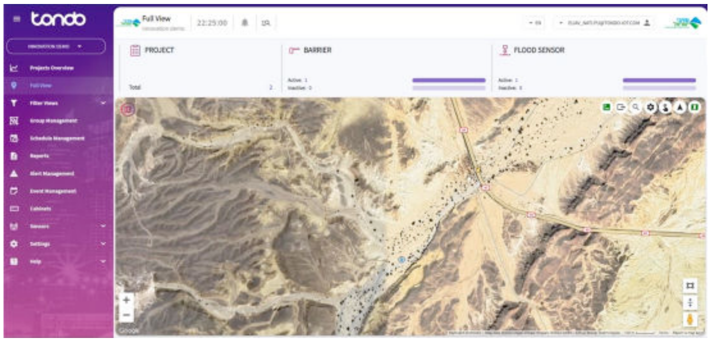

Figure 9: Tondo CMS Dashboard Map View

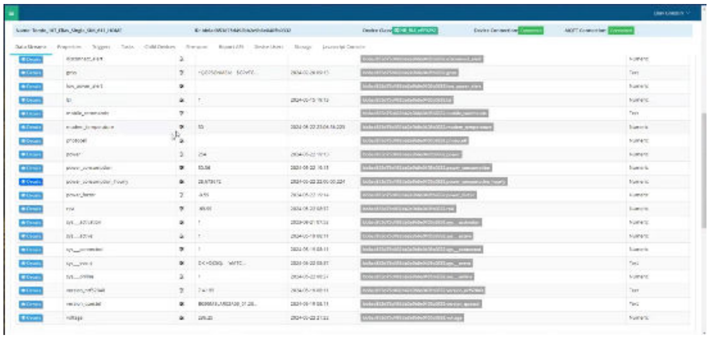

Figure 10: Tondo CMS Back-End (Fully-Managed)

Unfortunately, many early and existing CMS systems required cities to manage the "back-end" of the CMS. This added complexity either neutralized the operational benefits or worse, increased the demands on city operations and information technology teams.

A key advantage of using Tondo's Cloud IQ CMS is its fully managed "back-end" network (see Figure 10), making it entirely transparent to city operations teams.

Tondo customers do not see the Tondo back-end, and all devices produced for a customer system are coded and secured by Tondo before they leave Tondo's factory. This includes managing all cellular plans and connectivity and managing network performance for Tondo customers.

The advantage of Tondo's approach is that cities are not burdened by technology management that would neutralize the operational efficiency gains from the use of a CMS for lighting operations. The cost of non-maintenance operations is calculated based on a sampling of four cities, their number of full-time employees (FTEs), an average annual cost per FTE within a lighting operations team, and the number of fixtures for each city, **to derive a reasonable FTE cost per fixture of $16.29 per fixture.**

Although it is difficult to assess the precise value of these operational benefits as they will differ depending on the specific capabilities a city wishes to implement, **Tondo conservatively assumes a minimum 33% efficiency gain for city lighting operations.**

For a city of 10,000 fixtures, this would provide for the following costs and benefits using Tondo Smart Lighting:

Non-Maintenance Management Costs and Benefits	
Pre-deployment management costs	$162,876
Post-deployment management costs	$109,127
Non-maintenance management savings (33%)	**$53,749**

Table 13: Non-maintenance operational benefits

Non-Maintenance Operational Costs of Streetlighting					
City	Fixtures	FTEs	Fixtures per FTE	Annual Cost per FTE	Total FTE Costs
Ottawa	58,000	13	4,462	$85,000	$1,105,000
Brampton	42,403	7	6,058	$85,000	$595,000
Hamilton	45,470	8	5,684	$85,000	$680,000
San Francisco	42,000	8	5,250	$85,000	$680,000
Totals	**187,873**	**36**	**5,219**		**$3,060,000**
					$16.29 FTE cost per fixture

Table 12: Non-maintenance operational cost analysis, estimated

Carbon Credit Offset Savings

Most cities are pursuing "net-zero" carbon initiatives. In this case, we assume that a city will purchase carbon credits to offset the carbon footprint of their streetlighting electricity in some form.

In our analysis, we begin with a carbon credit value of $50.00, which is an approximate cost based on Tier 1 pricing available from California's Air Quality Board.

We then source the CO^2 equivalent footprint of electricity from www.electricitymaps.com, which in this case is 62g/kWh, and apply that to our model.

Cost of Carbon Credit Offsets	
Pre-Deployment Carbon Credit Costs	$8,951
Post-Deployment Carbon Credit Costs	$4,461
Non-maintenance operating savings	**$4,490**

Table 14: Carbon credit offset benefits

Other Benefits Not Included in Calculations

In addition to the economic benefits to the city budget, through delivering safe, consistent, standards-based lighting, Smart Lighting controls also support additional benefits that will be outside the scope of this white paper:

- AI-enabled anomaly detection such as electricity theft and wire theft
- Reduced vehicle accidents and fatalities involving vehicles
- Reduced personal and property crime
- Reduced impact on human endocrine health caused by disruption to circadian rhythms (sleep patterns)
- Reduced impact on wildlife migration and reproduction
- Increased business volumes from improved lighting and related perception of safety
- A 50%-80% reduction in the cost of deploying connected infrastructure solutions for Smart City enablement

Although these additional benefits are significant, they are not considered in this analysis.

LED Retrofit and Maintenance Assumptions

For the purposes of calculating the return on investment (ROI) for Smart Lighting and comparison to LED retrofit, there are several non-utility rate plan components included in the costing of a Tondo Smart Lighting project:

- Lamp replacement costs including labor
- Fixture replacement costs including labor
- Lifecycle costs (pre- and post-dimming control)

Fixture Maintenance Costs (Annual)	
Fixtures replaced per hour	4.2 fixtures
Labor per per crew per hour	$518.60 per hour
Driver replacement cost	$100.00 per fixture
Fixture replacement cost (50w)	$250 per fixture
Bucket truck cost per hour	$39.13 per fixture
Retrofit cost per fixture	$289.13 per fixture
Driver or LED lamp lifecycles	60,000 hours ea.
LED rated lamp lifecycle (dusk-to-dawn)	14.01 years
LED rated lamp lifecycle (dimmed)	34.55 years
LED Maintenance cost (dusk-to-dawn)	**$36.98 per fixture**
LED Maintenance cost (dimmed)	**$26.37 per fixture**

Table 15: Streetlighting asset maintenance cost assumptions

Conclusion

All efforts have been made to ensure accuracy and completeness of the costs and benefits of Tondo's Smart Lighting controls.

As described beginning on Page 5, Smart Lighting Costs and Benefits, Tondo's Smart Lighting solutions provide significant economic benefits not available from competitive solutions that include:

- Deep-Learning AI automation of complex lighting environments that represent **60% greater benefits** over competitive Smart Lighting solutions
- **A fully-managed back-end network** that eliminates any extra management burden on city lighting operations and information technology teams
- **Enablement of Smart City connected infrastructure** applications such as sensors, smart meters, and SCADA-type applications

If you have any comments, questions, corrections, **or would like a customized version of this document created for your specific city and utility rate plans,** please contact us at marketing@tondo-iot.com.

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