

2019

## **ENERGY EFFICIENT STREETLIGHT CONVERSION: INTEGRATING LEDS AND INTELLIGENT TRANSPORTATION SYSTEMS**

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ENERGY EFFICIENT STREETLIGHT CONVERSION: INTEGRATING LEDS  
AND INTELLIGENT TRANSPORTATION SYSTEMS

BY

JEFFREY REINKER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

SYSTEMS ENGINEERING

UNIVERSITY OF RHODE ISLAND

2019

MASTER OF SCIENCE

OF

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2019

## Abstract

This research was conducted to gain insight into energy efficient streetlight conversions through the integration of light-emitting diode (LED) technology and intelligent transportation systems (ITS). Existing streetlight technology utilized in Rhode Island was examined and found to be primarily high-pressure sodium (HPS) luminaires. Models for a standalone LED streetlight conversion and an ITS integrated LED streetlight conversion were developed. A detailed engineering economic analysis was conducted to build a business case for the future of streetlights in Rhode Island. It was found that both an LED streetlight conversion and an ITS integrated LED streetlight conversion were economically viable given current energy, hardware, installation, and maintenance costs. An LED streetlight conversion yielded the strongest twenty-year net present value (NPV) and had a favorable incremental internal rate of return ( $\Delta$ IRR). However, an LED streetlight conversion with ITS integration maintained favorable investment performance metrics while offering additional benefits associated with traffic and environmental data collection. Allowing the ITS to turn off streetlights when no traffic is present could offset operational energy cost in some environments, but that was not the case for Rhode Island highways analyzed in this study.

## Acknowledgements

I would like to thank my advisor, Dr. Maier-Sperdelozzi, and committee members, Dr. Wang and Dr. Hunter. Their help and guidance has been invaluable in completing this thesis.

I would also like to acknowledge the engineers and administrators of the Rhode Island Department of Transportation who assisted me with interviews and data collection. John Preiss, Glenn Cabral, Jeffry Martins, and Dan DiBiasio were instrumental contributors throughout my research.

Finally, I would like to thank my wife, Danielle, and parents, John and Cindy, for their patience and support throughout the pursuit of my degree.

## Preface

This paper is written in manuscript format for submission to the Transportation Research Board (TRB) Annual Meeting. At the time of defense, this paper has not yet been submitted to the TRB for review.

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## Manuscript

Prepared for submission to the Transportation Research Board (TRB) Annual Meeting.

# ENERGY EFFICIENT STREETLIGHT CONVERSION: INTEGRATING LEDS AND INTELLIGENT TRANSPORTATION SYSTEMS

## **INTRODUCTION**

The objective of this project is to collect data on the current costs of highway lighting and compare those with an engineering economic analysis of costs for updated systems, which would combine light-emitting diode (LED) technology with a network of sensors. The problem focuses on the application of these systems along freeways in rural areas of Rhode Island, where low traffic frequencies allow for potential energy savings by only illuminating streetlights when vehicles are present.

Streetlight technology currently utilized in Rhode Island is outdated and inefficient. Coupled with the rising cost of energy, lighting the roadways has become increasingly burdensome on operating budgets, which are ultimately funded by the taxpayers. Budget shortfalls have led to reductions in funding for operating budgets in Rhode Island, which has caused the state and some municipalities to turn off streetlights along numerous roadways (RIDOT 2010a, RIDOT 2010b).

Electric street lighting was successfully introduced at the end of the nineteenth century, replacing the gas lamps that had previously lined the roadway with electric incandescent bulbs (Electric, 1881). Contemporary street lighting applications typically utilize low-pressure sodium (LPS) or high-pressure sodium (HPS) technology (Kinzey & Myer, 2009). Kinzey and Myer (2009) pointed out LPS sodium lights are not appropriate for illuminating roadways because the light emitted can cause difficulty in distinguishing

between objects. In recent years, street lighting across the nation has slowly begun conversion from HPS to LED technology.

LEDs are solid-state devices with the ability to generate significant economic and environmental savings when replacing traditional light bulbs (Schubert & Kim, 2005). LEDs also benefit from greatly reduced emission of greenhouse gases and other environmental pollutants when compared to the traditional lighting technologies (Bergh, Craford, Duggal & Haitz, 2001). Versatility in color temperature, instant dimming capability and directional properties allow LEDs to conserve energy in most applications (Vitta, et al., 2012). Another benefit of LED streetlights is that they do not “burn out” like traditional HPS streetlights; instead, LEDs usually grow progressively dimmer over time (Kimber, Roberts & Logan, 2012). This, however, could make it more difficult to monitor when replacements are necessary. The authors suggest replacement when brightness dips below 70%, but this would require light sensors or other equipment to identify.

In 2010, the Rhode Island Department of Transportation (RIDOT) shut off streetlights on several sections of highway to save an estimated \$1 million in annual operating expenses (RIDOT 2010a, RIDOT 2010b). However, RIDOT also began looking at LED streetlight options, similar to the switch from incandescent traffic signals to LED signals completed in 2006, as an alternative step in energy savings (RIDOT 2010a). In Rhode Island, the opportunity exists not only to replace traditional HPS streetlights with LED streetlights, but also to further connect these LED streetlights to an intelligent

transportation system (ITS) network. This system would allow the streetlights to be turned on only as needed, such as in the case of approaching late night traffic. Utilizing an ITS network in this manner is similar to the concepts employed by many lights-out manufacturing or warehouse facilities where lights are turned on in a timed, rolling manner only if a sensor is triggered (Kusuda, 2008; Sprow, 1994). Since LED lighting does not require a warming period, unlike HPS lighting, LED streetlights can be turned on by motion or time sensors through an ITS network instantaneously.

The state of Rhode Island also is an ideal location to explore potential alternative energy sources, such as wind and solar generating devices, and their integration into ITS infrastructure. These alternative energy sources could be used as a primary or secondary power source to reduce LED streetlight energy costs even further. This is not a new idea, as a U.S. patent filed by Doan (1980) describes a solar powered street lighting system with an auxiliary wind turbine. Recently, Wang, et al. (2013) proposed an LED streetlight system with real-time monitoring capabilities that employed both grid and solar power. The authors found this system demonstrated feasible energy savings. Chedid, Akiki, and Rahman (1998) presented a technique that can be applied to find the most viable alternative energy sources for LED streetlights utilizing a combination of solar and wind power systems. Marino, Leccese, and Pizzuti (2017) successfully implemented adaptive streetlight ITS utilizing cameras to dim streetlights in Italy based on predicted and real time traffic volumes.

The feasibility of an LED street light conversion depends largely on the comparison of energy and maintenance cost savings to the upfront cost of the conversion (Gaston, 2013). Other contributing factors include road layout and fixture height and spacing, which must be considered in determining the light output required to match minimum recommended illumination guidelines specified by the Illuminating Engineering Society of North America (IESNA) (Kinzey & Myer, 2009). The U.S. Department of Energy (DOE) supports programs, including the Municipal Solid-State Street Lighting Consortium, to help state and local municipalities make informed decisions throughout the research and developmental stages of a solid-state street lighting project (Ledbetter, 2012). The DOE even supplies an excel-based financial analysis tool that allows users to easily compute “annualized energy and energy-cost savings, maintenance savings, greenhouse gas reductions, net present value and simple payback associated with potential lighting upgrades” (U.S. Department of Energy, 2013).

Pilot testing LED retrofit kits conducted on New York City’s FDR Drive showed energy savings ranging from 26 to 57 percent with the four different LED luminaires tested when compared to the HPS luminaires they replaced (Myer, Hazra & Kinzey, 2011). Similarly, a 55 percent energy savings was found in Portland during a residential area LED streetlight conversion study (Kinzey & Myer, 2009). Kimber et al. (2012) presented nine LED retrofit case studies in various townships spread across Iowa that saved approximately 1.2

million kWh of energy per year combined, which was a 50 percent annual reduction in annual energy consumption.

Arhin and Noel (2010) conducted an economic analysis, which found that approximately \$300,000 would be saved annually by installing LED streetlights in Washington, DC. An opinion survey also revealed an overwhelming majority of the residents surveyed preferred LED streetlights to HPS streetlights and they felt LED streetlights improved visibility (Arhin & Noel 2010). Another research study, presented at the 89th Annual Meeting of the Transportation Research Board (TRB), investigated public perception of different lighting technologies including LED and varying wattage alternatives in Anchorage, Alaska (Gibbons, Edwards, Clanton & Mutmansky, 2010). Gibbons et al. (2010) found public perception of the studied lighting systems showed LEDs are more readily accepted than the existing HPS lighting system despite shorter mean detection distances.

Kinzey, Royer, Hadjian and Kauffman (2013) studied nine unique LED street lighting products in Kansas City, Missouri. They stressed the importance of appropriately matching products to the application, acknowledging variability of applications seen in practice adds to this challenge. It was found that all of the LED products consumed less power than the HPS lights that were replaced, but they also emitted fewer lumens on average (Kinzey et al., 2013). This is similar to what Tuenge (2011) discovered during his assessment of LED technology in ornamental post-top luminaires. It was determined that the energy savings from the LED products examined occurred at the expense of

reduced illumination levels when compared to the existing streetlights (Tuenge, 2011). Vitta et al. (2012) identified a “decrease in efficiency under the dimming conditions and significant electromagnetic interference using conventional current regulating integrated circuits” in their study. To combat and overcome these limiting factors, they recommend waiting on further developments in LED based intelligent street lighting system technology (Vitta et al., 2012). Wordsworth (2010) discussed an intelligent street lighting system in Norway that successfully utilized dimmable LEDs with traffic sensors and a lux meter with no mentioned interference issues. Cities such as San Diego, California and Portland, Oregon have begun LED streetlight conversion projects with integrated cameras and weather sensors to build their “Smart City” infrastructure (PBOT, 2018; Perry, 2018).

Given the current state of LED streetlight research, this study will benefit transportation safety in Rhode Island while simultaneously reducing operating budgets for RIDOT. An interview with RIDOT Chief Civil Engineer John Preiss revealed RIDOT operates and maintains approximately 5,149 streetlights along state-owned roadways (J. Preiss, personal communication, April 3, 2014). The study will also provide a resource for cities and towns in the state to utilize when planning an LED streetlight conversion. It will enable both RIDOT and local municipalities to accurately assess the viability, costs and benefits of an LED conversion with ITS network integration before substantial financial resources are allocated toward a future project. An LED streetlight conversion with ITS network integration could potentially lead to significant



utility and maintenance cost savings in the long term. This work contributes to knowledge in the field by assisting transportation agencies in their decision process of selecting and justifying investment in alternative streetlight technologies.

## **METHODOLOGY**

Streetlights play an important role in the both the safety of Rhode Island roadways and the annual operations budget of RIDOT. Updating the infrastructure to improve safety while reducing operating costs has become a priority of freeway improvement efforts across the United States. With these objectives in mind, this study was proposed and conducted to investigate the possibility of converting existing streetlights along rural Rhode Island freeways to LED technology with the potential for additional cost and energy savings through the integration of an ITS network. This study assesses the current state of streetlight technology utilized in Rhode Island, a proposed LED streetlight conversion, and a proposed LED streetlight conversion with an ITS integration.

### **Existing Streetlight Technology Utilized in Rhode Island**

A detailed analysis of the current state of streetlight technology utilized in Rhode Island was performed. This evaluation included the existing streetlight hardware, the economics behind the existing streetlights, and an overall observation of the current state of streetlights along state-operated roadways.

Research on streetlight hardware currently utilized in Rhode Island was conducted. Information on the different types of streetlights installed along Rhode Island freeways was gathered. A comprehensive list of manufacturers of these streetlights was compiled and details of the various models of

streetlights currently in use were collected. Research into the technology behind the streetlights and how they work was conducted. Issues with the current hardware were also identified.

The three major costs for RIDOT to install, operate, and maintain the existing streetlights were examined. These costs included hardware, energy, and maintenance. The cost per luminaire for streetlighting currently in use was gathered from the Highway Maintenance division of RIDOT. Additionally, the cost of installing the hardware was collected, including equipment, manpower, and time required for installation. The energy consumption of each type of streetlight presently in use was located. The current commercial cost of electricity per kilowatt-hour (kWh) was collected. These figures were combined to determine an annual energy cost associated with operating streetlights in Rhode Island.

The frequency of maintenance activities involving streetlights was gathered. Previously collected information, including the cost per luminaire for streetlights currently in use and the cost of installation, was combined with the maintenance frequency data to determine annual maintenance costs. The Highway Maintenance division of RIDOT was consulted to determine where the streetlights are physically located along each roadway and how many are in operation. During this inquiry, specific locations were selected for analysis to determine the feasibility of an LED streetlight conversion and possible ITS integration.

## **LED Streetlight Conversion**

An analysis of an LED streetlight conversion for Rhode Island was performed. This evaluation included the LED technology to be utilized, the economics of an LED streetlight conversion, and a simulated LED streetlight conversion along state-operated roadways. Research on commercially available LED streetlights, including how they work and any known issues with the technology, was conducted.

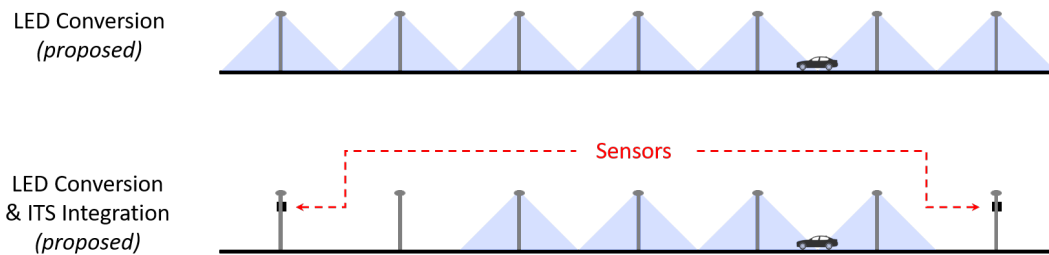
The three major costs for RIDOT to install, operate, and maintain LED streetlights were examined. These costs included hardware, energy, and maintenance. The cost per LED luminaire to replace streetlights currently in use was gathered from the manufacturer. Additionally, the cost of installing the hardware was collected, including equipment, manpower, and time required for installation. The manufacturer provided the energy consumption of each type of LED luminaire. The previously collected commercial cost of electricity was combined with the cost per LED luminaire to determine an annual energy cost associated with operating and maintaining streetlights in Rhode Island. LED luminaire failure rates were also researched to further refine the maintenance cost estimates.

The proposed locations for an LED streetlight conversion were modeled. The number of streetlights at each location combined with the hardware, energy, and maintenance costs created a baseline simulation of an LED conversion. A scalable model including energy savings and conversion

costs was developed to address additional possible scenarios for implementation of LED streetlights.

### **LED Streetlight Conversion with ITS Integration**

An analysis of an LED streetlight conversion with ITS integration in Rhode Island was performed. This evaluation included the LED technology to be utilized, the economics of an LED streetlight conversion, and a simulated LED streetlight conversion along state-operated roadways. Existing ITS Technology was thoroughly researched and information was collected on sensors and controllers utilized in an ITS network. Case studies were found where ITS technology was utilized, and their applications were reviewed. Finally, manufacturers of these sensors and controllers were identified and information on each product commercially available was gathered. Figure 1 reveals the similarities and differences between a standalone LED streetlight conversion and an ITS integrated LED streetlight conversion.



**FIGURE 1 Visualization of streetlight technologies.**

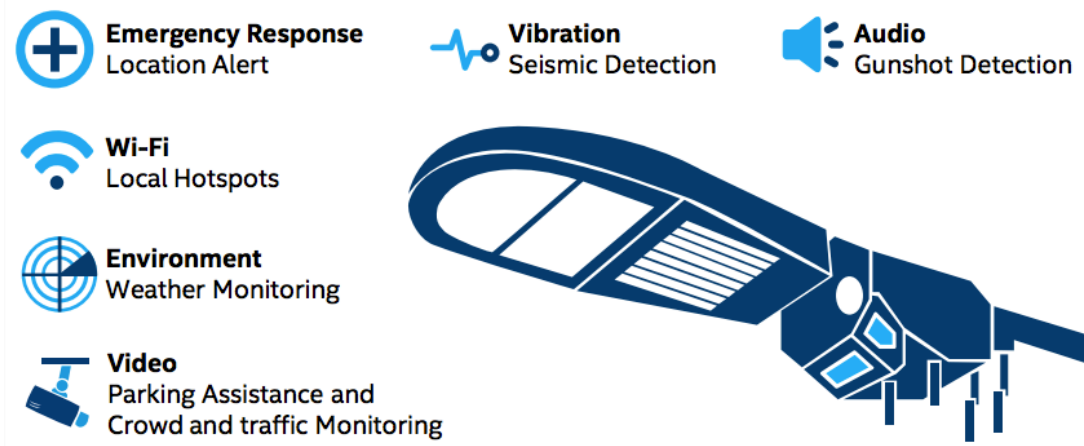
The three major costs for RIDOT to install, operate, and maintain LED streetlights with ITS network integration were examined. These costs included hardware, energy, and maintenance. The cost per for each type of sensor and controller required was gathered from the manufacturer. Additionally, the cost

of installing the hardware was collected, including equipment, manpower, and time required for installation. These estimates combined with the previous hardware cost estimates of an LED conversion to determine the overall hardware cost estimates of the entire system. The manufacturer provided the energy consumption of each type of sensor and controller. The previously collected commercial cost of electricity was combined with the cost per sensor and controller to determine an annual energy cost associated with operating streetlights in Rhode Island. These estimates were then combined with the energy cost estimates of an LED conversion to determine the overall energy cost estimates of the entire system. Traffic frequency data was then collected at each of the proposed locations. This data was then used to refine the annual energy cost estimates of the LED conversion with ITS integration. Since the ITS network allows the streetlights to be turned off when no vehicles are present, the energy cost estimates were adjusted according to the traffic frequency data.

The previously found maintenance cost estimates of an LED conversion were updated to reflect the additional maintenance associated with the ITS integration. These estimates account for the additional hardware and software required to maintain the entire system. Expected luminaire life was also adjusted according to the traffic frequency data gathered during the previous energy cost estimates. The proposed locations for an LED streetlight conversion were then remodeled to include ITS integration.

## **FINDINGS**

The RIDOT Highway Design Manual specifies all lighting mounted over expressways and freeways shall be 400-watt high-pressure sodium (HPS) cutoff-style cobra head luminaires mounted at 40 feet (RIDOT, 2008). Due to this requirement, existing HPS luminaires of 400-watt and 400-watt equivalent LED luminaires were evaluated. Existing 400-watt HPS luminaires along state-maintained highways were overwhelmingly found to be the discontinued GE M-400 Induction Roadway Luminaire with Cutoff Optics, with an actual power consumption of 460 Watts (TEN Connected Solutions, 2018). A 400-watt equivalent LED luminaire offered by the same manufacturer was evaluated against the incumbent HPS luminaire. The GE Evolve™ LED Roadway Lighting ERL1 was selected, with an actual power consumption of only 84 Watts (TEN Connected Solutions, 2018). The power consumption of an ITS unit varies by sensor and controller configuration. The unit evaluated contains two cameras, weather sensors, gateway controller, and modem with an estimated power consumption of 25 Watts under normal operating conditions (General Electric, 2015). The Current by GE CityIQ Solution was selected as the ITS unit due to its compatibility with the selected LED luminaire and the features it provided. Figure 2 describes all available features of the ITS hardware (Intel, 2017).



**FIGURE 2 Available features of the selected ITS (Intel, 2017).**

The annual power consumption by a single luminaire was calculated assuming 4,302.86 hours of darkness (U.S. Naval Observatory, 2015) annually in Rhode Island. The annual power consumption by a single ITS unit was calculated assuming the ITS remains operational 24 hours a day for 365 days each year. Annual energy cost for all hardware was calculated assuming a cost of 17.40 cents per kWh (U.S. Energy Information Administration, 2019). The hardware cost was found to be \$128.00 per HPS luminaire (G. Cabral, personal communication, May 20, 2014) and \$440.00 per LED luminaire (TEN Connected Solutions, 2018). The turnkey price per ITS unit is estimated at \$5,060.00 and includes all hardware, installation, communication, software, and programming costs associated with data collection and analysis (PBOT, 2018). This ITS pricing was found to be contingent upon the purchase of at least 200 units.

Each technology was evaluated on a per mile basis to account for variability at each site streetlights are present and assist with model scalability. Most Rhode Island freeways contain one mile of streetlighting at controlled



access points, primarily spanning entrance and exit ramps located at each marked exit. Additional lighting is also provided on isolated stretches of highway around corners or other dangerous areas. It is assumed a standard 220 foot spacing between streetlight poles and streetlights are required for each direction of travel. Therefore, it was found that 48 luminaires are required for each mile of illuminated highway. Similarly, four ITS units are required: one for each direction of travel and each end of a controlled access point. RIDOT labor costs for all luminaire installations are approximately \$250 per hour with a four-person crew at an installation rate of four luminaires per hour (G. Cabral, personal communication, May 20, 2014). Both the HPS and LED luminaires that were evaluated were built by the same manufacturer and installed in a similar manner.

Energy, hardware, and installation costs evaluated are presented in Table 1. These individual costs were then summed to determine the total cost per mile for each technology. The expected hardware lifetime for HPS luminaires is 20,000 hours (GE, 2014). All other hardware evaluated has an expected lifetime of 100,000 hours (Current by GE, 2018). As a result of the significant energy savings that LED luminaries were found to have over HPS luminaires, it was found that 77,658.14 kWh of power valued at \$13,512.52 could be recovered year over year per mile of converted streetlights. The ITS integrated LEDs had a slightly smaller energy savings valued at \$13,360.09 due to the ITS operating 24 hours continuously each day. Additionally, a relamp cost avoidance of \$9,144.00 can be claimed due to the limited lifetime

of HPS luminaires. The cost avoidance accounts for installation and hardware costs associated with replacing the HPS luminaires every five years or 20,000 hours. Annual maintenance cost per mile for all luminaires was calculated assuming a 2% failure rate. The failure rate accounts for manufacturing defects, installation defects, and vehicle collision damages (G. Cabral, personal communication, May 20, 2014). Annual maintenance cost per mile for ITS units considers annual cleaning of the sensors with RIDOT’s four-person processing four ITS units per hour. Manufacturing and installation defects are covered under warranty, while it is assumed vehicle collision damages to ITS units will be recovered from driver(s) determined to be at fault.

Metric	HPS	LED	LED + ITS	
	Luminaire	Luminaire	Luminaire	ITS
Hardware Lifetime (hr)	20,000	100,000	100,000	100,000
Power Consumption (W)	460	84	84	25
Annual Power Consumption (kWh)	1979	361	361	219
Annual Energy Cost (\$)	\$ 344.40	\$ 62.89	\$ 62.89	\$ 38.11
Hardware Cost (\$)	\$ 128.00	\$ 440.00	\$ 440.00	\$ 5,060.00
Hardware Quantity/Mile (units)	48	48	48	4
Hardware Cost/Mile (\$)	\$ 6,144.00	\$ 21,120.00	\$ 21,120.00	\$ 20,240.00
Labor Cost (\$/hr)	\$ 250.00	\$ 250.00	\$ 250.00	Included
Installation Time (hr/unit)	0.25	0.25	0.25	
Installation Cost/Mile (\$)	\$ 3,000.00	\$ 3,000.00	\$ 3,000.00	
Total Hardware Cost/Mile (\$)	\$ 9,144.00	\$ 24,120.00	\$ 24,120.00	\$ 20,240.00
Annual Energy Cost/Mile (\$)	\$ 16,531.27	\$ 3,018.75	\$ 3,018.75	\$ 152.42
Annual Maintenance Cost/Mile (\$)	\$ 182.88	\$ 482.40	\$ 482.40	\$ 250.00
YoY Energy Savings/Mile (\$)	N/A	\$ 13,512.52	\$ 13,360.09	N/A
5-Year Relamp Avoidance/Mile (\$)		\$ 9,144.00	\$ 9,144.00	

**TABLE 1 Performance and financials for each streetlight technology.**

A cash flow analysis was performed to evaluate costs calculated in Table 1. Twenty-year cash flows for each case are presented in Table 2. The initial cashflow incurred during Year 0 represents the total cost per mile for each installation including hardware cost and installation labor. All installations

incurred an annual maintenance cost for Year 1 through Year 20. HPS streetlighting incurred an additional cost associated with HPS luminaire replacement in Year 5, Year 10, Year 15, and Year 20 due to the 20,000-hour lifespan of the luminaires. Both stand-alone and ITS integrated LED streetlighting incurred replacement hardware and labor costs in Year 20 due to the 100,000-hour hardware lifespan. The LED conversion with ITS integration incurred an additional ITS hardware replacement cost in Year 10 due to 100,000-hour hardware lifespan with the ITS running constantly around the clock. All cashflows where significant hardware expenditure is required are shown in bold. It is important to note that the effect of inflation on hardware costs has not been included.

Present values were calculated for each cash flow with a prescribed discount rate of 7%, which was selected based on publicly available previous projects from the agency, and also served as the minimum attractive rate of return (MARR) in further analyses (RIDOT, 2016). Equation 1 demonstrates the present value (PV) formula utilized in these calculations (Newnan, et al., 2017), where  $F_n$  is the future cash flow in year  $n$ , and  $i$  is the discount (interest) rate.

$$PV = F_n(1 + i)^{-n} \quad (1)$$

Year	HPS		LED		LED + ITS	
	Cash Flow	Present Value	Cash Flow	Present Value	Cash Flow	Present Value
0	<b>\$ (9,144.00)</b>	\$ (9,144.00)	<b>\$ (24,120.00)</b>	\$ (24,120.00)	<b>\$ (44,360.00)</b>	\$ (44,360.00)
1	\$ (16,714.15)	\$ (15,620.70)	\$ (3,501.15)	\$ (3,272.11)	\$ (3,903.58)	\$ (3,648.20)
2	\$ (16,714.15)	\$ (14,598.79)	\$ (3,501.15)	\$ (3,058.04)	\$ (3,903.58)	\$ (3,409.54)
3	\$ (16,714.15)	\$ (13,643.72)	\$ (3,501.15)	\$ (2,857.98)	\$ (3,903.58)	\$ (3,186.48)
4	\$ (16,714.15)	\$ (12,751.14)	\$ (3,501.15)	\$ (2,671.01)	\$ (3,903.58)	\$ (2,978.02)
5	<b>\$ (25,858.15)</b>	\$ (18,436.50)	\$ (3,501.15)	\$ (2,496.27)	\$ (3,903.58)	\$ (2,783.20)
6	\$ (16,714.15)	\$ (11,137.34)	\$ (3,501.15)	\$ (2,332.97)	\$ (3,903.58)	\$ (2,601.12)
7	\$ (16,714.15)	\$ (10,408.73)	\$ (3,501.15)	\$ (2,180.34)	\$ (3,903.58)	\$ (2,430.95)
8	\$ (16,714.15)	\$ (9,727.79)	\$ (3,501.15)	\$ (2,037.70)	\$ (3,903.58)	\$ (2,271.92)
9	\$ (16,714.15)	\$ (9,091.39)	\$ (3,501.15)	\$ (1,904.40)	\$ (3,903.58)	\$ (2,123.29)
10	<b>\$ (25,858.15)</b>	\$ (13,144.97)	\$ (3,501.15)	\$ (1,779.81)	<b>\$ (24,143.58)</b>	\$ (12,273.37)
11	\$ (16,714.15)	\$ (7,940.77)	\$ (3,501.15)	\$ (1,663.37)	\$ (3,903.58)	\$ (1,854.56)
12	\$ (16,714.15)	\$ (7,421.28)	\$ (3,501.15)	\$ (1,554.55)	\$ (3,903.58)	\$ (1,733.24)
13	\$ (16,714.15)	\$ (6,935.78)	\$ (3,501.15)	\$ (1,452.85)	\$ (3,903.58)	\$ (1,619.85)
14	\$ (16,714.15)	\$ (6,482.04)	\$ (3,501.15)	\$ (1,357.81)	\$ (3,903.58)	\$ (1,513.87)
15	<b>\$ (25,858.15)</b>	\$ (9,372.18)	\$ (3,501.15)	\$ (1,268.98)	\$ (3,903.58)	\$ (1,414.84)
16	\$ (16,714.15)	\$ (5,661.66)	\$ (3,501.15)	\$ (1,185.96)	\$ (3,903.58)	\$ (1,322.28)
17	\$ (16,714.15)	\$ (5,291.27)	\$ (3,501.15)	\$ (1,108.38)	\$ (3,903.58)	\$ (1,235.77)
18	\$ (16,714.15)	\$ (4,945.11)	\$ (3,501.15)	\$ (1,035.87)	\$ (3,903.58)	\$ (1,154.93)
19	\$ (16,714.15)	\$ (4,621.60)	\$ (3,501.15)	\$ (968.10)	\$ (3,903.58)	\$ (1,079.37)
20	<b>\$ (25,858.15)</b>	\$ (6,682.24)	<b>\$ (27,621.15)</b>	\$ (7,137.83)	<b>\$ (48,263.58)</b>	\$ (12,472.23)
NPV = \$ (203,059.02)		NPV = \$ (67,444.34)		NPV = \$ (107,467.01)		

**TABLE 2 Twenty-year cash flows for each streetlight technology.**

An engineering economic analysis was conducted to assess the economic feasibility of each streetlight technology. Equation 2 demonstrates the net present value (NPV) formula used to find the NPV for each streetlight technology examined (Newnan, et al., 2017).

$$NPV = \sum_{n=0}^N F_n(1+i)^{-n} \quad (2)$$

The NPV for a standalone LED conversion was found to be the most desirable at \$(67,444.34) followed by the ITS integrated LED conversion NPV at \$(107,467.01) and the incumbent HPS streetlight NPV at \$(203,059.02), as seen in Table 2. Table 3 illustrates results of two incremental analysis comparing HPS to LED and HPS to LED with ITS integration. Equation 3 demonstrates the incremental internal rate of return ( $\Delta$ IRR) formula used to complete these incremental analyses (Newnan, et al., 2017).

$$\Delta IRR = \Delta(B - A) \quad (3)$$

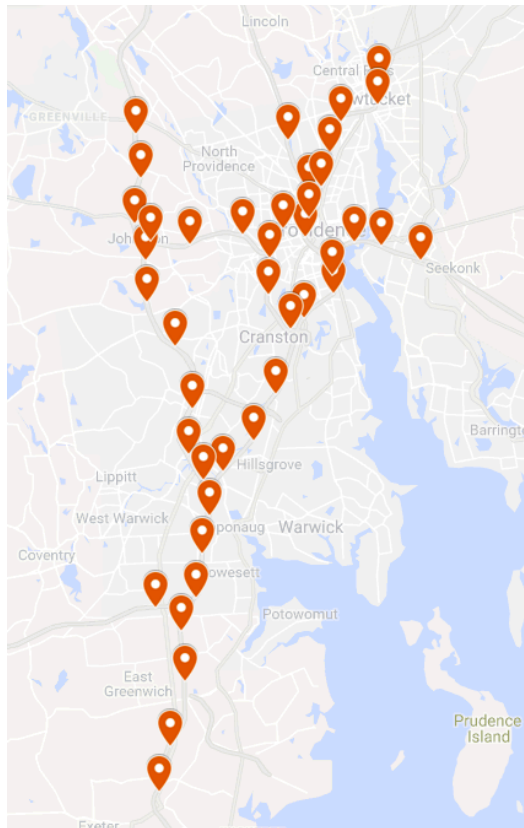
It was found that the  $\Delta IRR$  for the HPS – LED incremental analysis was 91% and the  $\Delta IRR$  for the HPS – LED with ITS integration incremental analysis was 38%. Both analyses yielded  $\Delta IRR$ s greater than the MARR of 7%, therefore standalone LED and ITS integrated conversions are better alternatives to HPS streetlights. Without being able to turn off the streetlights, the ITS integrated conversion will always be dominated by the standalone LED conversion.

Year	HPS	LED	Incremental Analysis	HPS	LED + ITS	Incremental Analysis
0	\$ (9,144.00)	\$ (24,120.00)	\$ (14,976.00)	\$ (9,144.00)	\$ (44,360.00)	\$ (35,216.00)
1	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
2	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
3	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
4	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
5	\$ (25,858.15)	\$ (3,501.15)	\$ 22,357.00	\$ (25,858.15)	\$ (3,903.58)	\$ 21,954.57
6	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
7	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
8	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
9	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
10	\$ (25,858.15)	\$ (3,501.15)	\$ 22,357.00	\$ (25,858.15)	\$ (24,143.58)	\$ 1,714.57
11	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
12	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
13	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
14	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
15	\$ (25,858.15)	\$ (3,501.15)	\$ 22,357.00	\$ (25,858.15)	\$ (3,903.58)	\$ 21,954.57
16	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
17	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
18	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
19	\$ (16,714.15)	\$ (3,501.15)	\$ 13,213.00	\$ (16,714.15)	\$ (3,903.58)	\$ 12,810.57
20	\$ (25,858.15)	\$ (27,621.15)	\$ (1,763.00)	\$ (25,858.15)	\$ (48,263.58)	\$ (22,405.43)
			$\Delta IRR = 91\%$			$\Delta IRR = 38\%$

**TABLE 3 Incremental analyses comparing streetlight technologies.**

RIDOT was able to provide substantial traffic data for evaluating the potential energy saving impact of an ITS integrated LED streetlight conversion that only illuminates when traffic is present. Traffic data along seven state-maintained highways was reviewed, including I-195, I-295, I-95, SR-10, SR-146, SR-4, and SR-6. The data was collected at 42 stations using 58 unique

sensors, showing traffic volumes at five-minute intervals over a 30-day period in June 2015. The sensors utilized weigh-in-motion and other traffic detection technology, collecting 81,178 lines of data each day (D. DiBiasio, personal communication, October 8, 2015). The location of these sensors across Rhode Island can be seen in Figure 3.



**FIGURE 3 Locations of traffic volume analyzed.**

Preliminary analysis of the data revealed traffic flow was present throughout all hours of the night in most locations, so the number of locations was reduced to the six areas with the lowest average traffic volumes as described in Table 4. Despite the focus on locations with less traffic, it was found that breaks in traffic occurred less than 5% of the time across all locations observed. The minimum traffic volume over a five-minute interval

was found to be along US-6, where at least one vehicle traveled through the location in each of the five-minute intervals from the dataset. This includes the assumption that a car travelling in the northbound lane of a highway would prevent turning off the streetlights in both the north and southbound directions, to prevent drivers from being distracted by streetlights suddenly turning on or off. Given this information, it was quickly determined that an ITS integration would provide minimal energy savings at these observed Rhode Island locations and system costs would not be recovered. It was found while researching energy cost data that the minimum required time the ITS system would need to turn the streetlights off in order to recover the per mile energy costs was 217.87 hours annually, or an average of 35.8 minutes per day. This threshold to offset the ITS system energy consumption is dependent on previously presented hardware and energy costs.

Road	Section	Traffic Volume	
		Average	Minimum
I-95	0.9 Mile South of Route 37	235	15
I-295	0.2 Mile South of US-6A	331	7
RI-4	0.6 Mile North of Route 102	223	3
RI-146	0.5 Mile South of Route 15	246	10
US-6	0.5 Mile West of Route 5	79	1
RI-10	0.6 Mile North of Broadway	147	10

**TABLE 4 Traffic data analysis at selected locations.**

## **CONCLUSION**

This study identified the most effective streetlight technology to be utilized in Rhode Island going forward. It was found that a standalone LED streetlight conversion would be the most fiscally responsible decision when compared to existing HPS streetlights or an LED streetlight conversion with ITS integration. However, this study also demonstrated that an ITS integrated LED streetlight conversion is economically feasible when compared to existing HPS streetlight technology.

The results of this study revealed significant energy savings and showed that favorable NPV and  $\Delta$ IRR are possible for LED streetlight conversion projects. A detailed method for modeling LED streetlighting cost impact per mile was constructed. The model is scalable and easily modified to account for rising energy and labor costs, as well as future technological innovations in hardware. The next stage of this research will involve conducting field testing and deployment of LED. It is recommended to pilot an LED conversion of the hardware evaluated in this study. If the annual capital budget allows for additional funding or new energy savings project related grants are available, it is recommended to move forward with an ITS integrated LED streetlight project.



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## Appendices

### RIDOT TRAFFIC DATA

The following is a sample of the dataset provided by RIDOT for evaluation throughout this project (D. DiBiasio, personal communication, October 8, 2015). Each data point in the Time column represents the beginning of a five-minute interval (e.g., 0:00 represents 12:00:00 AM to 12:04:59 AM). The full dataset is available upon request from the author of this paper.

Date	Time	Station	Route	Lane position	Direction	Volume	Average Speed	Occupancy
6/1/2015	0:00	8103	I-95	RIGHT	N	8	64	0.4
6/1/2015	0:00	8103	I-95	CENTER	N	27	68	1.1
6/1/2015	0:00	8103	I-95	LEFT	N	11	63	0.3
6/1/2015	0:00	8103	I-95	RIGHT CENTER	S	15	62	1
6/1/2015	0:00	8103	I-95	LEFT CENTER	S	16	64	1.2
6/1/2015	0:00	8103	I-95	LEFT	S	5	64	0.3
6/1/2015	0:00	8103	I-95	RIGHT	S	1	43	0
6/1/2015	0:00	8107	I-95	RIGHT	N	10	59	0.6
6/1/2015	0:00	8107	I-95	RIGHT CENTER	N	11	61	0.6
6/1/2015	0:00	8107	I-95	LEFT CENTER	N	26	70	1.4
6/1/2015	0:00	8107	I-95	LEFT	N	18	55	0.4
6/1/2015	0:00	8107	I-95	RIGHT	S	9	47	0.7
6/1/2015	0:00	8107	I-95	RIGHT CENTER	S	13	44	1.1
6/1/2015	0:00	8107	I-95	LEFT CENTER	S	18	58	1.6
6/1/2015	0:00	8107	I-95	LEFT	S	8	56	0.6
6/1/2015	0:00	8108	I-95	RIGHT	N	11	63	1
6/1/2015	0:00	8108	I-95	RIGHT CENTER	N	19	58	1.3
6/1/2015	0:00	8108	I-95	LEFT CENTER	N	20	55	1.4
6/1/2015	0:00	8108	I-95	LEFT	N	10	55	0.5
6/1/2015	0:00	8108	I-95	RIGHT	S	2	54	0.2
6/1/2015	0:00	8108	I-95	RIGHT CENTER	S	18	56	1.2
6/1/2015	0:00	8108	I-95	LEFT CENTER	S	20	55	1.3
6/1/2015	0:00	8108	I-95	LEFT	S	3	55	0.2
6/1/2015	0:00	8109	I-95	RIGHT	S	9	57	0.9
6/1/2015	0:00	8109	I-95	RIGHT CENTER	S	9	53	0.7
6/1/2015	0:00	8109	I-95	LEFT CENTER	S	17	57	1
6/1/2015	0:00	8109	I-95	LEFT	S	7	53	0.4
6/1/2015	0:00	8109	I-95	RIGHT	N	14	53	1.1
6/1/2015	0:00	8109	I-95	RIGHT CENTER	N	27	54	2.1
6/1/2015	0:00	8109	I-95	LEFT CENTER	N	19	51	1.1
6/1/2015	0:00	8109	I-95	LEFT	N	12	53	0.6

## US NAVAL OBSERVATORY DURATION OF DARKNESS DATA

The data below shows the daily duration of darkness in 2018 for Providence, Rhode Island (U.S. Naval Observatory, 2015).

Providence, Rhode Island Duration of Darkness for 2018												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
1	14:48	13:57	12:45	11:17	9:58	8:59	8:50	9:36	10:52	12:15	13:38	14:38
2	14:47	13:55	12:42	11:15	9:56	8:58	8:51	9:38	10:55	12:18	13:40	14:39
3	14:46	13:52	12:39	11:12	9:53	8:57	8:52	9:40	10:58	12:21	13:43	14:40
4	14:45	13:50	12:36	11:09	9:51	8:56	8:52	9:42	11:01	12:24	13:45	14:42
5	14:44	13:48	12:33	11:06	9:48	8:55	8:53	9:45	11:03	12:26	13:48	14:43
6	14:43	13:45	12:31	11:03	9:46	8:54	8:54	9:47	11:06	12:29	13:50	14:44
7	14:42	13:43	12:28	11:01	9:44	8:53	8:55	9:49	11:09	12:32	13:52	14:45
8	14:41	13:40	12:25	10:58	9:42	8:52	8:56	9:51	11:11	12:35	13:55	14:46
9	14:39	13:38	12:22	10:55	9:39	8:51	8:57	9:54	11:14	12:37	13:57	14:47
10	14:38	13:35	12:19	10:52	9:37	8:50	8:58	9:56	11:17	12:40	13:59	14:47
11	14:37	13:33	12:17	10:50	9:35	8:50	9:00	9:59	11:20	12:43	14:02	14:48
12	14:35	13:30	12:14	10:47	9:33	8:49	9:01	10:01	11:22	12:46	14:04	14:49
13	14:34	13:28	12:11	10:44	9:31	8:49	9:02	10:03	11:25	12:48	14:06	14:49
14	14:32	13:25	12:08	10:42	9:29	8:48	9:04	10:06	11:28	12:51	14:08	14:50
15	14:31	13:22	12:05	10:39	9:27	8:48	9:05	10:08	11:31	12:54	14:10	14:50
16	14:29	13:20	12:02	10:36	9:25	8:47	9:07	10:11	11:34	12:56	14:12	14:51
17	14:27	13:17	12:00	10:34	9:23	8:47	9:08	10:13	11:36	12:59	14:14	14:51
18	14:26	13:14	11:57	10:31	9:21	8:47	9:10	10:16	11:39	13:02	14:16	14:51
19	14:24	13:12	11:54	10:28	9:19	8:47	9:11	10:18	11:42	13:04	14:18	14:52
20	14:22	13:09	11:51	10:26	9:17	8:47	9:13	10:21	11:45	13:07	14:20	14:52
21	14:20	13:06	11:48	10:23	9:16	8:47	9:15	10:23	11:47	13:10	14:22	14:52
22	14:18	13:04	11:46	10:21	9:14	8:47	9:16	10:26	11:50	13:12	14:24	14:52
23	14:16	13:01	11:43	10:18	9:12	8:47	9:18	10:29	11:53	13:15	14:26	14:52
24	14:14	12:58	11:40	10:15	9:10	8:47	9:20	10:31	11:56	13:18	14:27	14:52
25	14:12	12:56	11:37	10:13	9:09	8:47	9:22	10:34	11:59	13:20	14:29	14:51
26	14:10	12:53	11:34	10:10	9:07	8:48	9:24	10:36	12:01	13:23	14:31	14:51
27	14:08	12:50	11:31	10:08	9:06	8:48	9:26	10:39	12:04	13:25	14:32	14:51
28	14:06	12:47	11:29	10:05	9:04	8:48	9:28	10:42	12:07	13:28	14:34	14:50
29	14:04		11:26	10:03	9:03	8:49	9:30	10:44	12:10	13:30	14:35	14:50
30	14:02		11:23	10:00	9:02	8:50	9:32	10:47	12:12	13:33	14:37	14:49
31	13:59		11:20		9:00		9:34	10:50		13:36		14:48