View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Elsevier - Publisher Connector

JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2015; 2 (3): 158–166

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jtte

Original Research Paper

Cost effectiveness of new roadway lighting systems

Yi Jiang [a,b,*], Shuo Li [c], Bowen Guan [d], Guangyuan Zhao [a]

[a] *Department of Building Construction Management, Purdue University, West Lafayette, IN 47907, USA*
[b] *School of Civil Engineering and Architecture, Wuhan Polytechnic University, Wuhan 430023, China*
[c] *Office of Research and Development, Indiana Department of Transportation, West Lafayette, IN 47906, USA*
[d] *School of Materials Science and Engineering, Chang'an University, Xi'an 710064, China*

ARTICLE INFO

Article history:
Available online 30 March 2015

Keywords:
Roadway lighting
Life cycle cost
Luminaire
Power consumption

ABSTRACT

Appropriate and adequate lighting at select locations on roadways is essential for roadway safety. As the lighting technologies advance, many types of new lighting devices have been developed for roadway lightings. The most promising new lighting technologies for roadway lighting include light emitting diode, induction, plasma, and metal halide lighting systems. A study was conducted to compare the new systems with the conventional high pressure sodium systems that are currently used on the Indiana roadway systems. In this study, the engineering issues, were analyzed such as illuminance, color rendering, power usage, cost effectiveness, and approval procedures for new roadway lighting systems. This paper, however, presents only the study findings related to cost effectiveness of the evaluated roadway lighting systems. Illustrated in this paper are the main features of the roadway lighting systems under evaluations, installations of the new lighting systems, measurements of power consumptions, and life cycle cost analyses of the lighting systems. Through this study, experience and knowledge have been obtained on the installations, power measurements, and cost effectiveness of the new types of the roadway lighting devices. The actual power values of various luminaires were obtained by measuring the electric current with a multi-meter. It was found that the differences between the rated and measured power values could be significant. The results of the life cycle cost analysis indicate that the lower life cycle costs of some of the alternative lighting devices are attributed to their relatively lower electricity usages and longer lamp/emitter replacement cycles.

© 2015 Periodical Offices of Chang'an University. Production and hosting by Elsevier B.V. on behalf of Owner. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

* *Corresponding author*. Department of Building Construction Management, Purdue University, West Lafayette, IN 47907, USA. Tel.: +1 765 494 5602.

E-mail addresses: jiang2@purdue.edu (Y. Jiang), sli@indot.in.gov (S. Li), guanbowen2001@163.com (B. Guan), zhao179@purdue.edu (G. Zhao).

Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2015.03.004

2095-7564/© 2015 Periodical Offices of Chang'an University. Production and hosting by Elsevier B.V. on behalf of Owner. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Appropriate and adequate lighting at select locations on roadways is essential for roadway safety. As the lighting technologies advance, many types of new lighting devices have been developed for roadway lightings. The most promising new lighting technologies for roadway lighting include light emitting diode (LED), induction, plasma, and metal halide (MH) lighting systems. Currently, the high pressure sodium (HPS) lighting systems are the only type of light source adopted by the Indiana Department of Transportation (INDOT) for its roadway lighting. The usages of the new lighting systems in Indiana are only limited to the lights for urban streets, residential streets, walkways, and other non highway applications. It was therefore desired for INDOT to determine if the new lighting systems could be utilized on Indiana's roadway systems. Therefore, a study was conducted to compare the new systems with the conventional HPS systems that are currently used on the Indiana roadway systems. The objectives of this study were to evaluate if the new lighting systems meet the required light output and if they are cost effective.

The study was performed through field measurements and evaluations on the new lighting systems in comparison with the conventional HPS lighting devices. In this study, the engineering issues were analyzed such as illuminance, color rendering, power usage, cost effectiveness, and approval procedures for new roadway lighting systems. This paper, however, presents only the study findings related to cost effectiveness of the evaluated roadway lighting systems. Other issues addressed in the study can be found in the technical report (Li et al., 2013). Illustrated in this paper are the main features of the roadway lighting systems under evaluations, installations of the new lighting systems, measurements of power consumptions, and life cycle cost analyses of the lighting systems. The new roadway lighting systems evaluated in this study include several types of LED, induction, plasma, and MH lighting systems.

2. Overview of roadway lighting systems

There are three types of lighting sources that have been widely used for indoor and outdoor lighting applications: incandescent, fluorescent, and high intensity discharge (HID) lights. For roadway facilities, lighting is commonly provided at interchanges, rest areas, weight stations, tunnels, parking lots, and signage boards. Traditionally, HID lighting systems have been widely used for roadway lighting. The HID light source family consists mainly of four members, including mercury vapor (MV), low-pressure sodium (LPS), HPS, and MH lights. Among these HID lighting systems, HPS lights are most commonly used for conventional and high mast roadway lighting due to their excellent luminous efficiency, power usage, and long life (INDOT, 2012).

An HPS lamp commonly consists of four basic components, including a sealed, translucent, ceramic arc tube, main electrodes, an outer bulb, and a base (Halonen et al., 2010; USDOE, 2010). An HPS lamp requires an inductive ballast to regulate the arc current flow and deliver the proper voltage to the arc. An HPS lamp is powered by an alternating current (AC) source. When the HPS lamp is turned on, the voltage is applied across the main electrodes and the xenon gas is easily ionized. The ionized xenon gas strikes the arc and generates heat. The heat then vaporizes the mercury and sodium. The resultant mercury vapor raises the gas pressure and operating voltage to a point so that the sodium vapor produces golden light. Similar to other HID lamps, a standard MH lamp consists of four basic components, including a quartz arc tube, main electrodes, outer bulb, and base. The operation of MH is similar to HPS lamps in that they produce light by way of an arc tube contained within a glass bulb. Inductive ballast is also used to regulate the current and the voltage to the lamp.

LED lighting is a type of solid-state lighting. It is a semiconducting device that produces light when an electrical current passes through it. Multiple LEDs can be combined into LED arrays. An LED lamp is defined as a lighting device with an integrated driver and a standardized base that is designed to connect to the branch circuit via a standardized lamp holder/socket (IESNA, 2008). A basic LED lamp consists of three groups of components, including optical, electrical, and mechanical and thermal components (Halonen et al., 2010; USDOE, 2008). When an LED is energized, the electrical current flows from one end of the diode to the other. Charge carriers are known as electrons and holes flow into the diode in the direction of the current flow. When an electron meets a hole, the electron falls into a lower energy state and releases a particle known as a photon, where is the visible light comes from. A heat sink is needed to draw the heat away from the LED array to cool them and prevent premature failure. The heat sink is typically integrated right into the outer housing of the fixture to maximize heat dissipation.

Plasma, formally known as lighting emitting plasma (LEP), is an ionized gas with equal number of positive and negative charges. Radio frequency waves are used to excite plasma within the bulb. A plasma lamp typically consists of four basic components, lightron, waveguide, cavity resonator and bulb assembly (LUXIM, 2014). When a plasma lamp is powered, radio frequency waves or microwaves are produced. Radio frequency waves are guided toward the bulb to energize the plasma gas inside the bulb. The gas (usually a noble gas) becomes ionized causing some electrons excited and collide with the gas and metal particles inside brought some electrons to a higher energy state. When the electrons return to their original state they emit a photon that gives off visible light.

An induction lamp consists of three major components, ballast, power coupler, and lamp bulb (ETC, 2014; LL, 2013). The ballast contains an oscillator and the preconditioning and filtering circuits. The power coupler contains an antenna that is made of a primary induction coil and ferrite core. It transfers energy from the ballast to the discharge inside the lamp bulb. The lamp bulb is a sealed glass bulb containing a low pressure inert gas with a small amount of mercury vapor. When an induction lamp is powered, the ballast generates a current. The current is sent through the electromagnet and a strong magnetic field is generated. The energy is transferred from the magnet to the mercury in the tube via the antenna and excites the mercury atoms. The mercury vapor emits UV light that is changed into visible light by the phosphor coating on the inside of the glass.

Many research projects have been conducted to evaluate the feasibilities of the new highway lighting technologies. Fotios and Cheal (2007) studied the efficiencies of different lighting sources through laboratory tests of visual performance and brightness perception. The study results indicated that "white" light sources (metal halide, fluorescent) could provide equivalent visibility under lower light levels than the yellowish illumination from high pressure sodium lamps.

Akashi et al. (2007) conducted a roadway lighting field experiment to test drivers' ability to detect and respond to moving targets while driving. They found that driver response times to roadside moving objects were essentially equivalent under similar mesopic vision. They also found that drivers' response times under MH illumination were shorter than that under HPS even with the same photopic light levels. The study by Rea et al. (2009) indicated that "white" light sources such as MH resulted in increased perceptions of brightness compared to the "yellower" illumination from HPS.

Beckwith et al. (2011) found that the LED systems with lower wattages than HPS system produced lower light levels. Except for the very lowest wattages, LED systems could achieve the recommended light levels of the Illuminating Engineering Society (IES).

Bullough (2012) examined the performances of several types of highway lighting luminaires and developed a guide for roadway lighting replacements to maintain visibility and safety with reduced energy use. Bullough and Radetsky (2013) evaluated some of the new highway lighting devices and concluded that LED roadway lighting was a feasible choice and could often lead to reductions of energy use and lower life-cycle costs in the long term.

Efforts were made by Srinivas and Narayanan (2013) to determine the most suitable and economic option for construction, design and maintenance of roadway lighting in North Carolina. The researchers indicated that appropriate LED luminaires could be used to replace HPS luminaires to achieve energy savings and reduce costs.

3. Luminaire installation

The test site for the new lighting evaluations was located at the interchange of I-74 and US-231, a partial cloverleaf interchange in Crawfordsville, Indiana. A total of 10 types of luminaires, including three HPS luminaires, four LED luminaires, one plasma luminaire, one induction luminaire, and one MH luminaire, were selected and installed for field evaluation and monitoring. The three HPS luminaires included 250 W and 400 W cobra head luminaires for roadside lighting and 1000 W cobra head luminaires for high mast lighting typically utilized by INDOT. The four LED luminaires comprised GE ERS4 258 W luminaires (GE, 2011), Philips RVM 270 W LED luminaires (Phillips, 2011) and Horner 200 W LED luminaires for roadside lighting (HETG, 2013), and Global Tech 392 W LED luminaires for high mast lighting (GTL, 2014). The Eco-Luminator 200 W induction luminaires (Eco-Luminator, 2013), the Stray Light 295 W plasma luminaires (SLOT, 2013), and GE 320 MH luminaires (Grainger, 2013) were installed in the test site for roadside lighting. Fig. 1 shows the photos of the existing HPS luminaires and the new types of luminaires tested in this study.

The selected luminaires were installed on the existing lighting poles at the test site. The field luminaire installations required a minimum of four technicians, one aerial/bucket truck, two attenuator trucks, and traffic cones. Traffic control was an important part of the luminaire installations. The Eco-Luminator induction and Philips RVM LED fixtures were installed on February 8, 2012. It took approximately 7.5 h to install a total of three induction fixtures and three LED fixtures. Three Tesla II plasma and three GE LED ERS4 fixtures were installed on February 9, 2012. It also took the technicians 7.5 h. The Horner LED and high mast LED fixtures were installed on May 16, 2012. It took 2 h to install three Horner LED fixtures and 4 h to install one set of the high mast LED fixture. Two hours were spent to install three MH fixtures on September 6, 2012.

It was the first time for the technicians to install these new types of lighting systems. It is believed that the installation time will be reduced in the future as the technicians get familiar with the installation procedures. The experiences and issues in installing the luminaires were summarized by the technicians as follows:

- Phillips RVM LED: Basically every aspect was user friendly. The fixtures were lighter and easier to hold and level.
- GE ERS4 LED: The fixtures were a little heavier and a little difficult to level. They were a solid unit and the internal access was user friendly.
- Stray Light Telsa II plasma: The fixtures were easy to install and level. The electrical connections were very user friendly and easy to access.
- Eco-Luminator EcoCoBra Induction: These fixtures were the most time consuming and difficult to install. They were the heaviest of the four. The terminal block was more difficult to access and had a small screw termination.
- Other fixtures: No issues were identified in installation.

4. Power measuring

Electrical power is defined as the rate at which electrical energy is supplied to a circuit or consumed by a load, or simply the rate of doing work. For lighting applications, the electrical power represents the rate at which energy is converted from the electrical energy into light, a form of radiant energy. Electrical power is commonly expressed in watts. Therefore, the term wattage is also colloquially referred to as electric power in watts. Power (p) in watts can be calculated in terms of current (I) in amperes and voltage (V) in volts:

$$p = IV \quad (1)$$

In this study, only amperage readings were taken by using a digital multi-meter. The measurements were made while

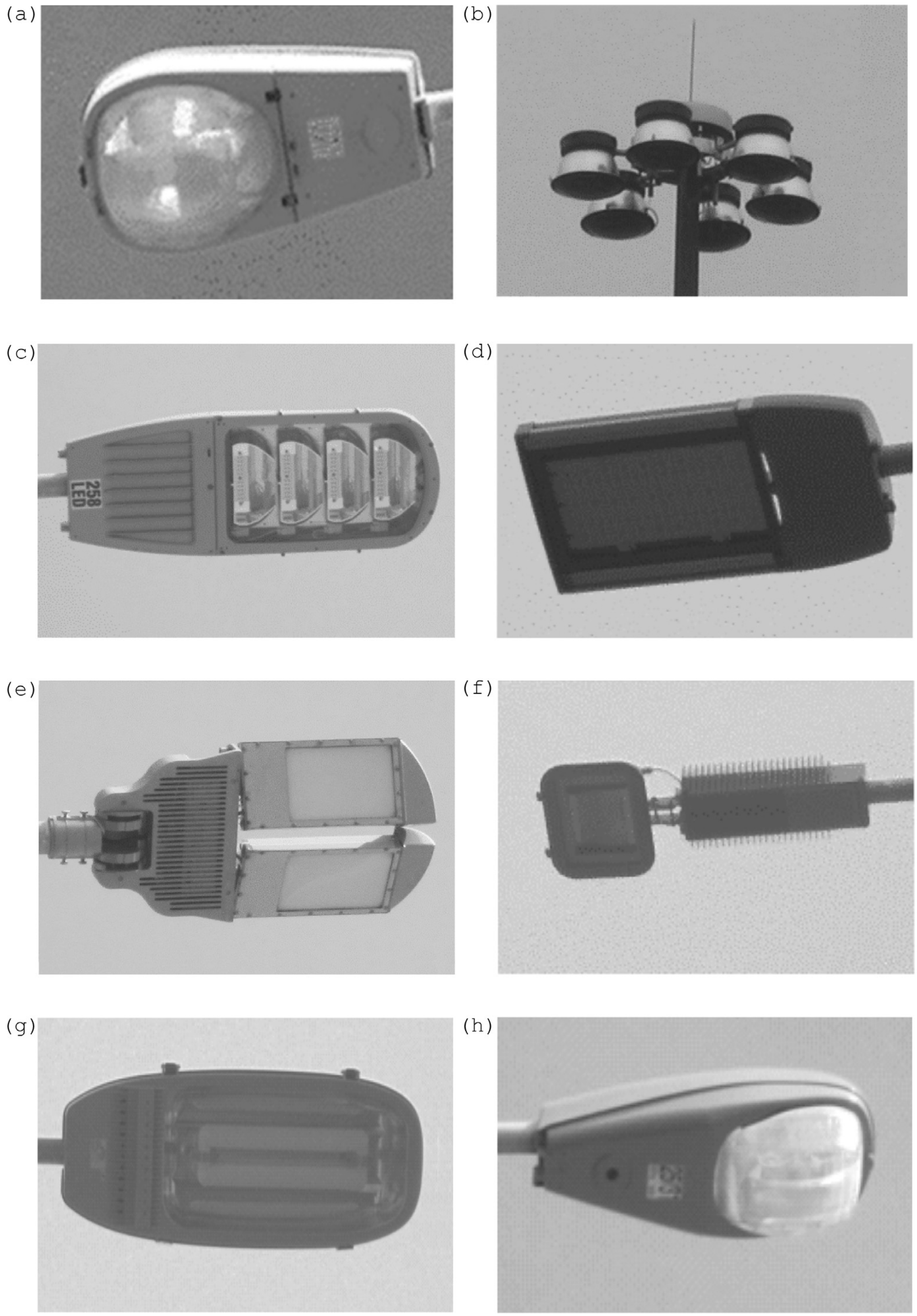

Fig. 1 – Photos of existing and new types of luminaires. (a) 250/400 W HPS. (b) 6×1000 W HPS/6×392 W LED. (c) GE 258 W LED. (d) Philips 270 W LED. (e) Horner 200 W LED. (f) Stray Light 295 W plasma. (g) Luxlite 200 W induction. (h) GE 310 W MH.

the power supply was switched on. For the HPS luminaires, the amperage readings (cold) were first taken as the light was powered and the luminaire was heating up, usually within first 5–15 min of being energized. After the luminaire had been energized all lights, the amperage readings (hot) were taken again as soon as the technicians came in the morning. For the LED, plasma and induction luminaires, the trial measurements did not demonstrate any differences between the cold and hot readings. Consequently, the amperage readings were taken once in the morning. Since no data was measured on the electric potential or voltage, an average voltage of 240 V was utilized in the calculation.

The rated and measured power values are presented in Table 1. The measured power values were obtained using the

Table 1 – Rated and measured luminaire power values.

Luminaire type	Rated power (W)	Measured power (W)	Difference (W)
GE LU250 HPS 250 W	250	302	52
GE LU400 HPS 400 W	400	473	73
GE Evolve ERS4 LED 258 W	258	244	−14
Philips RoadView RVM LED 270 W	270	241	−29
Horner ETG LED 200 W	200	254	54
Stray Light TESLA II Plasma 295 W	295	267	−28
Eco-Luminator Induction 200 W	200	227	27
GE LU1000 HPS 6 × 1000 W	6000	7430	1430
Global Tech SoLtice LED 6 × 392 W	2352	2196	−156

average measured current values and a nominal 240 V. As can be seen in the table, the differences between measured and rated power values can be significant. It is therefore important that, whenever it is possible, the measured power values rather than the rated power values should be utilized to calculate the costs associated with power consumptions.

Compared to the baseline HPS 250 W and HPS 400 W luminaires, all the tested roadside lighting systems had lower measured power values. That is, the new lighting systems would consume less power than the existing HPS lights. Similarly, for high mast lighting, the power consumption of the six Global Tech SoLtice LED luminaires would be much less than that of the six HPS luminaires. The above observations indicate that the new lighting sources are inherently energy saving.

5. Life cycle cost analysis

The FHWA publication, "Economic Analysis Primer" (FHWA, 2003), is a great source of economic analysis methods for highway projects. The FHWA publication indicates that life cycle cost analysis (LCCA) is applied when an agency must undertake a project and is seeking to determine the lowest life-cycle-cost (i.e., most cost-effective) means to accomplish the project's objectives. LCCA enables the analyst to make sure that the selection of a design alternative is not based solely on the lowest initial costs, but also considers all the future costs (appropriately discounted) over the project's usable life. To ensure that the alternatives can be compared fairly, the analyst specifies a multiyear analysis period over which the life-cycle costs will be measured.

The values of a certain amount of money are different at different points in time. Through LCCA, the future costs are converted to the present values using an interest rate so that the costs can be compared on a common basis. The values of interest rates used in highway projects range from 3% to 5% historically. The interest rate of 4% is currently used by INDOT in economic analysis of highway projects. Therefore, the interest rate of 4% is applied in this study for the life cycle costs of the lighting systems.

The service life of current Indiana highway HPS lighting fixtures is 25 years with a lamp replacement cycle of three years. It is expected that the service life of the lighting fixtures for LED, induction, and plasma should also be 25 years. The light emitter replacement cycles for the new lighting systems are not known. For the purpose of life cycle cost analysis, the warranty periods of the new lighting systems are used as their replacement cycles.

In this study, the initial investment of a lighting device is the total cost of the installed lighting fixture (including labor cost), the annual cost includes the electricity cost and maintenance cost, and the periodical cost is the lamp or emitter replacement cost at the fixed time interval. For one cycle of the service life, the costs for the HPS lights along the time line are shown in Fig. 2, where the estimated service life is 25, the initial investment is "*I*", the lamp replacement cost is "*r*", the annual maintenance cost is "*m*", and the annual electricity cost is "*e*".

To calculate life cycle cost, the following symbols are used in the formulas that convert monetary values at different points in time:

- *i* represents an interest rate per year.
- *n* represents a number of years in the interest period.
- *P* represents a present value of money, i.e., the value of money at Year 0.
- *F* represents the value of money at the end of the *n*th year from the present time (Year 0) that is equivalent to *P* with interest rate *i*.
- *A* represents the end-of-year payment in a uniform series continuing for the coming *n* years, the entire series equivalent to *P* at interest rate *i*.

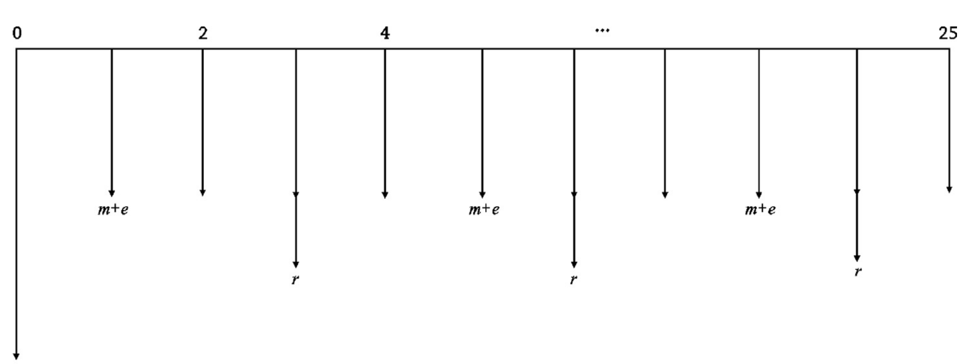

Fig. 2 – Cost flow along service life.

Table 2 – Emitter replacement cycles and costs.

Luminaire type	Lamp emitter life (year)	Installed luminaire price ($)	Lamp/emitter replacement cost ($)	Annual electricity cost[a] ($)	Annual maintenance cost ($)	Annual cost ($)
GE LU250 HPS 250 W	3	195	97	121	78	199
GE LU400 HPS 400 W	3	210	97	189	78	267
GE MH 320 W	5	500	155	128	40	168
GE Evolve ERS4 LED 258 W	5	800	195	98	40	138
Philips RoadView RVM LED 270 W	5	975	195	96	40	136
Horner ETG LED 200 W	3	850	195	102	40	142
Stray Light TESLA II Plasma 295 W	5	1100	195	108	40	148
Eco-Luminator Induction 200 W	5	500	175	91	40	131
GE LU1000 HPS 6 × 1000 W	3	630	450	2972	105	3077
Global Tech SoLtice LED 6 × 392 W	5	1900	521	878	105	983

[a] Annual electricity cost calculation: $0.10/kWh × measured power W × 4000 h÷1000.

The following three formulas that express the relationship between P, F, and A in terms of i and n are used to convert the lighting costs to the equivalent present values (Grant et al., 1982):

$$\text{Given } F, \text{ to find } P. \quad P = F\left|\frac{1}{(1+i)^n}\right| \tag{2}$$

$$\text{Given } A, \text{ to find } P. \quad P = A\left|\frac{(1+i)^n - 1}{i(1+i)^n}\right| \tag{3}$$

$$\text{Given } P, \text{ to find } A. \quad A = P\left|\frac{i(1+i)^n}{(1+i)^n - 1}\right| \tag{4}$$

Using an annual operating time of 4000 h estimated by the Traffic Administration Section of INDOT and Indiana electricity price of $0.10/kWh, the annual electricity costs are presented in Table 2. Also presented in Table 2 are the other cost items necessary for life cycle cost analysis. Currently, the HPS lamps are regularly replaced every three years in Indiana. Since the service lives of emitters of the new lighting sources were not known, the warranty periods provided by the vendors were used as their emitter replacement cycles. The costs for the high mast luminaires (1000 W HPS and 392 W LED) included the costs of six lamps for each type, while those for all other luminaires are single lamp costs.

The results of life cycle cost analysis are shown in Table 3. The life cycle costs of the alternative roadside lighting fixtures are compared to that of the 250 W HPS as shown in Fig. 3. In the figure, all of the individual life cycle costs are represented by the bars. In addition, the life cycle cost of the 250 W HPS fixture is plotted as a horizontal reference line. The life cycle cost bars below the reference line represent the more cost effective lighting fixtures and the bars above the reference line represent the less cost effective lighting fixtures as compared to the 250 W HPS light. As clearly illustrated in Fig. 3, the 250 W HPS is more cost effective than the 200 W LED and the 295 W plasma, and less cost effective than the other types of the lighting systems.

In a similar manner, the life cycle costs of the alternative roadside lighting fixtures are compared to that of the 400 W HPS fixture as shown in Fig. 4. Since the life cycle costs of all tested lighting systems are below the reference line, all the alternative lighting devices are more cost effective than that of the 400 W HPS device. The 392 W LED fixtures installed on the high mast tower are compared with the existing 1000 W HPS lights in terms of life cycle costs in Fig. 5. It is easy to see that the LED tower lights are more cost effective than the HPS tower lights.

In addition to the life cycle cost comparisons, the return period or payback period was also computed for each new lighting device to provide the information on the time needed for a new lighting device to have a break-even life cycle cost as compared to the conventional lighting device. The return period of a lighting device would be useful for identifying how soon the device can became cost effective within its service life and for determining the minimum warranty time period of the device. A return period is determined by comparing the present worth values of two lighting devices and identifying the point in time after which the cost of the new lighting device becomes less than that of the conventional lighting device. Fig. 6 illustrates an example of return period identification. As can be seen in the figure, the two curves intersect between Year 12 and Year 13 and thus the return period for the 258 W LED luminaire is 13 years as compared to the 250 W HPS luminaire. If a new luminaire is not cost effective than the conventional one, the two cost curves will not intersect within the service life and, therefore, no return period can be identified. The return periods are listed in Tables 4–6 for different lighting luminaires.

In summary, the life cycle cost analysis indicates that all the alternative new types of lighting devices (LED, plasma, and induction) are more cost effective than the existing 400 W HPS lights and 1000 W HPS tower lights. In comparison with the

Table 3 – Results of life cycle cost analysis.

Luminaire type	Lamp/emitter life (year)	Cost of new fixture installed ($)	Lamp/emitter replacement cost ($)	Annual cost ($)	Present worth of life cycle cost ($)	Equivalent uniform annual cost ($)
GE LU250 HPS 250 W	3	195	97	199	3774	242
GE LU400 HPS 400 W	3	210	97	267	4857	311
GE MH 320 W	5	500	155	168	3572	229
GE Evolve ERS4 LED 258 W	5	800	195	138	3512	225
Philips RoadView RVM LED 270 W	5	975	195	136	3668	235
Horner ETG LED 200 W	3	850	195	142	4015	257
Stray Light TESLA II Plasma 295 W	5	1100	195	148	3967	254
Eco-Luminator Induction 200 W	5	500	175	131	3048	195
GE LU1000 HPS 6 × 1000 W	3	630	450	3077	50,897	3258
Global Tech SoLtice LED 6 × 392 W	5	1900	521	983	18,766	1201

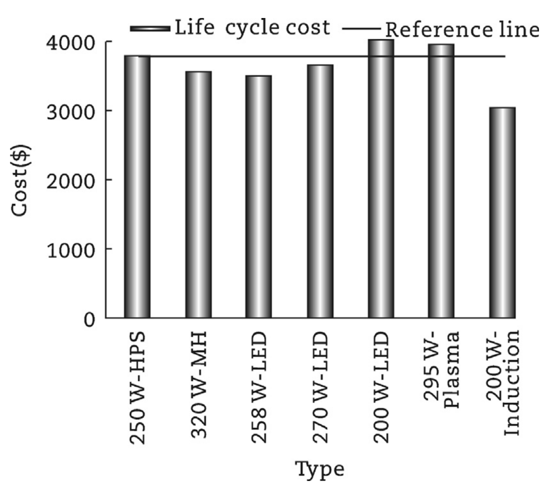

Fig. 3 – Comparison of life cycle costs with 250 W HPS.

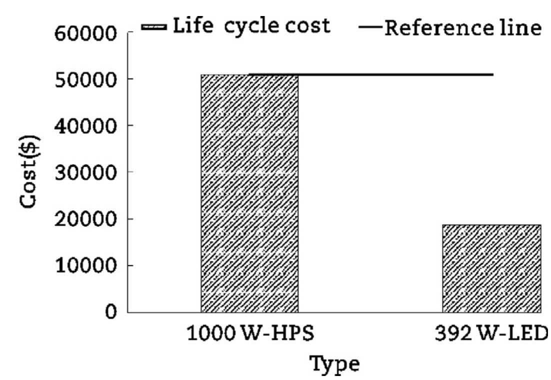

Fig. 5 – Comparison of life cycle costs of tower lights.

existing 250 W HPS lights, four of the six alternative lighting devices are more cost effective and two (200 W LED and 295 W plasma) of the six are less cost effective. The return periods of the new luminaires provide a new point of view for examining the cost effectiveness of individual luminaires, which would

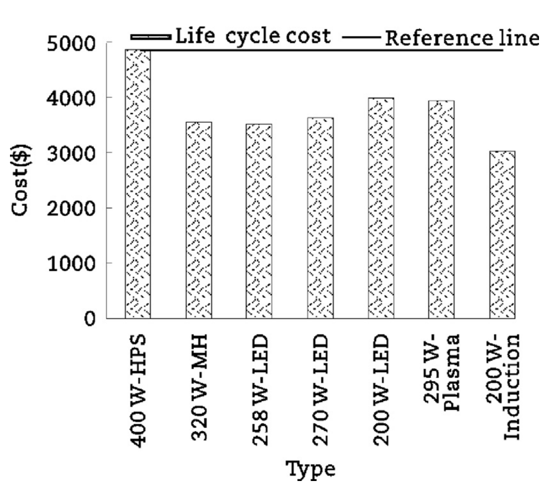

Fig. 4 – Comparison of life cycle costs with 400 W HPS.

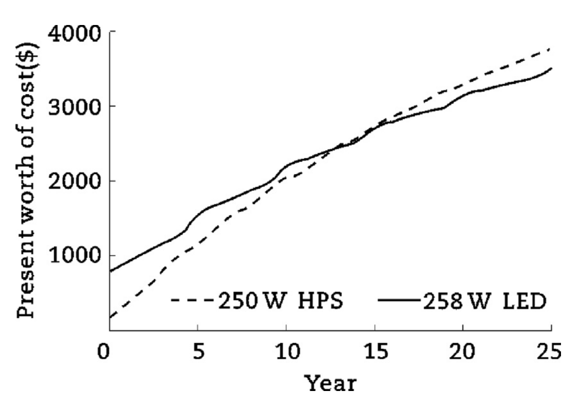

Fig. 6 – Return period identification.

Table 4 – Return periods of luminaires (Compared to 250 W HPS).

Luminaire type	Return period (year)
GE LU250 HPS 250 W	–
GE MH 320 W	12
GE Evolve ERS4 LED 258 W	13
Philips RoadView RVM LED 270 W	18
Horner ETG LED 200 W	N/A
Stray Light TESLA II Plasma 295 W	N/A
Eco-Luminator Induction 200 W	6

Table 5 – Return periods of luminaires (Compared to 400 W HPS).

Luminaire type	Return period (year)
GE LU400 HPS 400 W	–
GE MH 320 W	3
GE Evolve ERS4 LED 258 W	6
Philips RoadView RVM LED 270 W	7
Horner ETG LED 200 W	8
Stray Light TESLA II Plasma 295 W	9
Eco-Luminator Induction 200 W	3

Table 6 – Return periods of luminaires (Compared to 1000 W HPS high mast).

Luminaire type	Return period (year)
GE LU1000 HPS 6 × 1000 W	–
Global Tech SoLtice LED 6 × 392 W	1

be useful for selecting appropriate lighting devices and determining the minimum warranty periods of the products.

6. Conclusions

Through this study, experience and knowledge have been obtained on the installations, power measurements, and cost effectiveness of the new types of the roadway lighting devices. The new lighting systems were generally easy to install. However, the GE ERS4 LED system was heavier than other types of LED fixtures. It was reported by the technicians that the Eco-Luminator EcoCoBra induction fixtures were the most time consuming and difficult to install. They were the heaviest among the new lighting systems. The terminal block of the induction system was more difficult to access and had a small screw termination.

The actual power values of various luminaires were obtained by measuring the electric currents with a multi-meter. It was found that the differences between the rated and measured power values varied from small to significant. It is therefore recommended that the measured power values should be used in estimating power consumptions and life cycle costs.

The results of the life cycle cost analysis indicate that 1). all of the alternative types of lighting devices (LED, plasma, and induction) are more cost effective than the existing 400 W HPS lights; 2). in comparison with the existing 250 W HPS lights, four of the six alternative lighting devices are more cost effective and two (200 W LED and 295 W plasma) of the six are less cost effective; and 3). the Global Tech SoLtice 392 W LED lights are more cost effective than the existing 1000 W HPS tower lights.

The return or payback period is about six or more years to replace an HPS 250 W luminaire with a tested LED, plasma, or induction luminaire. It would take three or more years to replace an HPS 400 W luminaire to achieve the break-even point. It would take only one year to become cost effective if a 392 W LED is used in place of the existing high mast 1000 W HPS luminaire. The return period of a lighting device can be used by INDOT to identify how soon the device becomes cost effective within its service life and to determine the minimum warranty time period of the device. The lower life cycle costs of the alternative lighting devices are attributed to their relatively lower electricity usages and longer lamp/emitter replacement cycles.

REFERENCES

Akashi, Y., Rea, M.S., Bullough, J.D., 2007. Driver decision making in response to peripheral moving targets under mesopic light levels. Lighting Research and Technology 39 (1), 53–67.

Beckwith, D., Zhang, X., Smalley, E., et al., 2011. LED streetlight application assessment project: pilot study in Seattle, Washington. Transportation Research Record 2250, 65–75.

Bullough, J.D., 2012. Guide for Optimizing the Effectiveness and Efficiency of Roadway Lighting. Final Report No. C-10–14. New York State Energy Research and Development Authority; New York State Department of Transportation, Albany.

Bullough, J.D., Radetsky, L.C., 2013. Analysis of New Highway Lighting Technologies. Final Report 20-7/305. National Cooperative Highway Research Program, Washington DC.

Eco-Luminator, 2013. 250W EcoBra specification sheet. Eco-Luminator, Mitcham.

ETC, 2014. Induction Lamps. The Edison Tech Center (ETC). Available at: http://www.edisontechcenter.org/InductionLamps (html-works).

FHWA, 2003. Economic Analysis Primer. Federal Highway Administration (FHWA), Washington DC.

Fotios, S.A., Cheal, C., 2007. Lighting for subsidiary streets: investigation of lamps of different SPD: Part 1-visual performance, Part 2-brightness. Lighting Research and Technology 39 (3), 215–252.

GE, 2011. Evolve ™ LED Roadway Lighting-scalable Cobrahead, GE Lighting Solutions, OLP-2900. General Electric (GE), Fairfield.

Grainger, 2013. GE Lighting Quartz Metal Halide Lamp, ED28 320W Tech Specs. Grainger.

Grant, E.L., Ireson, W.G., Leavenworth, R.S., 1982. Principles of Engineering Economy, seventh ed. John Wiley & Sons, New York.

GTL, 2014. Solstice LED Module Application Guide. Global Tech LED (GTL), Bonita Springs.

Halonen, L., Tetri, E., Bhusal, P., 2010. Guidebook on Energy Efficient Electric Lighting for Buildings. Aalto University, Aalto.

HETG, 2013. Remote Phosphor Area Light A200. Horner Environmental Technology Group (HETG).

IESNA, 2008. Electrical and Photometric Measurements of Solid-state Lighting Products. LM-79–08. The Illuminating Engineering Society of North America (IESNA), New York.

INDOT, 2012. Design Specifications. Indiana Department of Transportation (INDOT), Indianapolis.

Li, S., Jiang, Y., Guan, B., et al., 2013. Cost- and energy-efficient (LED, Induction and Plasma) roadway lighting. FHWA/IN/JTRP-2013/19. In: Joint Transportation Research Program. Indiana Department of Transportation and Purdue University, West Lafayette.

LL, 2013. Induction Lighitng System-operating Principles. Lithonia Lighting (LL), Conyers.

LUXIM, 2014. How LEP Works. LUXIM. Available at: http://www.luxim.com/technology/how-lep-works.

Phillips, 2011. RoadView Series. Philips Roadway Lighting, Rosemont. RV100R01.

Rea, M.S., Bullough, J.D., Akashi, Y., 2009. Several views of metal halide and high pressure sodium lighting for outdoor applications. Lighting Research and Technology 41 (4), 297–320.

SLOT, 2013. FM000027B Specification Sheet, Telsa II. Stray Light Optical Technologies (SLOT), Scottsburg.

Srinivas, S.P., Narayanan, R.P., 2013. NC roadway Lighting Needs Assessment, Maintenance Prioritization Tool and Performance Measures. Final Report # 2012-14. North Carolina Department of Transportation, Raleigh.

USDOE, 2008. LED Basics. PNNL-SA-50007. U.S. Department of Energy, Washington DC.

USDOE, 2010. High-intensity discharge lamps: analysis of potential energy savings. In: EE-DET-03–001, Energy Efficiency Program for Commercial and Industrial Equipment. U.S. Department of Energy, Washington DC.