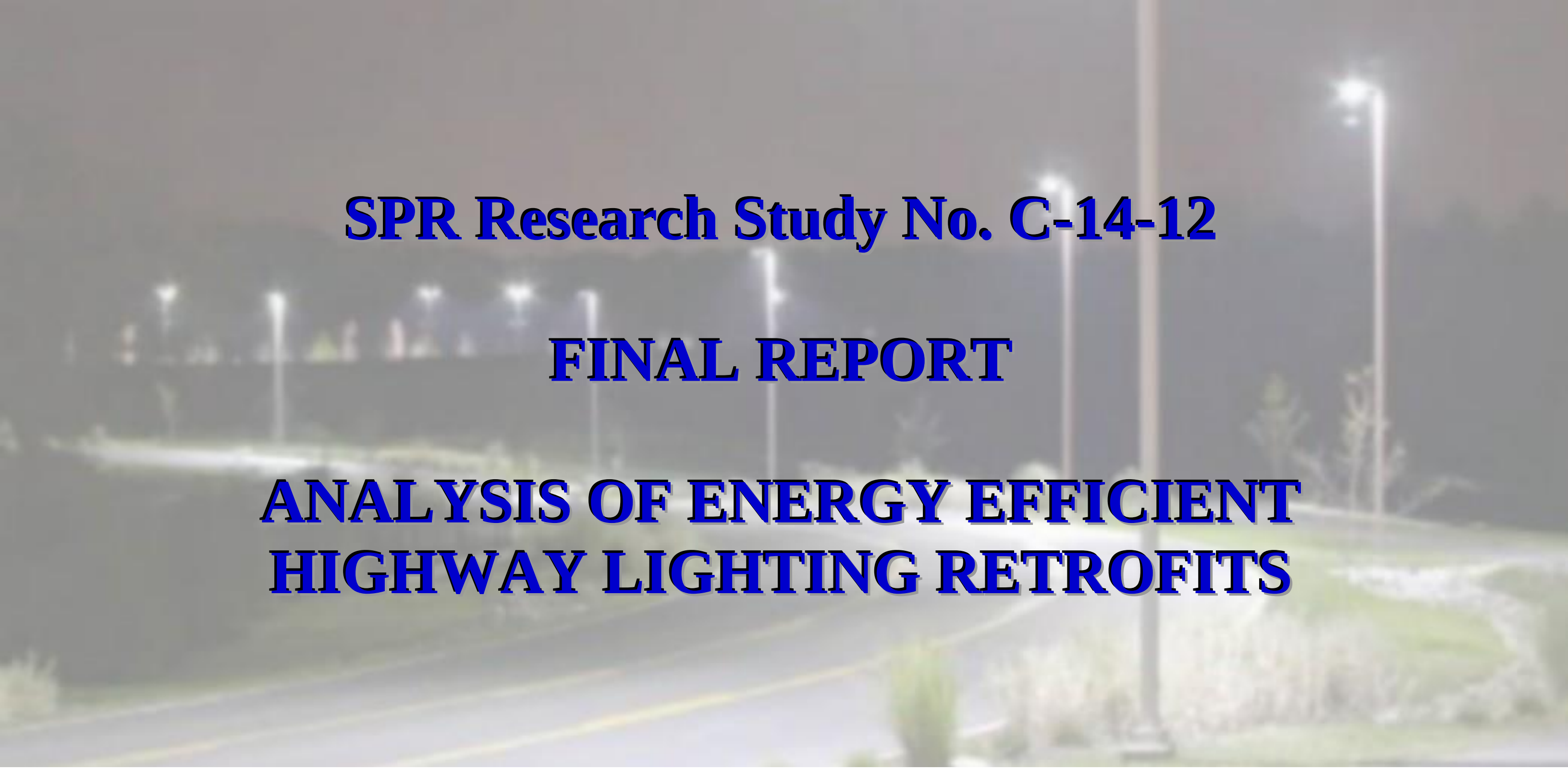

SPR Research Study No. C-14-12

FINAL REPORT

ANALYSIS OF ENERGY EFFICIENT HIGHWAY LIGHTING RETROFITS

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Conducted for the

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

By the

LIGHTING RESEARCH CENTER
RENSSELAER POLYTECHNIC INSTITUTE

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16. Abstract

Solid state lighting technology is advancing rapidly to a point where light emitting diode (LED) lighting systems can be viable replacements for existing lighting systems using high pressure sodium (HPS). The present report summarizes analyses conducted to document existing lighting conditions along a parkway (Southern State Parkway, Long Island) and an arterial roadway (Central Avenue, Albany County). Several LED alternative lighting systems were compared using photometric analyses to identify ones that meet light level criteria for each roadway type; several options were available that resulted in energy savings compared to the existing HPS lighting systems. Energy economic analyses confirmed that the initial investment could be paid back in terms of reduced operating costs, and that energy savings were larger for LED systems when compared to HPS systems that produced similar levels to those from the LED alternatives. Further energy cost savings would be expected with the use of adaptive lighting controls specified to take advantage of temporal nighttime traffic patterns on the roadways investigated. The report concludes with considerations for incorporating LED performance characteristics, such as ensuring they do not produce interference with radio equipment, into specifications for LED retrofit alternatives.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Solid state lighting technology is advancing rapidly to a point where light emitting diode (LED) lighting systems can be viable replacements for existing lighting systems using high pressure sodium (HPS). The present report summarizes analyses conducted to document existing lighting conditions along a parkway (Southern State Parkway, Long Island) and an arterial roadway (Central Avenue, Albany County). Several LED alternative lighting systems were compared using photometric analyses to identify ones that meet light level criteria for each roadway type; several options were available that resulted in energy savings compared to the existing HPS lighting systems. Energy economic analyses confirmed that the initial investment could be paid back in terms of reduced operating costs, and that energy savings were larger for LED systems when compared to HPS systems that produced similar levels to those from the LED alternatives. Further energy cost savings would be expected with the use of adaptive lighting controls specified to take advantage of temporal nighttime traffic patterns on the roadways investigated. The report concludes with considerations for incorporating LED performance characteristics, such as ensuring they do not produce interference with radio equipment, into specifications for LED retrofit alternatives.

ACRONYMS AND ABBREVIATIONS

AASHTO – American Association of State Highway and Transportation Officials
cd/m^2 – candelas per square meter, a unit of luminance
HPS – High Pressure Sodium
IES – Illuminating Engineering Society
LED – Light Emitting Diode
LRC – Lighting Research Center
lx – lux, a unit of illuminance (approximately 0.1 footcandle)
NYSDOT – New York State Department of Transportation
RPI – Rensselaer Polytechnic Institute
SSP – Southern State Parkway
W – watt, a unit of power

1. INTRODUCTION

Roadway lighting practices and technologies are undergoing a revolution in terms of lighting system efficacy and life, primarily driven by rapid advancements in solid state lighting technologies, particularly light emitting diode (LED) sources (Radetsky, 2010, 2011). LED roadway lighting systems are available for a wide range of roadway applications that exceed the energy efficiency of high pressure sodium (HPS) systems (Bullough, 2012; Bullough and Radetsky, 2013), which are the ones most commonly used for roadway lighting in New York State (NYS) and throughout the entire U.S. (Navigant Consulting, 2012). Presently it is possible to demonstrate that many LED lighting systems can result in longer pole spacing and reduced energy usage compared to conventional HPS lighting, while meeting existing standards and recommendations such as those published by the Illuminating Engineering Society (IES, 2000, 2014) and the American Association of State Highway and Transportation Officials (AASHTO, 2005).

Retrofit roadway lighting applications in particular can be challenging to specify, in part because the existing layout and pole spacing may have been optimized for a specific lighting system (e.g., lamp, wattage, luminaire type and mounting height). Although roadway luminaire classifications exist to identify particular types of luminaires that may be suitable for different roadway types and applications (IES, 2000, 2014; Bullough and Radetsky, 2014), the precise distributions cannot be known from type classifications and whether a new luminaire will meet important design criterion cannot be known in advance of photometric analysis. In addition, the governing criteria for a roadway lighting installation when it was first designed may change based on recent patterns in traffic volume, pedestrian use and the level of adjacent commercial development, for example. Another factor that can impact a retrofit roadway lighting application is if the poles used to mount the luminaires are existing utility poles, designed not for attaching lighting equipment but for carrying utility cables. In general, published design criteria (IES, 2000, 2014; AASHTO, 2005) are not applicable to such non-designed installations, and even if such installations meet certain criteria such as average light levels, they may be less likely to meet other criteria related to uniformity or glare (Bullough and Radetsky, 2014).

In order to assist the New York State Department of Transportation (NYSDOT) in identifying roadway lighting retrofit options for two types of highways, parkways and arterial roadways, the project team from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute (RPI) conducted field measurements, photometric analyses and energy analyses, using information about existing and alternative lighting configurations on two New York State highways. The following sections of the present report describe the analysis and evaluation methods used by the project team to identify the suitability of different retrofit lighting configurations.

2. EXISTING LIGHTING PRACTICES AND CONDITIONS

Roadway Lighting Practice in NYS

Roadway lighting practices as conducted by NYSDOT are described in several documents published on the NYSDOT website. They include:

- Policy on Highway Lighting (NYSDOT, 1979)
- Highway Design Manual (NYSDOT, 1995)
- Standard Specifications (NYSDOT, 2008)

The Policy on Highway Lighting (NYSDOT, 1979) serves primarily as NYSDOT's warranting procedure for deciding when to install roadway lighting. For example, lighting is considered for locations that exhibit high traffic volumes, high night-to-day crash ratios (when nighttime crashes form a larger-than-expected proportion of crashes relative to the proportion of traffic occurring at night), when highway interchanges are closely spaced together, and when large pedestrian populations are likely to be present. These criteria are fundamentally similar to those stated as guidelines for warrants by the American Association of State Highway and Transportation Officials (AASHTO, 2005). While NYSDOT generally pays for the design and installation of lighting, operation and maintenance is supposed to be paid for by the municipality in which the lighting is to be located.

The Highway Design Manual (NYSDOT, 1995) discusses issues related to the planning of lighting installations by NYSDOT. Specifically, the Manual stipulates that illuminance criteria (as opposed to luminance criteria) from AASHTO are to be used in the calculation and specification of light levels. The AASHTO (2005) guidelines for roadway lighting allow either illuminance or luminance criteria to be used for roadway lighting and are based on recommendations from the Illuminating Engineering Society (IES, 2000). The most recent recommended practice for roadway lighting from the Illuminating Engineering Society (IES, 2014) specifies the use of luminance criteria for lighting of straight roadways with regular pole spacing. It is worth noting that the luminance and illuminance criteria for the same roadway type result in similar illuminances on the roadway; the ratio between luminance and illuminance values is 1 cd/m² = 15 lx for asphalt pavement, and 1 cd/m² = 10 lx for concrete pavement (IES, 2014).

When curves or other irregularities exist that make it difficult to apply the luminance criteria, IES (2014) provides alternatives for determining illuminance equivalents to the luminance criteria for different pavement types (e.g., concrete or asphalt). Importantly, the equivalent light level criteria, whether in terms of luminance or illuminance, have not fundamentally changed since the publication of the IES recommendation practice in 1977 (IES, 1977, 1983, 2000, 2014). What this means is that whether a lighting engineer would base light level criteria on the present (AASHTO, 2005) or previous (AASHTO, 1984) guides from AASHTO, or on any of the IES recommended practices published since the mid-1970s (IES, 1977, 1983, 2000, 2014), the resulting design will be fundamentally the same. Thus, NYSDOT lighting design criteria are consistent with present day recommendations from IES and AASHTO (with the exception of explicitly permitting adaptive lighting, which is now permitted in the most recent IES (2014) guide.

The Manual further states that HPS lamps are preferred for roadway lighting, in semi-cutoff luminaires (usually having the characteristic "cobrahead" shape). When so-called "ornamental" lighting is to be used, any extra costs for equipment in addition to maintenance and operation are to be borne by the municipality in which the lighting will be located.

The NYSDOT (2008) Standard Specifications that address lighting are mainly concerned with issues regarding durability of equipment and electrical safety. It does list performance criteria required for lamps and includes both HPS and mercury vapor lamps (the latter type is often used in overhead highway sign lighting, although the ballasts for these lamps are being phased out by federal energy efficiency legislation, which will effectively phase out use and availability of these lamps as well). The Specifications were last updated in 2008.

Existing Lighting Conditions

Roadway Selection

The initial project description mentioned two highway types for analysis: parkways and arterial roadways. After discussion among the NYSDOT project manager and technical working group, the highway scenarios identified for analysis were a section of the Southern State Parkway (SSP) on Long Island from Exit 13 to Exit 37, and a section of NYS Route 5 (Central Avenue) in the town of Colonie between Madison Avenue and Reber Street. The SSP has three traveling lanes in each direction, while Central Avenue has two traveling lanes in each direction with a single left-turn lane in the center. Lane widths were approximately 12 ft.

The section of the SSP is further divided into two subsections based on the existing lighting system present on each subsection: one, extending from Exit 13 to Exit 28 (denoted SSP West), currently uses (almost exclusively) 250 W HPS floodlight luminaires (539 in number) mounted at an angle on dedicated poles (Figure 1), and the other, extending from Exit 28 to Exit 37 (denoted SSP East), currently uses conventional “cobrahead” type luminaires (almost exclusively 250 W HPS, and 588 in number), also mounted on dedicated poles (Figure 2). The target design illuminance criterion for both sections of the SSP was 6 lx. The lighting along Central Avenue uses primarily 150 W HPS (in the western portion) and 250 W HPS (in the eastern portion) “cobrahead” type luminaires (approximately 150 in number), which are mounted on existing utility poles (Figure 3).

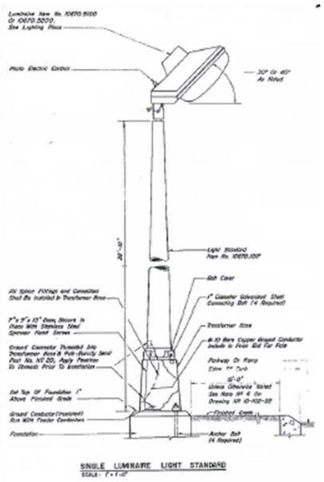


Figure 1. Luminaire type used to illuminate the SSP West section.

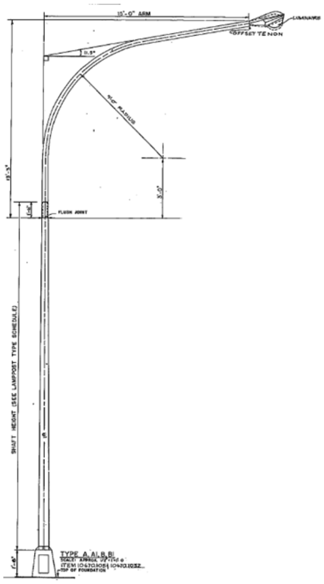


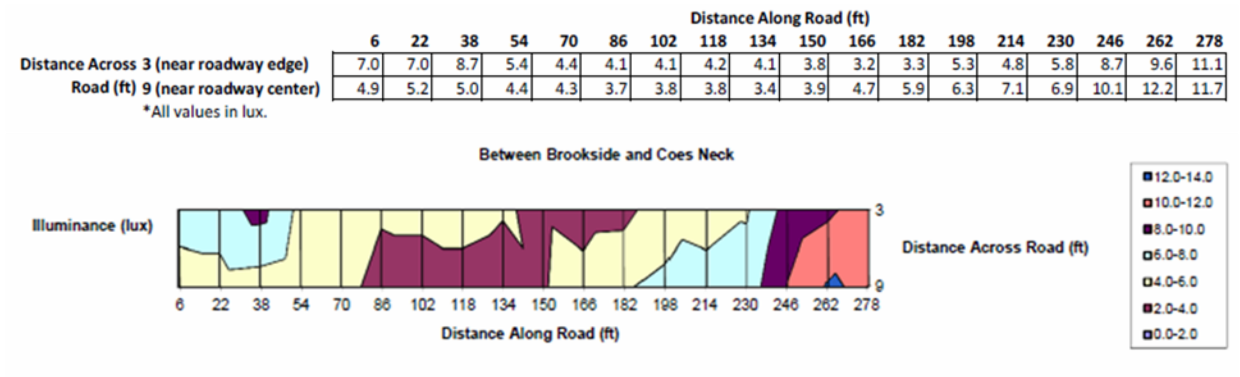
Figure 2. Luminaire type used to illuminate the SSP East section.

Figure 3. Luminaire type used to illuminate the Central Avenue section.

Drawings for each roadway section (SSP West, SSP East and Central Avenue) showing the lighting configurations (as designed in the 1970s and 1980s) were provided by NYSDOT to the project team. NYSDOT also provided a series of lighting model calculations developed by the engineering firm Creighton Manning as part of a pedestrian safety study along the Route 5 corridor (Creighton Manning, 2014), which included the section of Central Avenue evaluated for the present project.

Field Lighting Measurements

The project team conducted illuminance measurements at each of the roadway locations in order to assess the existing lighting conditions (in December 2014 for the SSP and in January 2015 for Central Avenue). Along the SSP West section, part of the area just west of Exit 21 in the leftmost traveling lane for westbound traffic, between luminaires was measured, following the guidance provided by IES (2000, 2014) for field measurements. Lane closure and traffic control was provided by NYSDOT Region 10. Two sets of illuminance measurements, spaced 15 ft apart, were made, one-quarter and three-quarters across the lateral width of the traveling lane. Figure 4 shows the illuminances measured in this part of the SSP West section. The average illuminance was 5.9 lx, with a minimum of 3.2 lx and an average-to-minimum illuminance ratio of 1.8.



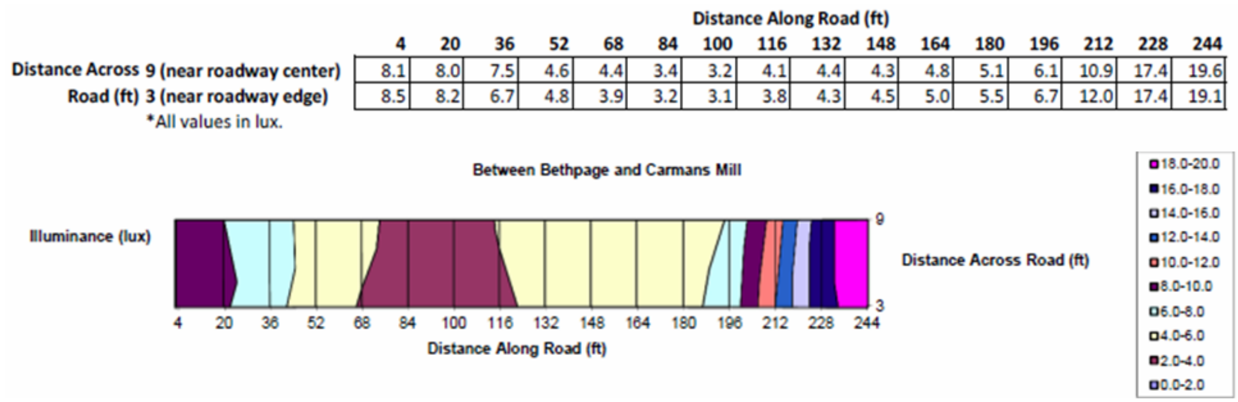
Distance Across Road (ft)	6	22	38	54	70	86	102	118	134	150	166	182	198	214	230	246	262	278
3 (near roadway edge)	7.0	7.0	8.7	5.4	4.4	4.1	4.1	4.2	4.1	3.8	3.2	3.3	5.3	4.8	5.8	8.7	9.6	11.1
9 (near roadway center)	4.9	5.2	5.0	4.4	4.3	3.7	3.8	3.8	3.4	3.9	4.7	5.9	6.3	7.1	6.9	10.1	12.2	11.7

Distance Along Road (ft)

*All values in lux.

Figure 4. Measured illuminances in the SSP West section.

Along the SSP East section, part of the area just east of Exit 31 in the rightmost traveling lane for eastbound traffic, between luminaires was measured, following the guidance provided by IES (2000, 2014) for field measurements. Lane closure and traffic control was provided by NYSDOT Region 10. Two sets of illuminance measurements, spaced 15 ft apart, were made, one-quarter and three-quarters across the lateral width of the traveling lane. Figure 5 shows the illuminances measured in this part of the SSP East section. The average illuminance was 7.3 lx, with a minimum of 3.1 lx and an average-to-minimum illuminance ratio of 2.3.



Distance Across Road (ft)	4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244
9 (near roadway center)	8.1	8.0	7.5	4.6	4.4	3.4	3.2	4.1	4.4	4.3	4.8	5.1	6.1	10.9	17.4	19.6
3 (near roadway edge)	8.5	8.2	6.7	4.8	3.9	3.2	3.1	3.8	4.3	4.5	5.0	5.5	6.7	12.0	17.4	19.1

Distance Along Road (ft)

*All values in lux.

Figure 5. Measured illuminances in the SSP East section.

Along Central Avenue, one portion of the sidewalk was measured with a single measurement every 15 ft, starting at the location of the luminaire on the north side of Central Avenue (adjacent to westbound traffic) and just east of the intersection with Nicholas Drive, and ending 90 ft away. Figure 6 shows the illuminances measured on the sidewalk in this part of Central Avenue. The average illuminance was 8.6 lx, with a maximum of 27.1 lx and a minimum of 3.1 lx. Another portion of the sidewalk was measured in the same manner, starting at the location of the luminaire on the north side of Central Avenue just east of the intersection with Reber Street, and ending 90 ft away. Figure 7 shows the illuminances measured on the sidewalk in this part of Central Avenue. The average illuminance was 3.8 lx, with a maximum of 9.3 lx and a minimum of 1.2 lx.

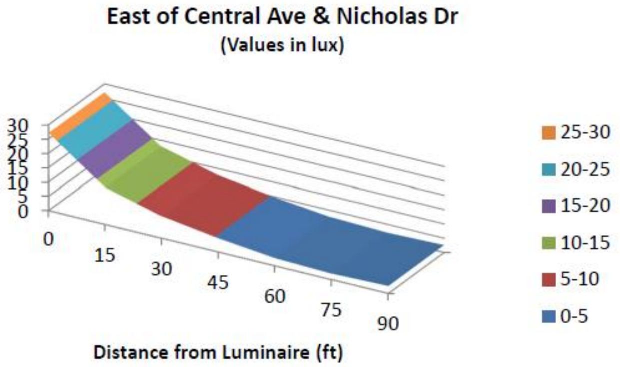


Figure 6. Measured illuminances along the sidewalk at Central Avenue and Nicholas Drive.

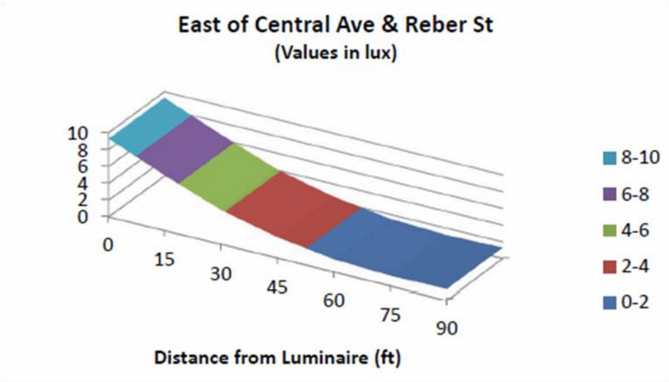


Figure 7. Measured illuminances along the sidewalk at Central Avenue and Reber Street.

Photometric Models of Existing Lighting

To identify whether the measured illuminances, representing existing lighting conditions, matched the designed conditions represented in the NYSDOT drawings, the project team developed photometric models of the lighting configurations from the drawings (Visual 2012, Roadway Tool, Acuity Brands). Light loss factors of 0.7 were incorporated into all analyses to identify maintained lighting conditions. For the SSP West section (Figure 8), the pole spacing was 284 ft in an opposite spacing for each traveling direction. The pole height was 33 ft with an arm bracket of 1 ft in length and the luminaires (Holophane, Mongoose, G250HPMCHDRVZR3) were tilted at an angle of 45 degrees. Poles were mounted 20 ft from the edge of the rightmost traveling lane in each direction. The average illuminance on the roadway was 7.6 lx, with a minimum of 2.1 lx and an average-to-minimum illuminance ratio of 3.7.

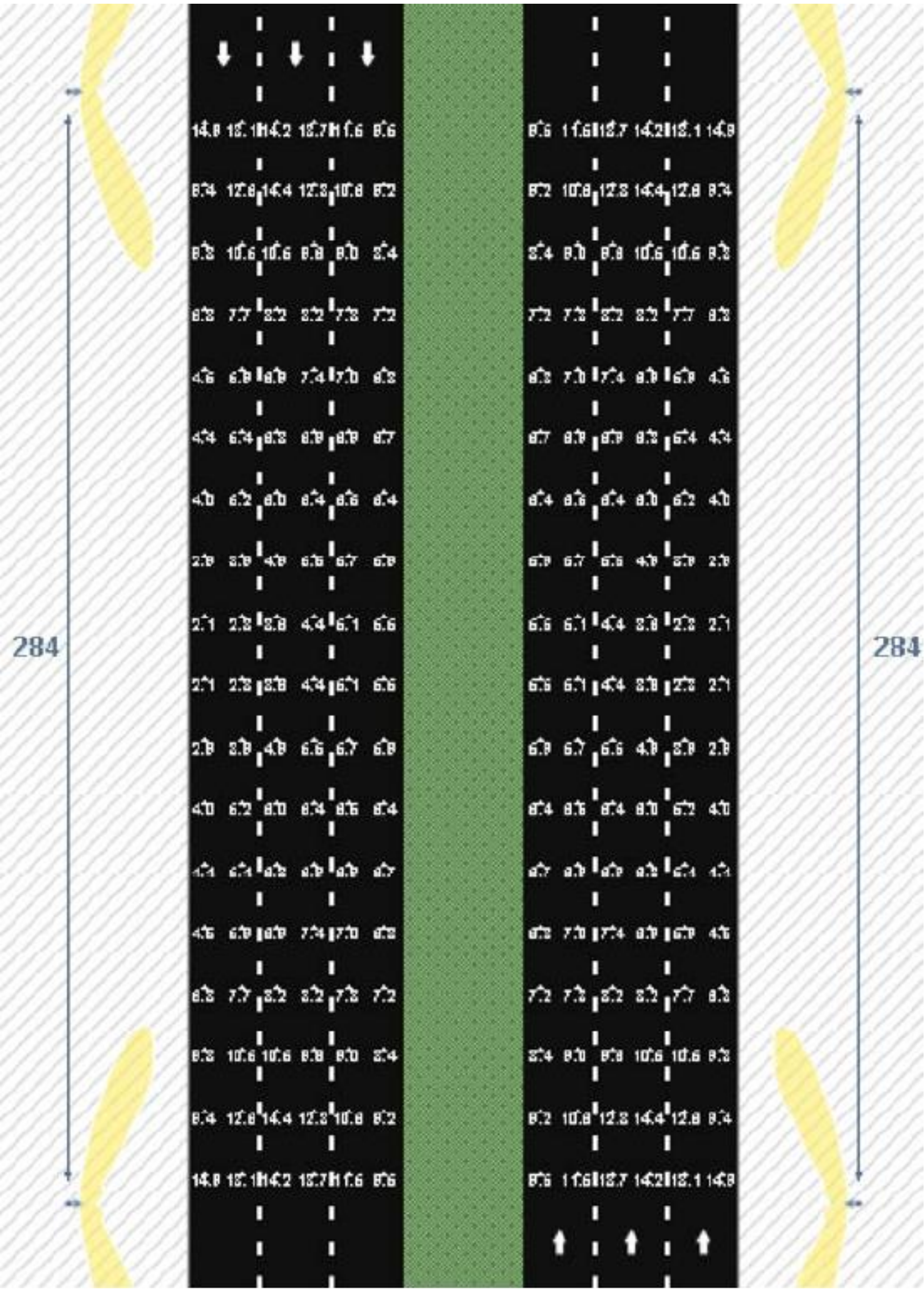


Figure 8. Photometric analysis of existing conditions along the SSP West section.

For the SSP East section (Figure 9), the pole spacing of the luminaires (assumed to be GE Lighting, M-RL40S-RMS2, 16,000 lm per lamp) was 249 ft in a staggered spacing for each traveling direction. The pole height was 40 ft (typical) with an arm bracket of 15 ft in length. Poles were mounted 20 ft from the edge of the rightmost traveling lane in each direction. The average illuminance on the roadway was 6.6 lx, with a minimum of 2.9 lx and an average-to-minimum illuminance ratio of 2.3.

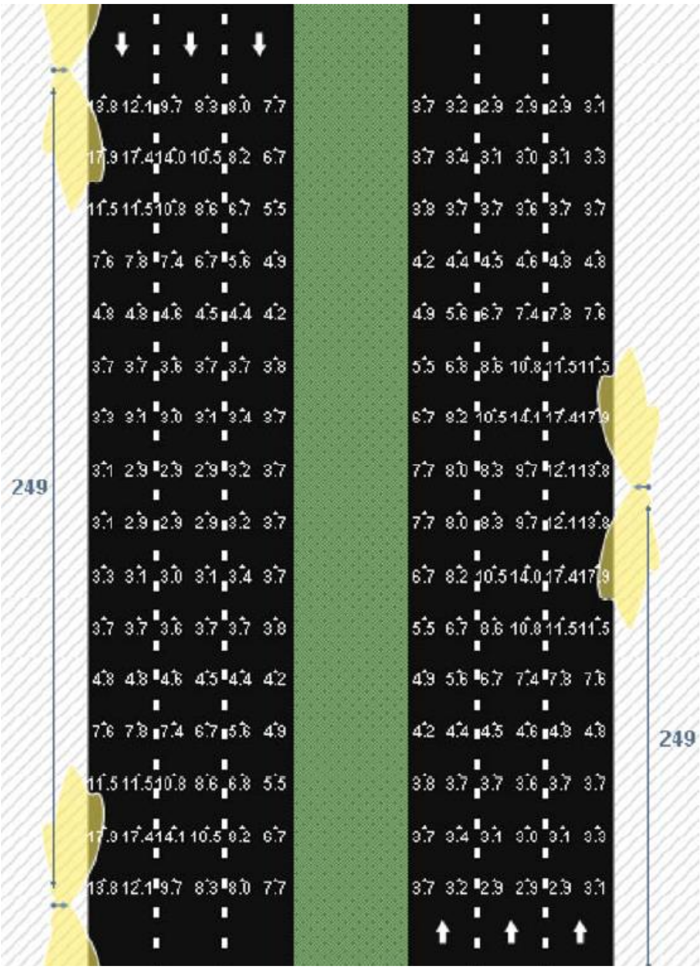


Figure 9. Photometric analysis of existing conditions along the SSP East section.

For the Central Avenue section (Figure 10), the pole spacing ranged from less than 100 ft in some locations to more than 260 ft in others; a typical spacing between poles was 200 ft in each traveling direction. (The presence of many driveways for commercial properties along this roadway made regular pole spacing an impossibility.) The pole height was 30 ft (typical) with an arm bracket of 8 ft in length. Poles were mounted about 2 ft from the edge of the roadway in each direction. With 150 W HPS luminaires (assumed to be GE Lighting, M-RL40S-RMS2, 16,000 lm per lamp) spaced 200 ft in a staggered layout, the average illuminance on the roadway was 8.9 lx, with a minimum of 3.2 lx and an average-to-minimum illuminance ratio of 2.8. On the sidewalk, the average illuminance was 5.5 lx, with a minimum of 2.0 lx. Using a spacing of 260 ft to represent conditions when spacing between luminaires was large, and with 150 W HPS luminaires, the average illuminance on the roadway was 6.9 lx, with a minimum of 1.9 lx and an average-to-minimum illuminance ratio of 3.6. On the sidewalk, the average illuminance was 4.4 lx, with a minimum of 1.1 lx. For both pole spacing values, when 250 W HPS luminaires (assumed to be GE Lighting, M-RL40S-RMS2, 28,000 lm per lamp) were used in the photometric models, the resulting light levels were increased by a factor of 1.7.

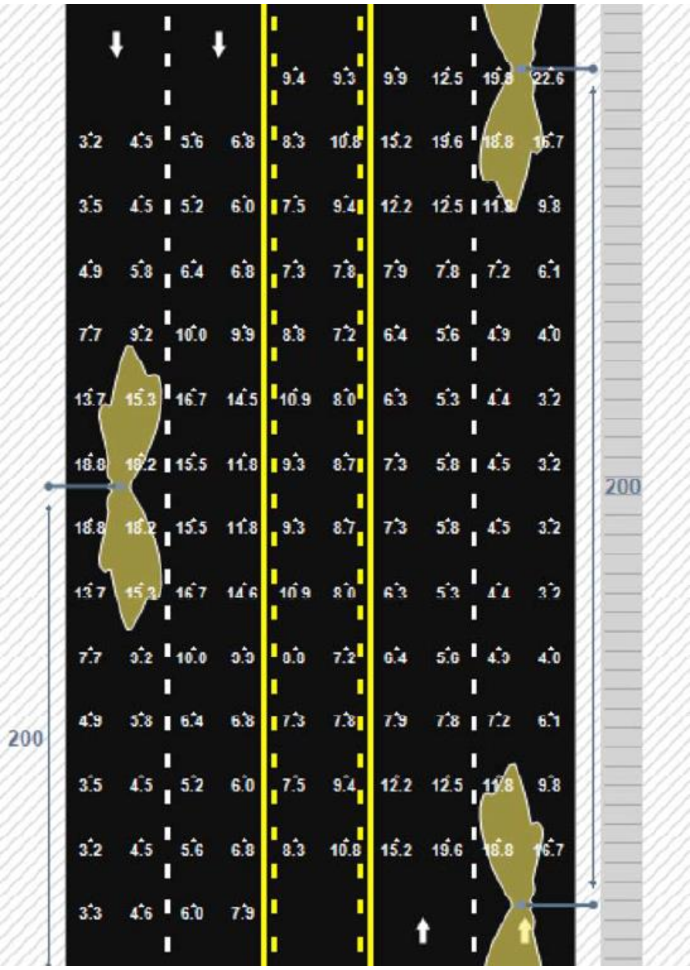


Figure 10. Photometric analysis of existing conditions along the Central Avenue section with 150 W HPS luminaires spaced 200 ft apart on each side of the road.

Summary of Existing Lighting Conditions

For the SSP West and SSP East sections, the field measurements and the photometric analyses confirmed that the lighting in both of these sections are performing as initially designed in the 1970s and 1980s and that they are being maintained to achieve the average design illuminance of 6 lx in the roadway traveling lanes. For the Central Avenue section, the measured light levels on the sidewalk areas are also consistent with the calculated values from the photometric models using 150 W HPS lighting systems. In the eastern portion of this section, measured light levels were consistent with the model calculations assuming 250 HPS lighting systems. This agreement between the measured and calculated values was sufficient to move forward in photometric analysis of alternative LED lighting systems in each section.

Existing Traffic and Pedestrian Volume Conditions

The project team gathered traffic volume information for the relevant sections of the SSP from NYSDOT Region 10 staff. Data from 2008 were available. Average annual daily traffic volumes for the SSP West section were 80,104 (eastbound) and 81,218 (westbound) vehicles per day between Exits 19 and 20; they were 88,069 (eastbound) and 81,821 (westbound) vehicles per day between Exits 21 and 22. For the SSP East section, average annual daily traffic volumes between Exit 31 and the Suffolk County line were 80,589 (eastbound) and 76,039 (westbound) vehicles per day. The SSP is a freeway with no pedestrian access facilities so data for pedestrian volumes are unavailable. When looking at hourly traffic volume throughout the nominal nighttime period (defined here as 7:00 p.m. to 6:59 a.m.), the distributions of nighttime traffic at each section followed similar patterns (Figures 11 and 12) to each other and to published data used by Bullough and Rea (2011) to investigate the effectiveness of adaptive lighting strategies.

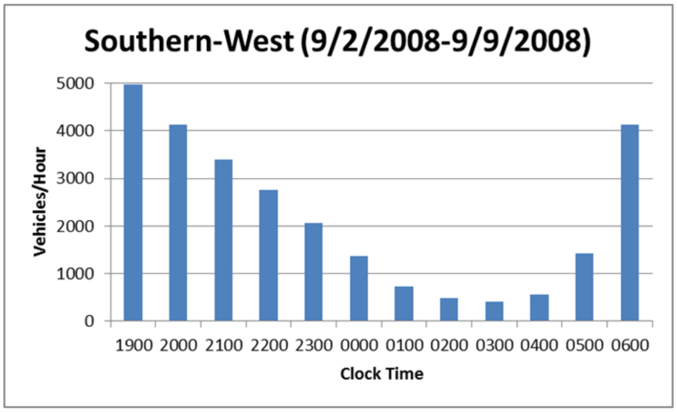


Figure 11. Histogram of hourly nighttime traffic along an SSP West segment.

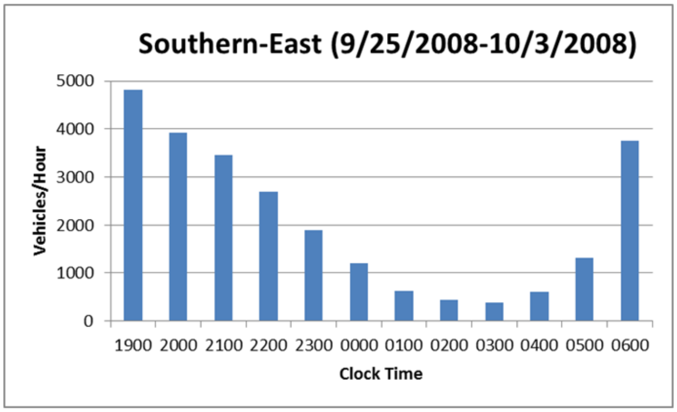


Figure 12. Histogram of hourly nighttime traffic along an SSP East segment.

The project team obtained traffic count data for the Central Avenue section from the NYSDOT Traffic Data Viewer website (http://gis.dot.ny.gov/tdv/). The total average annual daily traffic volume for traffic in both directions was 25,523 vehicles per day along the segment of Central Avenue west of New Karner Road, and 43,208 vehicles per day along the segment east of New Karner Road. To obtain the nighttime traffic volume profile in cooperation with NYSDOT Region 1, the project team installed a radar speed display sign (All Traffic Solution, Speed 15) to a pedestrian signal pole at the intersection of Central Avenue and Reber Street. The sign was set so that it collected traffic (and speed) data for traffic traveling in the westbound direction but did not display anything to oncoming traffic. Figure 13 shows the hourly temporal profile of nighttime traffic from 7:00 p.m. to 6:59 a.m. for a measurement made in 2015. These data should be considered relative rather than absolute because the speed display sign might not count following vehicles within a platoon of vehicles traveling closely together.

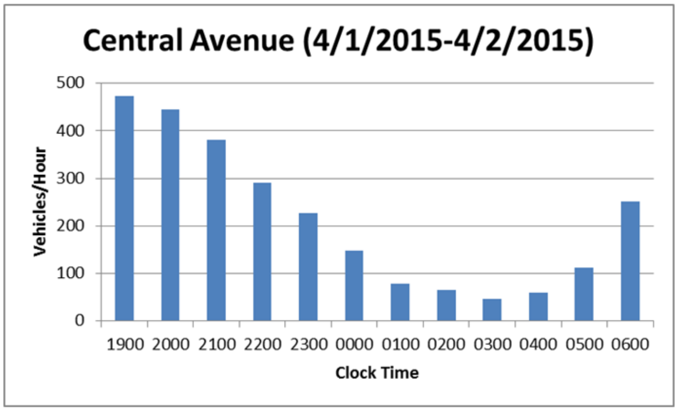


Figure 13. Histogram of hourly nighttime traffic along a Central Avenue segment.

The data in Figure 13 also appear qualitatively similar to those in Figures 11 and 12, and to the data used by Bullough and Rea (2011) in their investigation of adaptive lighting strategies. The project team also reviewed pedestrian count data from the NYSDOT study of pedestrian safety along the Route 5 corridor (Creighton Manning, 2014) for hours including darkness, generally in the early evening. Using the IES (2000, 2014) definition of nighttime pedestrian use as low (≤10 pedestrians per hour), medium (>10 and ≤100 pedestrians per hour), or high (>100 pedestrians per hour), the following locations along the Central Avenue section would be classified as follows:

- Vly Road: medium
- Wolf Road/I-87 ramp: medium
- Northway Mall West/Colonie Center: high
- Northway Mall East/Colonie Center: medium
- Fuller Road: medium
- Nicholas Drive: low
- Willow Avenue: medium
- Lanci Lane: medium
- Jupiter Lane: medium
- Parkwood Drive: medium
- Reber Street: medium
- Colonie Plaza: medium
- New Karner Road: medium

Most of these locations are consistent with a medium level of pedestrian use, which corresponds to a light level criterion of 13 lx on the roadway for major (arterial) roads.

3. PHOTOMETRIC ANALYSIS OF ALTERNATIVES

Lighting Criteria

As described above, the existing lighting systems along the segments of the SSP and Central Avenue that were investigated were designed in the 1970s and 1980s. The illuminance criterion of 6 lx used on the SSP corresponds to the “Freeway B” roadway type described by the IES (2000, 2014). Based on discussions about the traffic volume and safety issues on the SSP with NYSDOT engineers in Region 10 and in the Main Office, NYSDOT desired to use an increased illuminance of 9 lx on the SSP if the lighting were to be retrofitted, corresponding to a “Freeway A” classification, which is for roadways with high traffic volumes (recent traffic volume data for the SSP in the locations studied show an average annual daily traffic volume exceeding 75,000 vehicles per day).

On Central Avenue, the existing lighting system provides an average illuminance on the roadway of about 9 lx when the lighting uses a 150 W HPS system and about 15 lx when the lighting uses a 250 W HPS system. In the NYSDOT’s recent pedestrian safety study of the Route 5 corridor (Creighton Manning, 2014) it was pointed out that the light levels in several locations were lower than would be specified by present-day IES (2000, 2014) recommendations. For an arterial roadway like Central Avenue, the roadway illuminance criterion for medium levels of pedestrian use is 13 lx, and for high levels of pedestrian use is 17 lx.

The target illuminance values of 9 lx for the SSP, and 13 lx for Central Avenue when replacing a 150 W HPS lighting system are used in this section of the report to evaluate retrofit lighting options along the three roadway sections under evaluation.

SSP West Section

The project team identified several commercially-available LED roadway lighting products with suitable light output for the SSP West roadway section. As shown in Figure 14, poles on this segment are located across from each other, spaced 284 ft apart. This image was created in the lighting calculation software (AGi32, Lighting Analysts) used to consider the LED roadway lighting products.

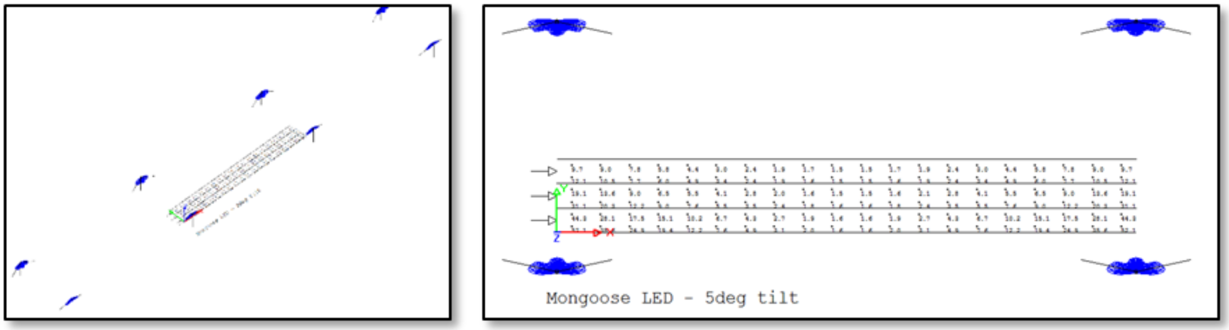
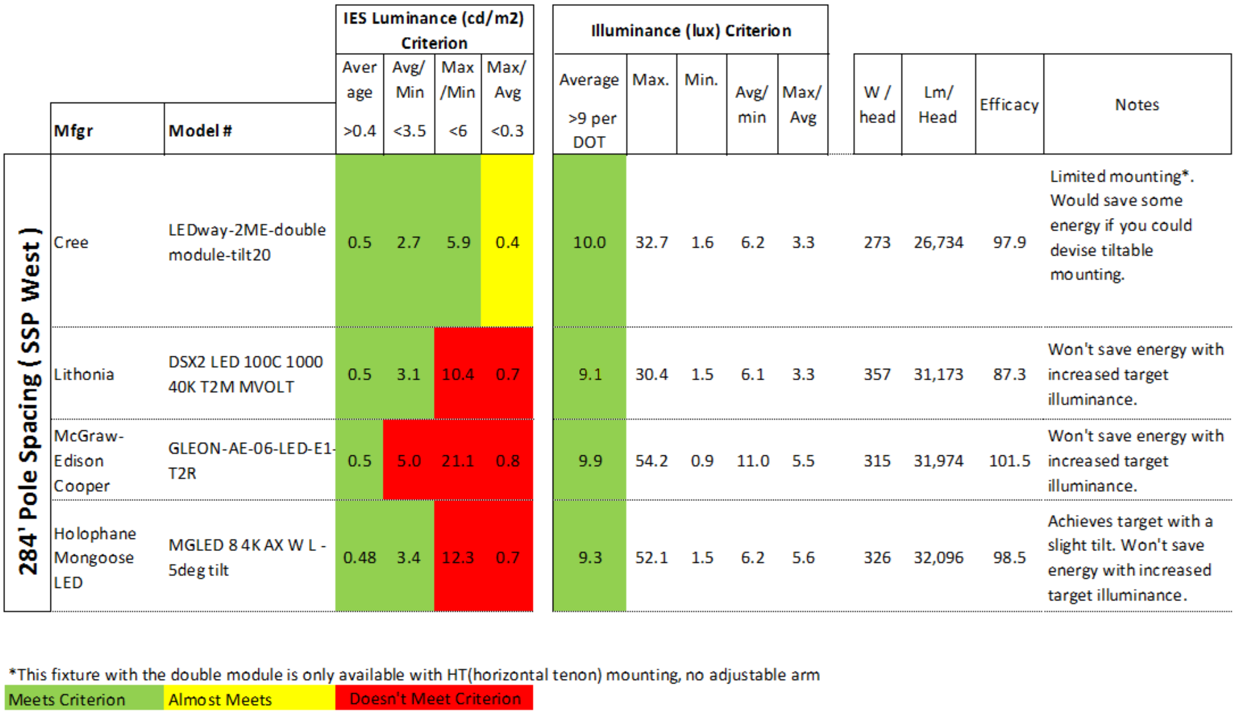


Figure 14. Example lighting calculation for the SSP West section, with poles spaced 284 ft apart.

The project team ran calculations for 40 different LED roadway lighting products from seven different manufacturers. Most were calculated assuming horizontal head orientation, not a tilted head, as this is consistent with recommended industry practice for minimizing offensive light such as sky glow or light trespass. The analyses focused on products with a Type II medium distribution and a light output ranging 25,000 to 32,000 lm, similar to the output of the existing HPS luminaire at this location. Shown in Table 1 are the four most promising options identified in this analysis (two required tilting, of 20° or 5° to produce the necessary illuminance). Each would meet the increased average maintained illuminance requirements preferred by NYSDOT (9 lx).



			IES Luminance (cd/m2) Criterion				Illuminance (lux) Criterion								
	Mfgr	Model #	Average >0.4	Avg/ Min <3.5	Max /Min <6	Max/ Avg <0.3	Average >9 per DOT	Max.	Min.	Avg/ min	Max/ Avg	W / head	Lm/ Head	Efficacy	Notes
284' Pole Spacing (SSP West)	Cree	LEDway-2ME-double module-tilt20	🟩 0.5	🟩 2.7	🟩 5.9	🟨 0.4	🟩 10.0	32.7	1.6	6.2	3.3	273	26,734	97.9	Limited mounting*. Would save some energy if you could devise tiltable mounting.
	Lithonia	DSX2 LED 100C 1000 40K T2M MVOLT	🟩 0.5	🟩 3.1	🟥 10.4	🟥 0.7	🟩 9.1	30.4	1.5	6.1	3.3	357	31,173	87.3	Won't save energy with increased target illuminance.
	McGraw-Edison Cooper	GLEON-AE-06-LED-E1-T2R	🟩 0.5	🟥 5.0	🟥 21.1	🟥 0.8	🟩 9.9	54.2	0.9	11.0	5.5	315	31,974	101.5	Won't save energy with increased target illuminance.
	Holophane Mongoose LED	MGLED 8 4K AX W L - 5deg tilt	🟩 0.48	🟩 3.4	🟥 12.3	🟥 0.7	🟩 9.3	52.1	1.5	6.2	5.6	326	32,096	98.5	Achieves target with a slight tilt. Won't save energy with increased target illuminance.

*This fixture with the double module is only available with HT(horizontal tenon) mounting, no adjustable arm

🟩 Meets Criterion 🟨 Almost Meets 🟥 Doesn't Meet Criterion

Table 1. LED retrofit alternative photometric analysis summary for the SSP West section.

Also shown in Table 1 are the IES (2000, 2014) luminance (cd/m^2) criteria for overall average luminance and three possible luminance ratios. All four systems pass the average luminance criterion. None of these four LED products pass all of the luminance and glare ratio criteria at this (wide) pole spacing. One luminaire approaches the glare criterion while meeting the luminance ratio criteria, but a mounting bracket to allow it to be tilted is not available commercially.

SSP East Section

The project team conducted photometric analyses for the western section of the SSP, where the poles are spaced closer together (typical spacing: 249 ft) than in the SSP West section (typical spacing: 284 ft). Assuming that it would be preferable to retrofit the SSP East section with luminaires in the same luminaire manufacturer's family, LRC considered the four products shown in Table 1 for the SSP East section. In the portion of this section in which field measurements were made, the poles have a staggered spacing, and a longer mast arm that brings them closer to the roadway (Figure 15).

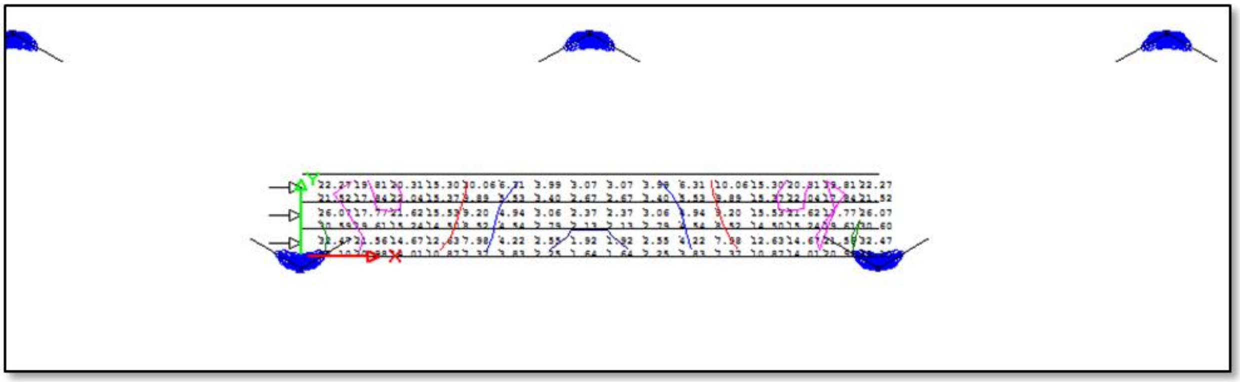
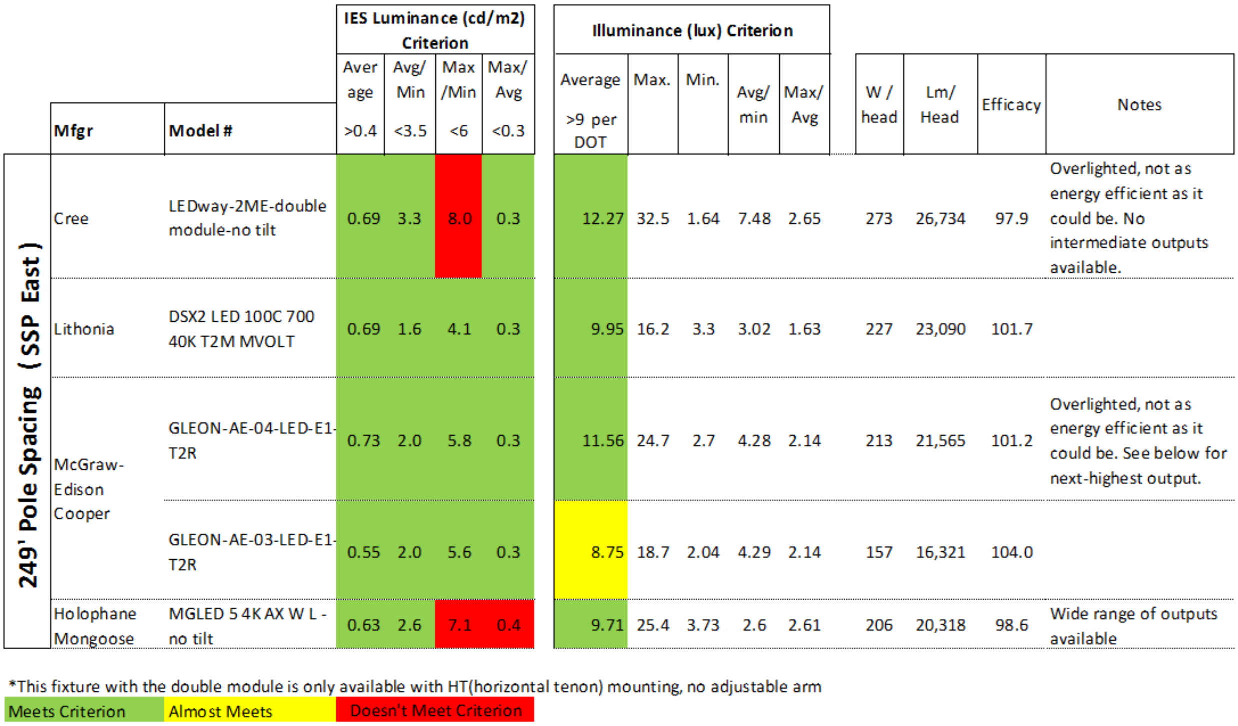


Figure 15. Example lighting calculation for the SSP East section, with poles spaced 249 ft apart.

Shown in Table 2 are the results of the photometric analyses for the SSP East section. Because of the available lumen output values of the lighting systems that were evaluated, some of the retrofit options in Table 2 result in light levels that are substantially higher than the 9 lx illuminance criterion used as a target value. One LED system using 157 W produced just barely under 9 lx when producing 70% of its initial light output.



			IES Luminance (cd/m2) Criterion				Illuminance (lux) Criterion								
	Mfgr	**Model #**	Average >0.4	Avg/ Min <3.5	Max /Min <6	Max/ Avg <0.3	Average >9 per DOT	Max.	Min.	Avg/ min	Max/ Avg	W / head	Lm/ Head	Efficacy	Notes
249' Pole Spacing (SSP East)	Cree	LEDway-2ME-double module-no tilt	0.69	3.3	🟥 8.0	0.3	12.27	32.5	1.64	7.48	2.65	273	26,734	97.9	Overlighted, not as energy efficient as it could be. No intermediate outputs available.
	Lithonia	DSX2 LED 100C 700 40K T2M MVOLT	0.69	1.6	4.1	0.3	9.95	16.2	3.3	3.02	1.63	227	23,090	101.7	
	McGraw-Edison Cooper	GLEON-AE-04-LED-E1-T2R	0.73	2.0	5.8	0.3	11.56	24.7	2.7	4.28	2.14	213	21,565	101.2	Overlighted, not as energy efficient as it could be. See below for next-highest output.
		GLEON-AE-03-LED-E1-T2R	0.55	2.0	5.6	0.3	🟨 8.75	18.7	2.04	4.29	2.14	157	16,321	104.0	
	Holophane Mongoose	MGLED 5 4K AX W L - no tilt	0.63	2.6	🟥 7.1	🟥 0.4	9.71	25.4	3.73	2.6	2.61	206	20,318	98.6	Wide range of outputs available

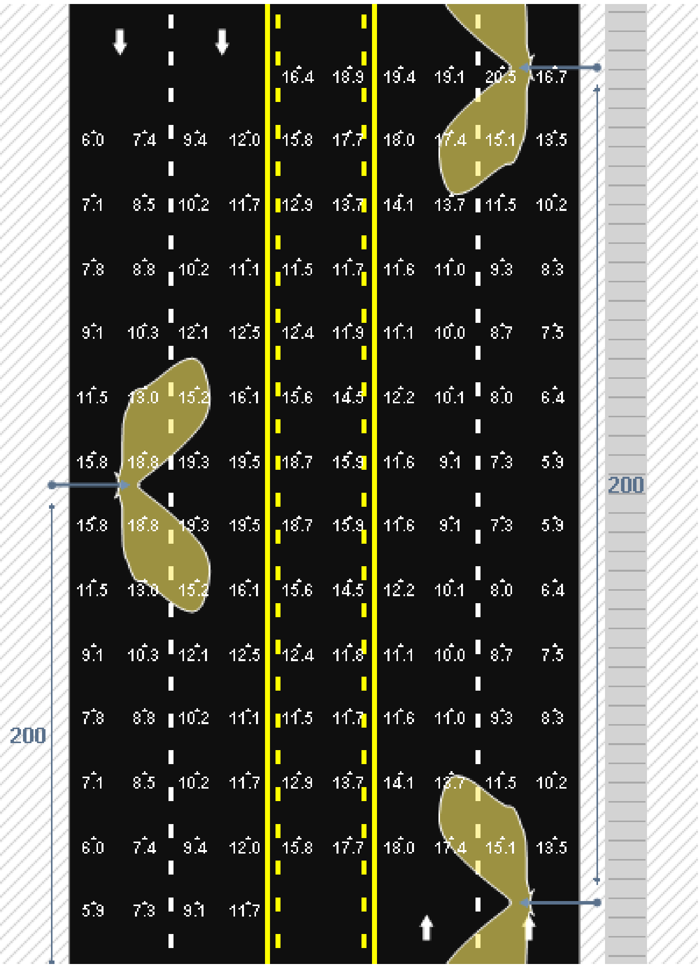
*This fixture with the double module is only available with HT(horizontal tenon) mounting, no adjustable arm

🟩 Meets Criterion 🟨 Almost Meets 🟥 Doesn't Meet Criterion

Table 2. LED retrofit alternative photometric analysis summary for the SSP East section.

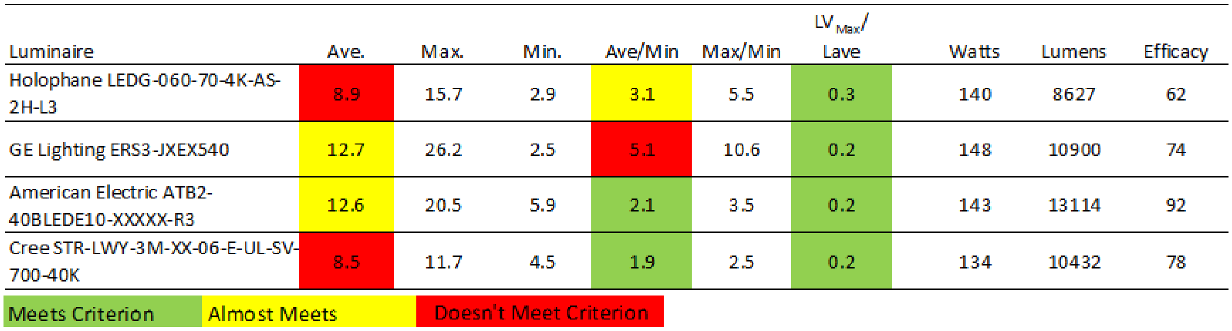
Central Avenue Section

The project team evaluated several LED luminaire options for the Central Avenue section using photometrically accurate lighting calculation software (Visual 2012, Roadway Tool, Acuity Brands), assuming a pole spacing of 200 ft in a staggered layout (Figure 16). Two of the systems produce maintained illuminances just barely under the target criterion level of 13 lx, while the other two fall short of meeting this criterion. All of the luminaires evaluated met the luminance ratio criterion for the maximum veiling luminance to the average roadway luminance.



				16.4	18.9	19.4	19.1	20.5	16.7
6.0	7.4	9.4	12.0	15.8	17.7	18.0	17.4	15.1	13.5
7.1	8.5	10.2	11.7	12.9	13.7	14.1	13.7	11.5	10.2
7.8	8.8	10.2	11.1	11.5	11.7	11.6	11.0	9.3	8.3
9.1	10.3	12.1	12.5	12.4	11.9	11.1	10.0	8.7	7.5
11.5	13.0	15.2	16.1	15.6	14.5	12.2	10.1	8.0	6.4
15.8	18.8	19.3	19.5	18.7	15.9	11.6	9.1	7.3	5.9
15.8	18.8	19.3	19.5	18.7	15.9	11.6	9.1	7.3	5.9
11.5	13.0	15.2	16.1	15.6	14.5	12.2	10.1	8.0	6.4
9.1	10.3	12.1	12.5	12.4	11.8	11.1	10.0	8.7	7.5
7.8	8.8	10.2	11.1	11.5	11.7	11.6	11.0	9.3	8.3
7.1	8.5	10.2	11.7	12.9	13.7	14.1	13.7	11.5	10.2
6.0	7.4	9.4	12.0	15.8	17.7	18.0	17.4	15.1	13.5
5.9	7.3	9.1	11.7						

Figure 16. Example lighting calculation for the Central Avenue section, with poles spaced 200 ft apart.



Luminaire	Ave.	Max.	Min.	Ave/Min	Max/Min	LV_{Max}/ Lave	Watts	Lumens	Efficacy
Holophane LEDG-060-70-4K-AS-2H-L3	8.9	15.7	2.9	3.1	5.5	0.3	140	8627	62
GE Lighting ERS3-JXEX540	12.7	26.2	2.5	5.1	10.6	0.2	148	10900	74
American Electric ATB2-40BLEDE10-XXXXX-R3	12.6	20.5	5.9	2.1	3.5	0.2	143	13114	92
Cree STR-LWY-3M-XX-06-E-UL-SV-700-40K	8.5	11.7	4.5	1.9	2.5	0.2	134	10432	78

🟩 Meets Criterion 🟨 Almost Meets 🟥 Doesn't Meet Criterion

Table 3. LED retrofit alternative photometric analysis summary for the Central Avenue section.

Summary

For each location, there is at least one lighting system that can meet (or just barely meet) the light level criteria for each roadway (9 lx average on the SSP, 13 lx average on Central Avenue) with the existing pole spacing conditions as evaluated above, while using less power than the incumbent systems (295 W per pole for the 250 W HPS systems, and 190 W per pole for the 150 W HPS systems). In the subsequent section of the present report, economic analyses will be performed for those systems to identify whether they can result in a net benefit in terms of overall life cycle costs.

4. ECONOMIC ANALYSES

Retrofit of Existing Lighting Systems

For the LED lighting system on the SSP West section that used less energy than the existing lighting system, a simple energy economic analysis was performed to identify the relative payback of installing the LED system, compared to utilizing the existing system. Energy cost information from Regions 1 and 10 and from the Long Island Power Authority (LIPA) and National Grid tariffs for street lighting was used, along with an estimated luminaire installation cost of $110/luminaire (Swanson and Carlson, 2012). For all economic analyses, luminaire cost data were provided by manufacturers' representatives/distributors, and using price information obtained on the Internet, with adjustments for high-volume purchasing.

Southern State Parkway West			
Cree LEDway-2ME-double module-tilt20			
Luminaires	Wattage	Subtotal	
539	295	159005	W
Power Savings (%)		7.5%	
Power Savings		11858	W
Hours/yr		4380	hr
kWh/yr savings		51938	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$10,543	
Luminaire price (ea)		$690	ea
Luminaire cost		$371,910	
Installation cost		$59,290	
Payback		41	yr

Table 4. Energy economic analysis for the SSP West section LED alternative.

Primarily because of the relatively low energy savings compared to the existing lighting that is achievable at this location, the payback period is quite long (>40 years). In part this is related to the lack of energy-reducing options for achieving the 9 lx criterion with the high pole spacing used along this portion of the SSP.

For the SSP East section, there were several viable LED alternative systems able to achieve the 9 lx criterion with the pole spacing at this location. Table 5 shows the energy economic analyses for the alternative systems at this location, compared to the existing lighting configuration. Because the magnitude of energy savings for the SSP East section is larger than for the SSP West section, payback periods are relatively shorter in these comparisons, and are influenced by the initial cost of the luminaires ($850-$1112).

Southern State Parkway East			
Lithonia DSX2 LED 100C 700 40K T2M MVOLT			
Luminaires	Wattage	Subtotal	
588	295	173460	W
Power Savings (%)		23.1%	
Power Savings		39984	W
Hours/yr		4380	hr
kWh/yr savings		175130	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$35,551	
Luminaire price (ea)		$1,112	ea
Luminaire cost		$653,856	
Installation cost		$64,680	
Payback		20	yr

Southern State Parkway East			
McGraw GLEON-AE-04-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	295	173460	W
Power Savings (%)		27.8%	
Power Savings		48216	W
Hours/yr		4380	hr
kWh/yr savings		211186	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$42,871	
Luminaire price (ea)		$1,086	ea
Luminaire cost		$638,568	
Installation cost		$64,680	
Payback		16	yr

Southern State Parkway East			
McGraw GLEON-AE-03-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	295	173460	W
Power Savings (%)		46.8%	
Power Savings		81144	W
Hours/yr		4380	hr
kWh/yr savings		355411	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$72,148	
Luminaire price (ea)		$912	ea
Luminaire cost		$536,256	
Installation cost		$64,680	
Payback		8	yr

Southern State Parkway East			
Holophane Mongoose MGLED 5 4K AX W L-no tilt			
Luminaires	Wattage	Subtotal	
588	295	173460	W
Power Savings (%)		30.2%	
Power Savings		52332	W
Hours/yr		4380	hr
kWh/yr savings		229214	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$46,530	
Luminaire price (ea)		$850	ea
Luminaire cost		$499,800	
Installation cost		$64,680	
Payback		12	yr

Table 5. Energy economic analysis for the SSP East section LED alternatives.

For the Central Avenue section, the energy economic analyses for the viable LED alternatives are shown in Table 6. Largely because of the reduced energy savings in this location compared to the SSP East section, the payback periods based on energy use are longer.

Central Avenue			
GE Lighting ERS3-JXEX540			
Luminaires	Wattage	Subtotal	
150	190	28500	W
Power Savings (%)		22.1%	
Power Savings		6300	W
Hours/yr		4380	hr
kWh/yr savings		27594	kWh/yr
Cost/kWh		$0.15	
Energy savings/yr ($)		$4,078	
Luminaire price (ea)		$708	ea
Luminaire cost		$106,200	
Installation cost		$16,500	
Payback		30	yr

Central Avenue			
American Electric ATB2-40BLEDE10-XXXXX-R3			
Luminaires	Wattage	Subtotal	
150	190	28500	W
Power Savings (%)		24.7%	
Power Savings		7050	W
Hours/yr		4380	hr
kWh/yr savings		30879	kWh/yr
Cost/kWh		$0.15	
Energy savings/yr ($)		$4,564	
Luminaire price (ea)		$730	ea
Luminaire cost		$109,500	
Installation cost		$16,500	
Payback		28	yr

Table 6. Energy economic analysis for the Central Avenue section LED alternatives.

Updating Lighting Criteria

The energy economic analyses for the comparisons listed above for the retrofit scenarios take into account both an increase in the criterion light levels and the cost of the LED retrofit lighting system. In order to assess a more direct comparison between the existing HPS technology and the LED alternatives, the economic analyses were performed using an increased HPS wattage for the baseline system (from 250 W HPS to 400 W HPS, and from 150 W HPS to 250 W HPS). Table 7 shows the economic analysis for the SSP West section; Table 8 shows the analyses for the SSP East section; and Table 9 shows the analyses for the Central Avenue section. In each case the payback periods based on energy use are lower than reported in Tables 4, 5 and 6.

Southern State Parkway West			
Cree LEDway-2ME-double module-tilt20			
Luminaires	Wattage	Subtotal	
539	465	250635	W
Power Savings (%)		41.3%	
Power Savings		103488	W
Hours/yr		4380	hr
kWh/yr savings		453277	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$92,015	
Luminaire price (ea)		$690	ea
Luminaire cost		$371,910	
Installation cost		$59,290	
Payback		5	yr

Table 7. Energy economic analysis for the SSP West section LED alternative, compared to the higher-wattage baseline.

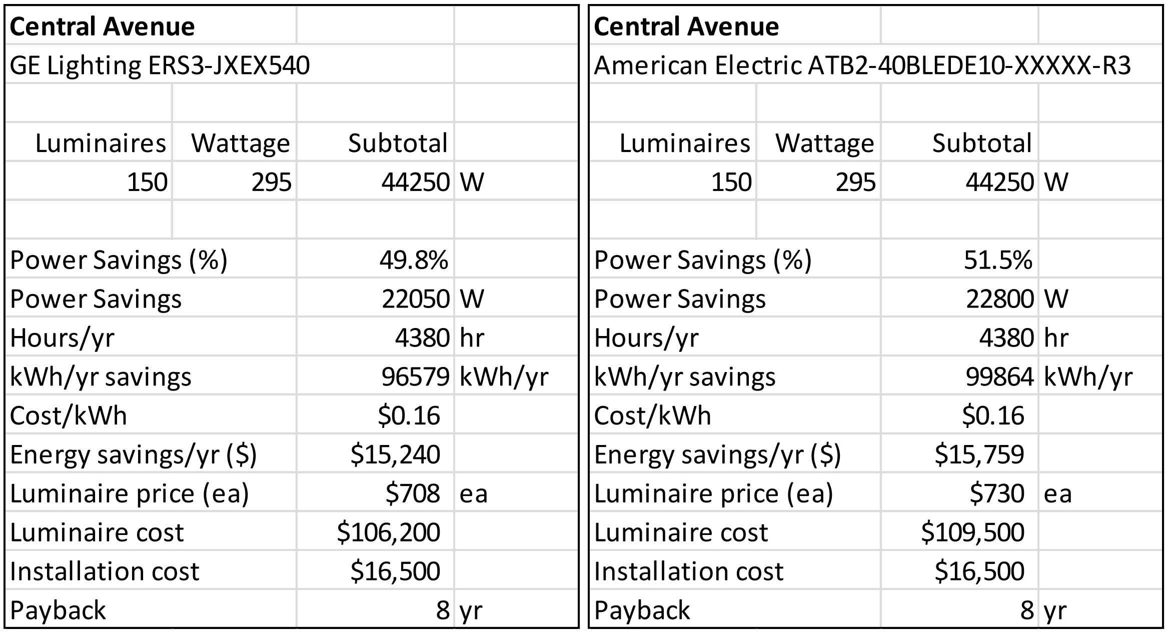
Southern State Parkway East			
Lithonia DSX2 LED 100C 700 40K T2M MVOLT			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		51.2%	
Power Savings		139944	W
Hours/yr		4380	hr
kWh/yr savings		612955	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$124,430	
Luminaire price (ea)		$1,112	ea
Luminaire cost		$653,856	
Installation cost		$64,680	
Payback		6	yr

Southern State Parkway East			
McGraw GLEON-AE-04-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		54.2%	
Power Savings		148176	W
Hours/yr		4380	hr
kWh/yr savings		649011	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$131,749	
Luminaire price (ea)		$1,086	ea
Luminaire cost		$638,568	
Installation cost		$64,680	
Payback		5	yr

Southern State Parkway East			
McGraw GLEON-AE-03-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		66.2%	
Power Savings		181104	W
Hours/yr		4380	hr
kWh/yr savings		793236	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$161,027	
Luminaire price (ea)		$912	ea
Luminaire cost		$536,256	
Installation cost		$64,680	
Payback		4	yr

Southern State Parkway East			
Holophane Mongoose MGLED 5 4K AX W L-no tilt			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		55.7%	
Power Savings		152292	W
Hours/yr		4380	hr
kWh/yr savings		667039	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$135,409	
Luminaire price (ea)		$850	ea
Luminaire cost		$499,800	
Installation cost		$64,680	
Payback		4	yr

Table 8. Energy economic analysis for the SSP East section LED alternatives, compared to the higher-wattage baseline.



Central Avenue			
GE Lighting ERS3-JXEX540			
Luminaires	Wattage	Subtotal	
150	295	44250	W
Power Savings (%)		49.8%	
Power Savings		22050	W
Hours/yr		4380	hr
kWh/yr savings		96579	kWh/yr
Cost/kWh		$0.16	
Energy savings/yr ($)		$15,240	
Luminaire price (ea)		$708	ea
Luminaire cost		$106,200	
Installation cost		$16,500	
Payback		8	yr

Central Avenue			
American Electric ATB2-40BLEDE10-XXXXX-R3			
Luminaires	Wattage	Subtotal	
150	295	44250	W
Power Savings (%)		51.5%	
Power Savings		22800	W
Hours/yr		4380	hr
kWh/yr savings		99864	kWh/yr
Cost/kWh		$0.16	
Energy savings/yr ($)		$15,759	
Luminaire price (ea)		$730	ea
Luminaire cost		$109,500	
Installation cost		$16,500	
Payback		8	yr

Table 9. Energy economic analysis for the Central Avenue section LED alternatives, with the higher-wattage baseline.

Analyses with Adaptive Lighting Controls

Adaptive, or dynamic, roadway lighting is the use of different light levels for different times of the night, in response to changes in traffic volume or pedestrian use (Bullough, 2010). It can be achieved by specifying the use of lower light levels during specific hours of the night, such as after midnight. In some applications such as parking lot lighting, adaptive lighting could use occupancy/motion sensor control to reduce light levels when a parking lot or portion thereof is inactive (Figure 17).

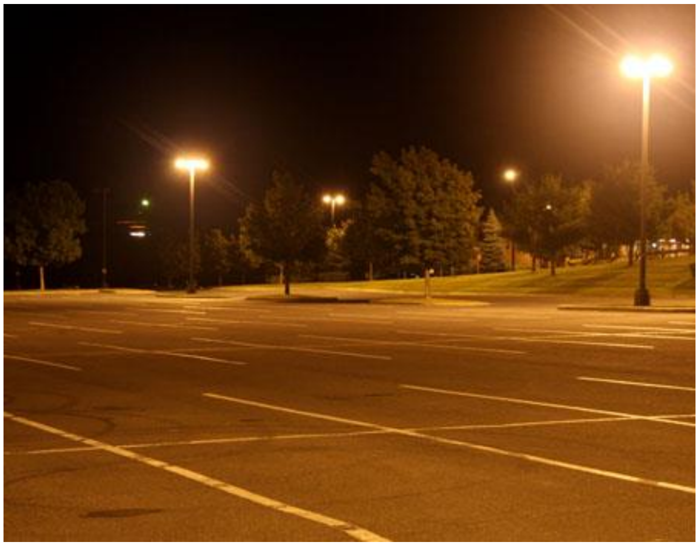
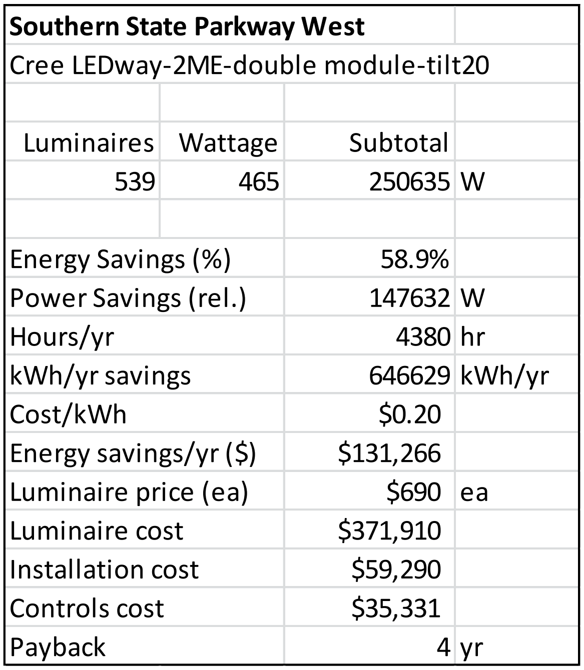


Figure 17. Adaptive lighting could help avoid excessive energy use by switching off outdoor lighting when levels of use are low.

The traffic volume information provided in an earlier section of this report indicate that there is substantially lower traffic volumes in the late night hours than in the initial hours of the evening (although on the SSP, even in the least busy periods, several hundred vehicles per hour use this highway). According to IES (2014) recommendations, light levels may be adjusted based on pedestrian use; when major roadways change from high to medium pedestrian activity, a light level reduction of 25% is permissible. When the pedestrian activity level changes from medium to low pedestrian activity, a reduction in light level of 33% is permissible.

IES (2014) also states that jurisdictions may adjust light levels, if the traffic patterns change sufficiently so that the classification of a roadway corresponds to a lower category. If the roadway classification changes because of traffic volume from a major to a local roadway, the light level reductions would be on the order of 50%. Bullough (2010) estimated that overall energy savings of 30% could be achievable with adaptive lighting strategies that reduced the light level by 50% during less busy periods of the night. Winner and Arnold (2014) estimated that lighting controls for adaptive LED roadway lighting cost, on average, 9.5% of the cost of the LED luminaire equipment costs. Tables 10, 11 and 12 show the economic analyses from Tables 7, 8 and 9 including the initial costs of lighting controls and the additional 30% energy savings that they could yield.

Despite the increased costs of installing lighting controls, the increased energy savings would be expected to reduce the payback periods compared to the scenarios without adaptive lighting controls.



Southern State Parkway West			
Cree LEDway-2ME-double module-tilt20			
Luminaires	Wattage	Subtotal	
539	465	250635	W
Energy Savings (%)		58.9%	
Power Savings (rel.)		147632	W
Hours/yr		4380	hr
kWh/yr savings		646629	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$131,266	
Luminaire price (ea)		$690	ea
Luminaire cost		$371,910	
Installation cost		$59,290	
Controls cost		$35,331	
Payback		4	yr

Table 10. Energy economic analysis for the SSP West section LED alternative with adaptive controls, compared to the higher-wattage baseline.

Southern State Parkway East			
Lithonia DSX2 LED 100C 700 40K T2M MVOLT			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Energy Savings (%)		65.8%	
Power Savings (rel.)		179987	W
Hours/yr		4380	hr
kWh/yr savings		788342	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$160,033	
Luminaire price (ea)		$1,112	ea
Luminaire cost		$653,856	
Installation cost		$64,680	
Controls cost		$62,116	
Payback		5	yr

Southern State Parkway East			
McGraw GLEON-AE-04-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		67.9%	
Power Savings		185749	W
Hours/yr		4380	hr
kWh/yr savings		813581	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$165,157	
Luminaire price (ea)		$1,086	ea
Luminaire cost		$638,568	
Installation cost		$64,680	
Controls cost		$60,664	
Payback		5	yr

Southern State Parkway East			
McGraw GLEON-AE-03-LED-E1-T2R			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		76.4%	
Power Savings		208798.8	W
Hours/yr		4380	hr
kWh/yr savings		914539	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$185,651	
Luminaire price (ea)		$912	ea
Luminaire cost		$536,256	
Installation cost		$64,680	
Controls cost		$50,944	
Payback		4	yr

Southern State Parkway East			
Holophane Mongoose MGLED 5 4K AX W L-no tilt			
Luminaires	Wattage	Subtotal	
588	465	273420	W
Power Savings (%)		69.0%	
Power Savings		188630.4	W
Hours/yr		4380	hr
kWh/yr savings		826201	kWh/yr
Cost/kWh		$0.20	
Energy savings/yr ($)		$167,719	
Luminaire price (ea)		$850	ea
Luminaire cost		$499,800	
Installation cost		$64,680	
Controls cost		$47,481	
Payback		4	yr

Table 11. Energy economic analysis for the SSP East section LED alternatives with adaptive controls, compared to the higher-wattage baseline.

Central Avenue			
GE Lighting ERS3-JXEX540			
Luminaires	Wattage	Subtotal	
150	295	44250	W
Energy Savings (%)		64.9%	
Power Savings (rel.)		28710	W
Hours/yr		4380	hr
kWh/yr savings		125750	kWh/yr
Cost/kWh		$0.15	
Energy savings/yr ($)		$18,586	
Luminaire price (ea)		$708	ea
Luminaire cost		$106,200	
Installation cost		$16,500	
Controls cost		$10,089	
Payback		7	yr

Central Avenue			
American Electric ATB2-40BLEDE10-XXXXX-R3			
Luminaires	Wattage	Subtotal	
150	295	44250	W
Power Savings (%)		66.1%	
Power Savings		29235	W
Hours/yr		4380	hr
kWh/yr savings		128049	kWh/yr
Cost/kWh		$0.15	
Energy savings/yr ($)		$18,926	
Luminaire price (ea)		$730	ea
Luminaire cost		$109,500	
Installation cost		$16,500	
Controls cost		$10,403	
Payback		7	yr

Table 12. Energy economic analysis for the Central Avenue section LED alternatives with adaptive controls, compared to the higher-wattage baseline.

Summary

The economic analyses summarized above suggest that there are opportunities for saving energy by retrofitting existing HPS lighting systems on parkways such as the SSP and on arterial roadways such as Central Avenue, with LED lighting systems. This is true even when the light level criteria for the retrofit systems are higher than for the original HPS systems currently in place: energy savings of 7%-48% were possible, despite higher light levels. Greater energy savings would be achievable when comparing installations with similar light levels, or when LED systems are used in conjunction with adaptive lighting strategies. In all cases, simple payback based on energy savings was able to recover initial costs with payback periods ranging from 4 to 41 years.

5. DISCUSSION AND CONCLUSIONS

The results of the photometric and economic analyses in the previous sections of this report suggest that there are opportunities for saving energy by retrofitting existing HPS lighting systems on parkways such as the SSP and on arterial roadways such as Central Avenue, with LED lighting systems. This is true even when the light level criteria for the retrofit systems are higher than for the original HPS systems currently in place: energy savings of 7%-48% were possible, despite higher light levels. When comparing the energy savings with HPS systems of comparable light levels, the energy savings was even larger: 41%-66%; including adaptive lighting control resulted in greater energy savings of 59%-76%. The energy savings for each roadway section evaluated would result in the following reductions of greenhouse gas emissions, based on U.S. Environmental Protection Agency (2009) estimates:

- SSP West section: 0.05-0.64 tons of NO_x per year, 0.14-1.7 tons of SO_2 per year, 34-429 tons of CO_2 per year
- SSP East section: 0.17-0.91 tons of NO_x per year, 0.46-2.4 tons of SO_2 per year, 116-607 tons of CO_2 per year
- Central Avenue section: 0.03-0.13 tons of NO_x per year, 0.07-0.34 tons of SO_2 per year, 18-85 tons of CO_2 per year

In all cases, simple payback based on energy savings was able to recover initial costs, albeit with payback periods ranging from 4 to 41 years. Of course, in addition to energy savings, an additional expected source of economic savings would be maintenance savings, given expected lives of 50,000 hours as a typical rated life for LED systems compared to 24,000-30,000 hours for conventional HPS lighting systems. It is estimated by Winner and Arnold (2014) that maintenance savings will be at least as large as, or larger than, energy savings in terms of economics. LED luminaire costs are relatively high in comparison to conventional luminaires, and when HPS systems fail only the lamp typically needs replacement. For example, Region 10 estimated that their relamping costs along the SSP were approximately $75 per luminaire every 1-2 years. Whether the higher initial cost of LED luminaires would be offset by the need for less frequent maintenance, or possibly by reductions in costs in the future, remains to be seen. It is for this reason that economic analyses in the present report have been focused on energy costs.

Specification Issues

Warranty

A concern when installing new lighting technologies such as LED roadway lighting is the system reliability, particularly in the face of rapidly evolving technologies, a wide variety of lighting system configurations, and many manufacturers. It has been typical to find that when installing a large number of luminaires that some percentage of them will exhibit early initial failures (Peterson et al., 2014). Most manufacturers offer warranties for luminaire performance of five years; one manufacturer (Cree) offers a warranty of ten years. Warranties typically cover luminaire defects in materials or workmanship, including the drivers for the LED light sources. For example, one manufacturer's warranty states that if more than 10% of the LEDs in the luminaire are not operating, the warranty would trigger. Warranties for controls and photocells may be covered under separate warranties with different durations. These warranty periods are similar in magnitude to the shortest payback periods indicated in Tables 4 through 12. Additionally it should be noted that all of the LED lighting systems meeting the necessary photometric criteria for retrofit applications come from manufacturers with histories in the lighting industry preceding the LED lighting transformation (Cree, a solid state lighting company, acquired Ruud Lighting which has been in the lighting manufacturing business). This may indicate that replacement products compatible with the evaluated systems might continue to be available in the future, even after warranty periods expire. In addition, product warranties for HPS systems range from two to five years. NYSDOT may wish to specify a minimum warranty period of five years in specification requirements for LED lighting systems. For projects using federal funding, additional warranty requirements are specified in the Code of Federal Regulations (CFR) Title 23, Section 635.413.

Radio Frequency Interference

The existing NYSDOT (2008) Standard Specifications do not contain any particular requirements for roadway luminaires that are related to radio interference. The Standard Specifications do include requirements for documentation that LED traffic signal modules conform to Federal Communications Commission (FCC) Title 47, Subpart B, Section 15 regulations to avoid interfering with radio equipment. This requirement includes self-certification from the manufacturer that the product meets these regulations, specifically between frequencies of 30 to 50 MHz as these are used for public safety-related activities. To help ensure against problems, with radio interference NYSDOT could require documentation of the laboratory test conducted on behalf of the manufacturer to confirm that a product conforms to these requirements, as part of a submittal for consideration. Prior to units being installed, NYSDOT could inspect whether there is any interference with the device at all stages of operation including startup, dimming, operating at any light output, and shutting down. Similar testing could also be performed on sample units during and after the installation of the device on the roadway.

Conclusions and Recommendations

The analyses presented in this report provide an approach to evaluating different LED lighting technologies in terms of their suitability for meeting NYSDOT light level criteria in retrofit lighting situations, when pole spacing is not able to be determined as part of the design process. As reported previously by Bullough and Radetsky (2013), LED roadway lighting system performance has improved in recent years to the point where they are viable replacement options compared to HPS lighting systems, but the variation in performance among systems means specifically classified systems (e.g., Type II or III) and those with particular wattage ranges need to be analyzed to ensure they will be suitable for the particular applications.

For the specific roadway sections evaluated for the present study, the SSP East and Central Avenue sections appear to be more conducive to being economic, energy efficient (saving more than 20% of the current energy use) choices for retrofitting with LED alternative systems. Although payback periods from the existing conditions designed in the 1970s and 1980s could be relatively long (up to 41 years), the periods were shorter when compared with HPS lighting systems meeting the same light level criteria as the LED retrofit alternatives. Including adaptive lighting control made small reductions in the payback periods, but reduced energy use by more than half compared to equivalent light level criteria, in all roadway scenarios that were studied.

Implementing retrofit projects on the SSP and Central Avenue will each carry challenges. NYSDOT owns and maintains (through a contractor) the lighting along the SSP and has flexibility for removing and retrofitting these systems, provided the initial investment for lighting equipment and installation costs can be achieved. On Central Avenue, the existing lighting is owned and maintained by the local utility (National Grid) and costs for maintaining and operating the lighting are borne by the local municipality (Town of Colonie), which pays the utility to carry out this service. A utility tariff exists for LED roadway lighting that is based on the wattage of the LED luminaires used, but requires the lighting to be installed, operated and maintained by the local municipality. Additionally, there are potential recovery costs for existing HPS lighting equipment that would need to be paid to the local utility, because street lighting tariffs stretch lighting installation costs over a long-term period into a monthly tariff paid by the municipality. Nonetheless, the potential benefits in terms of reducing energy use and emissions reductions, make LED retrofit roadway lighting attractive for consideration.

6. STATEMENT ON IMPLEMENTATION

The findings from the present project can be used by NYSDOT and other agencies to prioritize retrofit lighting applications along parkway and arterial roadways in New York State. The analysis methods employed in the present project can be used to compare retrofit lighting options on other roadways than the ones investigated in this study. The photometric and economic analyses can serve as the foundation for a systematic methodology for identifying appropriate energy-efficient options for roadway lighting in retrofit applications.

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