DEMONSTRATION OF ROUNDABOUT LIGHTING BASED ON THE ECOLUMINANCE APPROACH

Final Report

Prepared for

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16. Abstract

Roundabout lighting consisting of pole-mounted high pressure sodium luminaires can be energy intensive and does not necessary provide clear delineation for drivers and pedestrians navigating a roundabout. Using the ecoluminance concept developed in a previous study, lighting integrated with vegetation using lower mounting heights and reflected light from plants and retroreflective elements, it could be possible to provide illumination at a roundabout using substantially less energy. Two short term lighting demonstrations, using the ecoluminance approach and using lower-wattage luminaires producing “white” illumination, were conducted at a real-world roundabout location in New York State. Feedback from transportation engineers and members of the public was used to refine the ecoluminance concept for a final lighting demonstration, consisting of shrubs and trees in the central roundabout island, landscape lighting for these items, pedestrian bollard lighting at crosswalks, overhead light-emitting diode (LED) luminaires in sidewalk and roadway areas, and retroreflective markers to delineate the perimeter of the central island. Photometric measurements confirmed the simulations performed during the design phase, and supported that pedestrians and roadway elements were visible to drivers and pedestrians. Observations of approaching vehicle speeds with the ecoluminance system installed and with the conventional lighting installed revealed little difference in approach speeds. The ecoluminance system had similar initial costs, mainly because of high LED equipment costs (which are decreasing over time) and used only one-fourth the energy of the conventional roundabout lighting system.

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ABSTRACT

Roundabout lighting consisting of pole-mounted high pressure sodium (HPS) luminaires can be energy intensive and does not necessary provide clear delineation for drivers and pedestrians navigating a roundabout. Using the ecoluminance concept developed in a previous study, lighting integrated with vegetation using lower mounting heights and reflected light from plants and retroreflective elements, it could be possible to provide illumination at a roundabout using substantially less energy. Two short term lighting demonstrations, using the ecoluminance approach and using lower-wattage luminaires producing "white" illumination, were conducted at a real-world roundabout location in New York State. Feedback from transportation engineers and members of the public was used to refine the ecoluminance concept for a final lighting demonstration, consisting of shrubs and trees in the central roundabout island, landscape lighting for these items, pedestrian bollard lighting at crosswalks, overhead light-emitting diode (LED) luminaires in sidewalk and roadway areas, and retroreflective markers to delineate the perimeter of the central island. Photometric measurements confirmed the simulations performed during the design phase, and supported that pedestrians and roadway elements were visible to drivers and pedestrians. Observations of approaching vehicle speeds with the ecoluminance system installed and with the conventional lighting installed revealed little difference in approach speeds. The ecoluminance system had similar initial costs, mainly because of high LED equipment costs (which are decreasing over time) and used only one-fourth the energy of the conventional roundabout lighting system.

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Roundabout lighting consisting of pole-mounted high pressure sodium (HPS) luminaires can be energy intensive and does not necessary provide clear delineation for drivers and pedestrians navigating a roundabout. Using the ecoluminance concept developed in a previous study, lighting integrated with vegetation using lower mounting heights and reflected light from plants and retroreflective elements, it could be possible to provide illumination at a roundabout using substantially less energy.

RESEARCH APPROACH

Two short term lighting demonstrations, using the ecoluminance approach and using lower-wattage luminaires producing “white” illumination, were conducted at a real-world roundabout location in New York State. Feedback from transportation engineers and members of the public was used to refine the ecoluminance concept for a final lighting demonstration, consisting of shrubs and trees in the central roundabout island, landscape lighting for these items, pedestrian bollard lighting at crosswalks, overhead light-emitting diode (LED) luminaires in sidewalk and roadway areas, and retroreflective markers to delineate the perimeter of the central island.

ANALYSES

Photometric measurements confirmed the simulations performed during the design phase, and supported that pedestrians and roadway elements were visible to drivers and pedestrians. Observations of approaching vehicle speeds with the ecoluminance system installed and with the conventional lighting installed revealed little difference in approach speeds.

CONCLUSIONS

The ecoluminance system had similar initial costs, mainly because of high LED equipment costs (which are decreasing over time) and used only one-fourth the energy of the conventional HPS roundabout lighting system.

Section 1
INTRODUCTION AND BACKGROUND

ROUNDABOUT LIGHTING

Roundabout intersections are increasing in number across New York State. These intersections generally increase traffic throughput while reducing the severity, if not the frequency, of vehicle-to-vehicle crashes. As relatively new traffic features, modern roundabouts are sometimes described as confusing for drivers to navigate. One difference between roundabouts and conventional cross-type intersections is the location of pedestrian crosswalks. Drivers may be less familiar with the usual locations of these facilities when driving through a roundabout.

Most roundabouts are lighted using pole-mounted luminaires arranged to illuminate the roadway lanes within the circular portion of the roundabout as well as the segments of the entering roadways. Figure 1 shows a photograph of a roundabout in New York State (taken from NYSDOT's website on roundabouts) showing the proliferation of pole-mounted luminaires, typically having 150 W or 250 W HPS lamps based on the current lighting practices of NYSDOT.

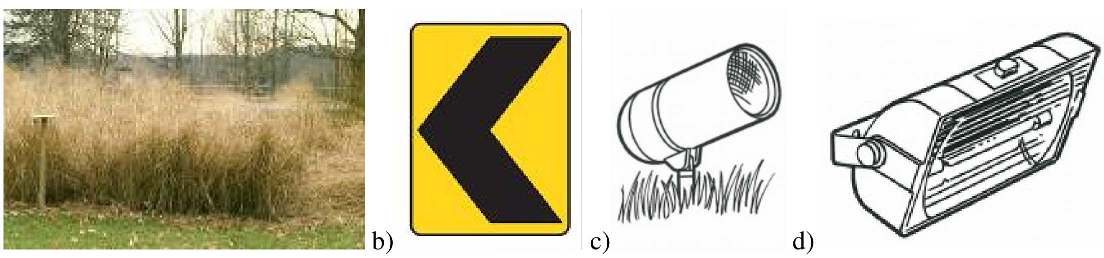
Figure 1. Photograph of a roundabout in New York State, showing the use of pole-mounted lighting (from NYSDOT website).

Guidance from the Illuminating Engineering Society (IES, 2008) are generally consistent with New York State practices for roundabout lighting using overhead pole-mounted luminaires. The high energy use of a large number of pole-mounted luminaires each with 150- to 250-W lamps has resulted in increased concern over costs of operation, as well as light pollution and glare. New York State has therefore studied whether alternative lighting approaches might be able to convey the necessary visual information to drivers as they navigate roundabouts, while using less energy. A recently completed project with the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of

Transportation (NYSDOT) outlined such an alternative approach integrating lighting and roadside vegetation, entitled *ecoluminance* (Bullough et al., 2009).

ECOLUMINANCE CONCEPT

The ecoluminance concept is an approach to providing visual information not solely through *illuminance*, which is the primary purpose of conventional pole-mounted lighting systems, but also through *luminance*, using a combination of roadside vegetation to provide visual delineation, lower-level lighting such as landscape lighting to reinforce delineation, pedestrian level lighting to provide illumination for important safety hazards and concerns, and retroreflective elements to provide cues about road geometry. Figure 2 shows examples of the basic elements of the ecoluminance concept.



a) b) c) d)

Figure 2. The four elements of the ecoluminance concept: a) vegetation, b) retroreflective elements, c) landscape lighting, and d) pedestrian-level illumination systems.

Figure 3 shows a rendering of a preliminary roundabout lighting design using an ecoluminance approach. Vegetation in the central island is illuminated by a combination of vehicle headlamps and landscape lighting, and pedestrians are illuminated by low-level luminaires that result in high luminance contrast between the pedestrian in the right-hand side of Figure 3 and the background.

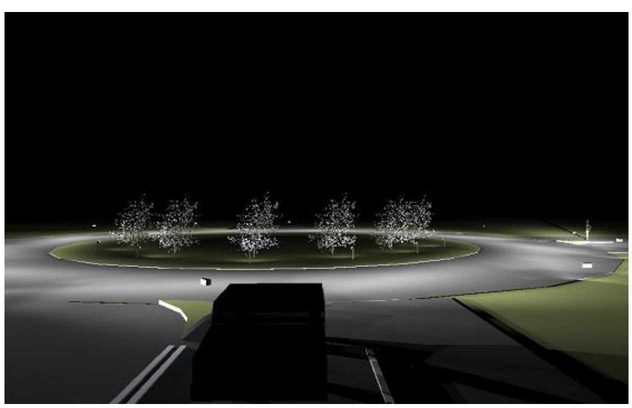


Figure 3. Rendered image of the roundabout with the ecoluminance solution shown.

As described by Bullough et al. (2009), the ecoluminance concept for roadway lighting was applied to roundabouts as well as other roadway types (urban boulevards, freeways and entrance/exit ramps) and the results of technical and economic analyses suggested that the ecoluminance approach could result in lower energy costs and improved visual information, especially for roundabouts. In a roundtable meeting held with individuals from state and local transportation agencies, the Federal Highway Administration (FHWA), and lighting design professionals, the consensus emerged that roundabout applications probably held the most promise for the ecoluminance concept. As a result, the project team from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute was asked to submit a proposal for a full-scale demonstration of the ecoluminance concept at a real-world roundabout location in New York State. The LRC project team was joined by the State University of New York College of Environmental Science and Forestry (SUNY-ESF) for technical assistance in selecting appropriate roadside vegetation, and also included in-kind support and cost-sharing by General Electric Lighting in terms of lighting equipment and lighting design assistance.

TEST LOCATION AND COORDINATION

A location within New York State's capital district (Albany-Troy-Schenectady region, corresponding to NYSDOT Region 1) was judged the most desirable to facilitate installation and monitoring by the project team. A recently constructed roundabout at the intersection of State Routes 85, 140, and New Scotland Avenue in the hamlet of Slingerlands in the Town of Bethlehem, in Albany County, was selected as a suitable location pending agreement and support from the Town of Bethlehem. The roundabout is a state-owned facility, but the project team wanted to ensure that the Town supported the project and would be willing to coordinate with items such as scheduling of mowing operations, which are performed by the Town per their agreement with the state.

The principal investigator (PI) presented the project to a meeting of the Bethlehem Town Board in November 2010 and the Town Board voted to support the demonstration project. In April 2011, the PI met with the Town of Bethlehem's Bicycle and Pedestrian Committee to increase awareness of the project and request participation in the demonstrations by committee members. The project team's point of contact with the Town was the Commissioner of Public Works.

The project team also regularly met with staff from NYSDOT Region 1 to ensure that plans and activities for installing and conducting the demonstrations followed appropriate safety procedures and to coordinate assistance from Region 1 in terms of setting up "Work Ahead" signage during installation activities. All installation work was conducted under a work permit approved by NYSDOT Region 1.

Figure 4 shows the existing light levels at the Slingerlands roundabout under the present HPS lighting system.

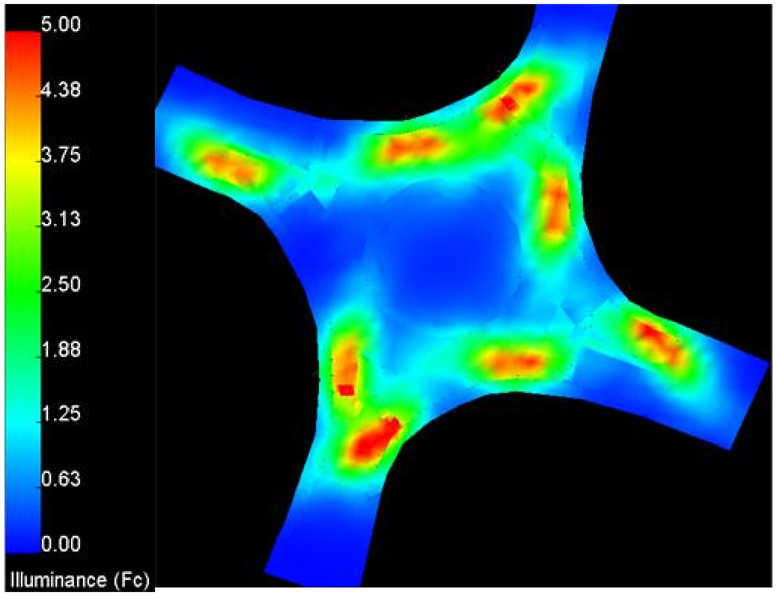


Figure 4. Horizontal illuminances from the HPS lighting system at the test location (in fc: 1 fc = ~10 lx).

Section 2

INITIAL LIGHTING DEMONSTRATIONS

The proposed initial lighting demonstrations consisted of a one-night demonstration of the ecoluminance concept at one entrance of the Rte. 85/140 roundabout, and a one-night demonstration of "white" overhead lighting in contrast to the "yellowish" illumination from the existing HPS lighting system at this location. The latter demonstration, while not strictly part of the original ecoluminance concept, was deemed of interest to NYSDOT because of evidence that "white" illumination from lamps such as metal halide or LED sources can provide superior peripheral visibility (Rea et al., 2004), brightness (Rea et al., 2011) and perceptions of safety and security (Rea et al., 2009) over HPS illumination of the same measured light level. This could lead to the possibility of using lower wattage sources while providing equivalent visual effectiveness.

PRELIMINARY ECOLUMINANCE DEMONSTRATION

Design Goals

The ecoluminance design options used for the initial ecoluminance demonstration were developed based on the goals listed in Table 1.

Table 1. Goals of the ecoluminance design concept.

Goal	Purpose	Method of accomplishment
Create a luminance signal to show drivers the presence of the center island.	To alert drivers to the fact that they are entering a roundabout and shouldn't drive straight across.	By illuminating vegetation in the center island.
Illuminate pedestrians in crosswalks.	To prevent drivers from hitting pedestrians.	Bollards in the pedestrian islands.
Allow drivers at a roundabout entrance to be able to see cars on the opposite side of the roundabout.	Drivers that can see cars driving in the roundabout on the opposite side will feel more comfortable entering the roundabout, and may be safer.	The solution presented here is to space the vegetation out enough so that drivers can see between the plants. Alternatively, shorter vegetation can be used, but wouldn't be visible in the winter due to snow.

Table 1. Goals of the ecoluminance design concept (cont'd.).

Provide ecoluminance all year round.	To provide a safe and attractive roundabout even when there is snow on the ground.	The design presented here installs plants and lighting so they will not be covered by snow. Alternatively, the design can rely on headlight reflectance off of plowed snow bank. Also, vegetation combinations are presented that have foliage year-round.
Reduce the lighting power demand compared with the current lighting design.	Environmental sustainability	The current ecoluminance design (if built out to the entire roundabout) requires about half the power of the current streetlight installation.
To not introduce invasive vegetation to the area.	Environmental sustainability	Only non-invasive species are presented.

Vegetation Options

An important feature of the ecoluminance concept is that a roadway boundary is marked with illuminated vegetation. In conjunction with SUNY-ESF the project team identified the most suitable plants for roundabouts in upstate New York. Species were selected for traits deemed favorable to ecoluminance applications as described by Bullough et al. (2009). Tolerance to roadside conditions common of New York State was deemed an essential selection characteristic from the outset. Species that maintain a high optical 'density' in winter were favored to provide consistent lighting enhancements and visual edge delineation on a year round basis. Species were also screened for commercial availability in semi-mature forms suitable for demonstration and trial purposes. Potential limitations of ideal species were also considered. Species listed here could be planted singularly or in combination depending on soil parameters and other considerations. Based on the above considerations, the four species described below were recommended for consideration.

- Inkberry (Ilex glabra, Figure 5) is a native evergreen shrub that grows five feet tall with equal width. Tolerant to salt, wetter sites, and acidic to neutral soils. Palatable wildlife browse, prone to stem breakage.
- Sea Green Juniper (Juniperuschinensis var. sea green, Figure 6) is an evergreen shrub 4 - 6' tall and slightly wider. Popular ornamental with an arching habit. Widely adaptable. Tolerates salt, drought, and slightly acidic to slightly basic soils. Non-native.

- Switchgrass (Panicumvirgatum, Figure 7) is a native bunch grass 4- 5’ in height. Tolerant of salt, drought, and wide range of soil conditions. Favorable ecological and aesthetic properties on its own or mixed with other vegetation. Must be cut back in the spring, but regrows quickly.
- Northern bayberry (Myrica Pensylvanica, Figure 8) is a semi-evergreen shrub, up to seven feet tall at maturity with equal width. Holds fruit and sometimes foliage through winter. Native to the North Eastern United States. Highly tolerant of salt, drought, and poor soils. pH adaptable. Prefers well drained, coarser textured soils.

Figure 5. Inkberry.

Figure 6. Sea green juniper.

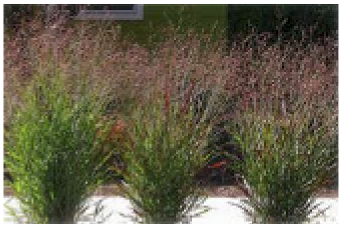


Figure 7. Switchgrass.

Figure 8. Northern bayberry.

Luminaire Options

Pedestrian Crosswalk Bollard. The crosswalks were illuminated with bollards mounted in the pedestrian islands. One bollard model, based on its light distribution and aesthetics, is shown in Figure 9. The project team contacted the manufacturer (Forms + Surfaces) and obtained two of these bollards as a donation for the short-term demonstration.

Figure 9. Pedestrian crosswalk bollard.

Landscape Lighting. Two types of landscape lighting were proposed to the initial ecoluminance demonstration. The first is adjustable lighting on 2-foot stakes (Figure 10). This would allow the fixture heads to be above the top of snow during most of the winter. The second is in-ground fixtures (Figure 11), but these could be below the snow for much of the winter. They would be located so that they will not be in range of snow banks created in the central island during winter plowing, but they would still receive cover from snowfall. The project team obtained a sample for the project of an in-ground landscape luminaire (Philips Bronzelite) from a local lighting representative (Lightspec Albany).

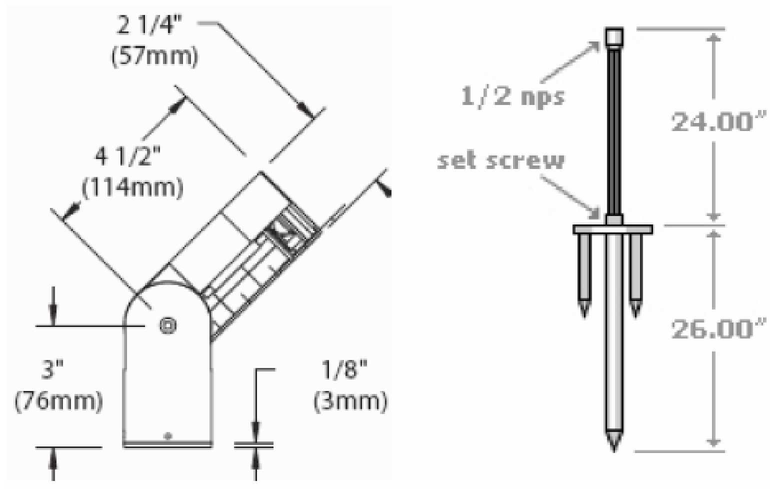


Figure 10. Adjustable landscape lighting.

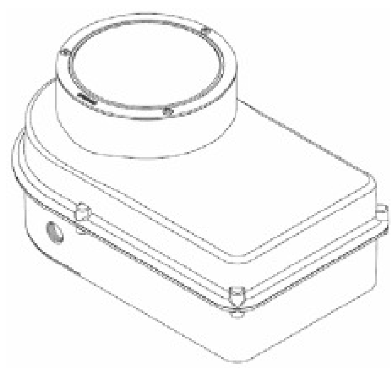


Figure 11. In-ground landscape lighting.

<u>Lighting Layout</u>

For the short-term demonstration, the LRC planned to place vegetation and lighting at one entrance to the roundabout for evaluation. The following layout shows the intended placement of the bollards, plants, and landscape lighting for the short-term demonstration. This layout achieves a suitable luminance contrast so that drivers can detect the presence of the center island and pedestrians in crosswalks based on calculations using the relative visual performance (RVP) method (Rea and Ouellette, 1991). Although the layout (Figure 12) shows the items at the southern entrance to the roundabout, any one of the entrances could be used (and eventually, the northern entrance was selected). All of the images show the same layout (only the perspective changes). In these images, green rectangles mark the location of landscape lighting fixtures and blue circles mark the location of the bollards. The distance between the plants is about 10 ft from center to center. The distance between the landscape luminaires is 11 ft from center to center. Figures 13 and 14 illustrate renderings of the layout.

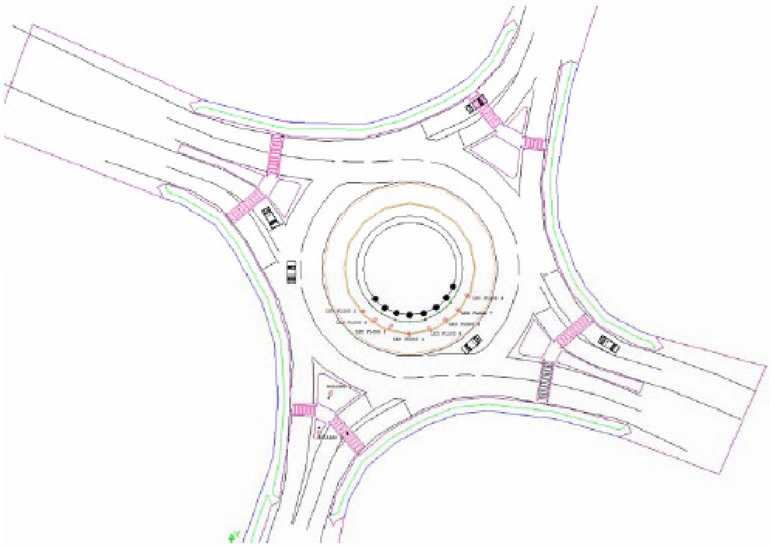


Figure 12. Ecoluminance concept lighting layout.

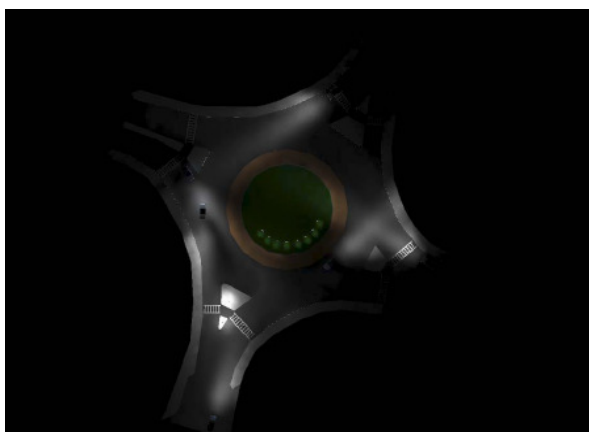


Figure 13. Overhead rendering of the ecoluminance concept layout.

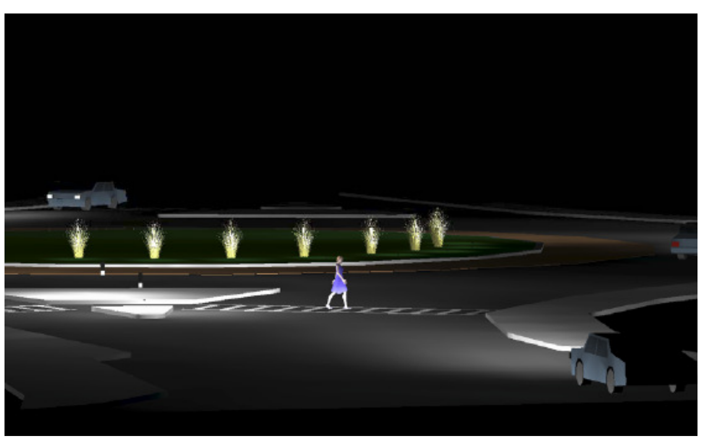


Figure 14. Perspective view rendering of the ecoluminance concept layout.

Installation

On June 27, 2011 from 9:00 PM to 10:00 PM, the project team installed and conducted the demonstration of the ecoluminance lighting technique at the roundabout at the intersection of Rt. 85, Rt. 140, and New Scotland Rd. in Slingerlands. Illuminated vegetation and bollard crosswalk lighting was installed at the New Scotland Rd. (northeast) entrance to the roundabout (Figures 15 and 16). Sixteen people, including representatives from local and state organizations, attended and provided feedback, which is summarized below and was used in the design of the final ecoluminance demonstration.

Figure 15. Photograph of ecoluminance vegetation.

Figure 16. Crosswalk bollard lighting.

Equipment and Vegetation

Figure 17 shows the location of the vegetation and bollards during the ecoluminance demonstration. Table 2 provides a description of each plant and lighting product.

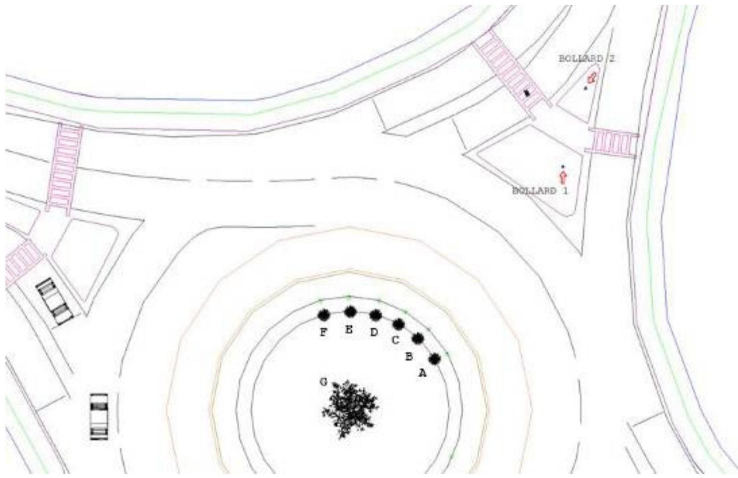


Figure 17. Location of vegetation and lighting equipment.

Table 2: Vegetation and lighting equipment used.

Label	Vegetation		Light				
	Common name	Latin name	Make	Model	Lamp/ Light Source	Description	Power (W)
A	Sea Green Juniper	Juniperus chinensis var. sea green	Kichler	15742AZT	LED	Stake mount, 8.5W, 35 deg	8.5
B	Inkberry	Ilex glabra	Kichler	15742AZT	LED	Stake mount, 8.5W, 35 deg	8.5
C	Sea Green Juniper	Juniperus chinensis var. sea green	HK Lighting	ZX16A-MH01	halogen MR16	24" adjustable stake, 20W, 40 deg beam	20
D	switchgrass	Panicum virgatum	HK Lighting	ZX16A-MH01	halogen MR16	24" adjustable stake, 20W, 40 deg beam	20
E	Sea Green Juniper	Juniperus chinensis var. sea green	HK Lighting	ZX16A-MH01	halogen MR16	24" adjustable stake, 24deg beam	35
F	Inkberry	Ilex glabra	Kichler	15742AZT	LED	Stake mount, 8.5W, 35 deg	8.5
G	Tree, unknown species	unknown	Philips Bronzelite	TL4012	LED	stake mount, 25 deg. 3000K	10
			Kichler	15758 BKT	LED	Well mount, 12.4W, 60 deg	12.4
Bollard 1	N/A		Forms+Surfaces	LBCOL-504	Fluorescent T5		48
Bollard 2	N/A		Forms+Surfaces	LBCOL-504	Fluorescent T5		48
TOTAL							218.9

Results

Power. The total electrical power to the bollards and vegetation lighting was 220 W. For this demonstration, three 250 W HPS cobraheads (using 295 W including ballast power) were de-energized, so the reduction in power to the overhead lighting system was 885 W. Therefore, the lighting power was cut by approximately three quarters for the portion of the roundabout included in the demonstration.

Photometric Measurements of Vegetation. Table 3 shows the luminance measurements of each plant that was illuminated. The luminance was measured as a 1-degree spot in the mass of the plant. Luminance is the photometric quantity that corresponds most closely with the perception of brightness, so the greater the luminance, the brighter the vegetation appeared.

Table 3. Vegetation luminance measurements.

Label	Vegetation	Luminance (cd/m^2)
A	Sea Green Juniper	2.0
B	Inkberry	2.0
C	Sea Green Juniper	1.5
D	Switchgrass	8.0
E	Sea Green Juniper	20
F	Inkberry	2.0
G	Tree, unknown species	2.0

The lowest luminance found is consistent with the ecoluminance design values, so the LRC considers that the lighted vegetation was highly visible, based on relative visual performance (Rea and Ouellette, 1991) calculations.

<u>Photometric Measurements of Bollard Crosswalk Lighting.</u> The project team measured vertical illuminances in the crosswalk that was lit by the bollards. All illuminances were measured 3 ft above the ground in the center of the crosswalk, facing the direction of oncoming vehicle traffic. No oncoming headlamps were present during the measurements. For the single-lane portion (exiting the roundabout), vertical illuminances facing the south ranged from 20 lx close to the pedestrian island, to 7 lx at the far end of the crosswalk. The levels dropped off quickly from 20 lx. For the double-lane portion (entering the roundabout), vertical illuminances facing the north ranged from 40 lx close to the pedestrian island, to about 5 lx at the far end of the crosswalk. The levels dropped off quickly from the maximum levels on both portions of the crosswalk. The lowest illuminance found was greater than the ecoluminance design values, so pedestrians would be highly visible based on relative visual performance (Rea and Ouellette, 1991) calculations.

The illumination from the bollards was compared with the illumination from the existing HPS cobrahead streetlights at the eastern (Rt. 140) entrance. A nearby streetlight was cycling; the measurements were made while this light was on. For the double-lane portion (entering the roundabout), vertical illuminances facing the east ranged from 6 lx close to the pedestrian island to 8 lx at the far end of the crosswalk. For the double-lane portion (exiting the roundabout), vertical illuminances facing the west remained at 7 lx along the entire length of the crosswalk.

Survey Results. Representatives from federal, local and state organizations attended the demonstration. The project team asked the participants at the demonstration to evaluate the ecoluminance lighting using a questionnaire form comparing the new lighting to conventional overhead HPS lighting. Sixteen people, ranging in age from 31 to 67 years old, completed surveys. All participants were provided reflective safety vests and white hard hats to wear during the demonstration. Participants were asked to observe the scene on foot and were not asked to drive through the roundabout. For each survey questions, the respondent was asked to indicate his or her level of agreement with each statement compared to the existing overhead lighting. A score of -2 meant that the respondent felt the existing overhead lighting was significantly better than the ecoluminance lighting, a score of +2 indicated the ecoluminance lighting was significantly better than the existing lighting, and a score of 0 meant they were both the same. T-tests were computer to indicate whether the average result was significantly different ($p<0.05$) than the result that would be obtained randomly. The results are shown in Table 4.

Table 4. Survey results: visibility and safety.

Question	Average Score	Standard Deviation	T-test
I feel secure while walking on the sidewalk	+0.19	1.6	Not significant
As a pedestrian, I can see vehicles approaching clearly	+1.6	0.81	Significant
As a pedestrian, I can see other pedestrians clearly	0	1.0	Not significant
I would feel safe while driving	+0.63	1.1	Significant
I would be able to see pedestrians clearly while driving	-0.19	1.1	Not significant
I would be able to see other vehicles clearly while driving	+0.69	1.0	Significant
I would be able to see where the road is going while driving	+0.75	0.86	Significant
Overall, the lighting is comfortable	+0.31	1.2	Not significant

Of the four questions that had statistically significant scores, participants felt that the ecoluminance lighting was an improvement over the existing lighting. Of these, participants felt that the biggest improvement was in pedestrians being able to see vehicles approaching. Participants were also asked what their most and least preferred plant appearance and lighting was. The results for vegetation are shown in Table 5 and for lighting in Table 6. In Table 6, the last row represents the lighting of the tree, for which two different fixtures were used.

Table 5. Survey results: vegetation preferences.

Vegetation	Which plant has the most preferred appearance? (Number of participants selecting this plant)	Which plant has the least preferred appearance? (Number of participants selecting this plant)
Sea Green Juniper	3	9
Inkberry	6	4
Switchgrass	4	4
Tree, unknown species	7	0

Participants preferred the appearance of the tree the most. Among the perimeter vegetation, the Inkberry bush was most preferred.

Table 6. Survey results: lighting preferences.

Light			Which plant has the most preferred appearance? (Number of participants selecting this lighting)	Which plant has the least preferred appearance? (Number of participants selecting this lighting)
Lamp/ Light Source	Description	Lum-inance (cd/m^2)		
LED	Stake mount, 35 deg beam	2	6	6
Halogen MR16	24" adjustable stake, 40 deg beam	1.5	2	7
Halogen MR16	24" adjustable stake, 24 deg beam	20	4	3
Halogen MR16	24" adjustable stake, 40 deg beam	8	1	1
LED	Stake mount, 25 deg beam	2	7	0
LED	Well mount, 60 deg beam			

The lighting of the tree was most preferred. The stake mount LED luminaires received a strong positive and negative response. There may be a correlation between the low luminance (1.5 cd/m^2) provided by the luminaire with the 40 degree beam angle halogen and the large number of people who did not prefer its appearance. Participants were also invited to provide comments on the ecoluminance demonstration. In random order, the comments received were:

- *Cross walk lights are a bit too bright for pedestrians crossing in the dark.*
- *The ground source lighting does not create blind spots after looking away from light source.*

- *Concern about: (1) Intensity of bollard lighting. Very bright relative to surroundings and may be distracting. (2) Glare from landscape lighting when driving on opposite side of roundabout. Lights are at driver's eye level. These may or may not improve with others in middle of roundabout. (3) Should have full shield on bollards. Consider bollard on edges too. (4) Could you uplight within foliage of bushes?*
- *I really thought the ornamental grass was very reflective, I was surprised. The tree was lit quite nicely. It was difficult to visualize entire roundabout, but the bollards lit the sidewalk and crosswalk areas nicely. Bollards lit the Yield sign quite nicely too.*
- *I do not like the bollard lights which was displayed, it does not lit the whole cross walk, so definitely I like different type of bollard which will give more lights on sideways. The trees, I think is too short for winter snow plowing, I like the plants little higher. The tree behind the plants were giving more reflection than the small plants.*
- *Pedestrian posts are too bright. View of opposite side of lights is too distracting.*
- *Pedestrian bollard lights too bright. Consider bollard lights on both sides of leg. Bollard lights too distracting to driver, should aim directly at pedestrian.*
- *The bollard concept was great at crosswalk but all light should be cut off to approaching motorist (too much glare). Center island tree in my opinion provided best target value from all quadrants without glare from any. All other plant lighting produced glare on opposite side of quadrant…. Bollards I believe have a lot of promise from pedestrians.*
- *Bollard lights are too bright and distracting. The sidewalk needs to be lit. Emphasis should be placed on masses of plants, not individual plants.*
- *Pedestrian lighting not great. I like the look of the center island lighted vegetation and think it's probably ok for vehicles but I would be very leary of walking here at night (or in the day for that matter). Glare on post office side of road- too much glare.*
- *The approach to the roundabout (any side) should have some light for pedestrians/ crosswalks. I changed some of my answers after I walked to the opposite side of the lights/ vegetation were. This influenced me in a negative way. But perhaps if the vegetation/ lighting were all the way around it would not have been a negative impact.*
- *The bollard lighting is much too bright. When looking at plants from West to East the lights looked like headlights. Hard to walk on sidewalks without overhead lighting. The lights in the center of the roundabout would be nice compliment to overhead lighting.*
- *The overhead lights illuminated the crosswalk pavement better and I felt more comfortable. The bollards had some glare for drivers. The overhead lights were supposed to be lit kept cycling on and off complicating the comparison. Vegetation lights produced glare on back side of plants.*
- *Bollards not good as located; too bright, distract driver from actual cross walk. Believe more research needed into location/ type/ light level/ color/ actuated vs. always on.*

- *Driving into the roundabout, I think the pedestal lights in the roundabout will confuse the driver. (These are the lights illuminating the plants on the back side of the entry vehicle.) Bollard lights shouldn't be illuminated 360 degrees- also very confusing. Overhead lighting is best- illuminates entire roundabout without distraction to drivers. Up above- lighting is out of sight and out of mind. Existing lighting is best.*

Discussion. The project team gained valuable feedback from the initial short-term ecoluminance demonstration. Some aspects of the demonstration that were successful include:

- The ecoluminance design reduced lighting power demand by two thirds.
- Of the four survey questions that had statistically significant scores, participants felt that the ecoluminance lighting was an improvement over the existing lighting. Participants felt that with the ecoluminance lighting (compared with existing HPS), pedestrians could see vehicles more clearly, they would feel safer while driving, they would be better able to see other vehicles while driving, and they would be better able to see the path of the road while driving.
- Participants liked the appearance and lighting of the illuminated tree.
- Of the shrubs, participants liked the Inkberry.

Some aspects of the design that needed to be re-examined going forward, based on the feedback received, include:

- Several problems with the crosswalk lighting were noted. Complaints included that it was too bright for both pedestrians and drivers, it was distracting for drivers, and it didn't allow pedestrians to see the ground well enough.
- Participants did not like the appearance of the Juniper shrub.
- Participants did not like the lighting provided by the halogen fixture with the 40 degree beam angle. This might be because the resulting luminance of the vegetation was only 1.5 cd/m^2, which is lower than the other luminances.
- The vegetation lighting on the shrubs created glare when viewed from the opposite roundabout entrance.
- Some participants suggested that the sidewalks be illuminated too.

To address these concerns, the following aspects were considered as possible modifications to the ecoluminance design to be implemented in the final demonstration:

- To provide a better demarcation of the center island and outer curbs for drivers, retroreflective materials could be installed on the curbs. In this way, the demarcation would provide a similar luminance as the existing retroreflective signs, which is greater than the luminances of the vegetation.

- To provide a better indication of the spatial location of the center island and to increase the density (which will help reduce glare), the vegetation should be installed closer to the center of the island. At least two layers of lighting would be used: the trees in the center surrounded by one or more layers of vegetation.
- Vegetation lighting should be angled upward more to avoid causing glare. Unfortunately, this may mean that the fixtures could be covered with snow for a greater part of the winter because they would not be able to be mounted as high from the ground.
- To improve the bollard lighting, improvements to be considered include adding lighting louvers or barn doors to the bollard, or using a different commercially available bollard that has a more suitable intensity distribution.

PRELIMINARY WHITE LIGHT DEMONSTRATION

As described above, a short-term demonstration of overhead lighting of a roundabout using a "white" light source was conducted to permit comparison with the "yellowish" color of HPS lamps normally used for roadway lighting. This section describes the installed white light streetlights and summarizes the subjective impressions from invited participants.

Experimental Setup

GE Lighting provided 8 LED streetlights (Evolve LED R150 Roadway Medium with catalog number ERMC0C343A1GRAY, using 157 W each). The project team provided GE with an AutoCAD file of the roundabout and illuminance measurements for the location under the existing lighting. Using this information, GE created a lighting layout, as shown in Figure 18, based on a 25 ft mounting height. The layout was checked using AGi32 photometric modeling software and it was found that the lighting design would provide similar illuminance levels as the existing HPS lighting. The average calculated light level within the roundabout intersection roadway area was predicted to be 16 lx. This light level would allow for an eventual 30% light loss factor to account for system age and dirt and still exceed guidelines from the Illuminating Engineering Society (IES, 2008) for an average illuminance of 12 lx at this location.

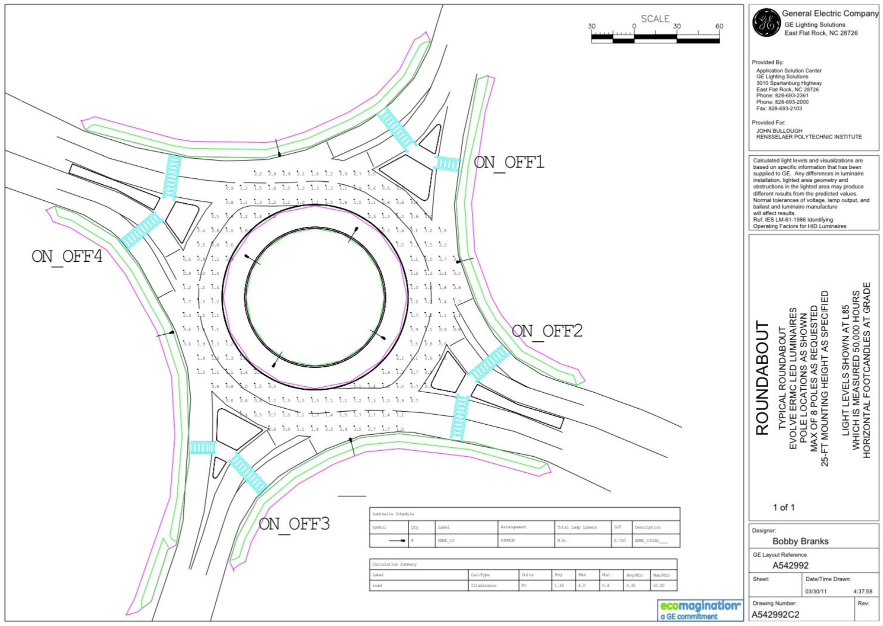


Figure 18. Lighting layout created by GE Lighting.

The project team rented eight standard light towers or light plants (Figure 19) used for nighttime roadway construction, on which the LED streetlights were mounted. Although they were manufactured by various companies, each included a 6 kW generator with 120 V outlets and a 30 ft mast with HID luminaires installed. In July 2011, the LRC towed each unit into place at the roundabout according to Figure 18, leveled each unit with the built-in outriggers, attached the LED luminaires to the mast top using custom mounting brackets designed and fabricated at the LRC, and raised the towers so the luminaires were approximately 25 ft above the ground (with the exception of the luminaire to the southwest of the roundabout which was left a few feet lower due to ensure sufficient distance from existing power lines.) The HID luminaires were switched off, and the LED luminaires were powered via the AC outlets in each generator unit. NYSDOT de-energized six of the eight existing HPS streetlights, leaving two energized for safety reasons (one each at the roundabout entrances from Rt. 85 and Rt. 140, but the one at the Rt. 85 entrance was non-operational at the time of the demonstration). The demonstration setup is shown in Figure 20.

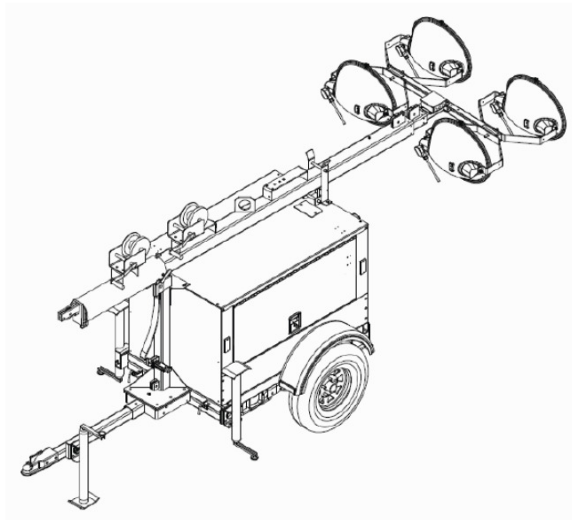


Figure 19. Portable light tower used for mounting the LED street light luminaires.

Figure 20. White light streetlight demonstration. Photo taken from Rt. 85 entrance to roundabout.

Results

Power. The total power of the LED installation was 1256 W, compared to more than 2300 W for the existing HPS installation.

Photometric Measurements. LRC made several "spot checks" illuminance measurements at various locations, as shown in Table 7, and found that the measured illuminance values agreed well with the predicted values for locations where light level calculations were made.

Table 7. Measured and predicted illuminance values.

Location	Measured Illuminance	Predicted Illuminance
Central island:		
Underneath northernmost luminaire, at edge of island:	38.8 lx	38 lx
Underneath westernmost luminaires, at edge of island:	35.7 lx	36 lx
Between northern- and westernmost luminaires, at edge of island:	12.9 lx	16 lx
Pedestrian crosswalks:		
Center of westernmost crosswalk:	4.7 lx	n/a
Center of northernmost crosswalk:	3.4 lx	n/a
Center of northernmost crosswalk (vertical, toward island):	6.4 lx	n/a
Center of easternmost crosswalk:	7.3 lx	n/a
Sidewalks:		
Sidewalk at western end of northern crosswalk, at curb:	4.7 lx	n/a
Sidewalk at northern end of western crosswalk, at curb:	2.0 lx	n/a
Sidewalk at southern end of western crosswalk, at curb:	2.7 lx	n/a
Sidewalk at northern end of eastern crosswalk, at curb:	8.0 lx	n/a
Sidewalk between northern and eastern crosswalks, at curb:	42.7 lx	40 lx
Sidewalk between northern and western crosswalks, at curb:	25.3 lx	28 lx

Subjective Responses. Representatives of local and state organizations attended the demonstration. Participants at the demonstration were asked to evaluate the street lighting using a questionnaire form provided to each participant. Five people completed surveys. Participants were asked to observe the scene on foot and were not asked to drive through the roundabout. For each survey question, the respondent was asked to indicate his or her level of agreement with each statement compared to the existing HPS overhead lighting. A score of -2 meant that the respondent agreed with the statement more for the HPS streetlights than the LED lighting, a score of +2 indicated the respondent agreed with the statement more for the LED lighting than the HPS streetlights, and a score of 0 meant they were both the same. The T-test indicates whether the average result is significantly different ($p<0.05$) than the result that would be obtained randomly. The results are shown in Table 8.

Table 8. Survey results.

Question	Average Score	Standard Deviation	T-test
I feel secure while walking on the sidewalk	+0.80	0.73	Not significant
As a pedestrian, I can see vehicles approaching clearly	+1.80	0.20	Significant
As a pedestrian, I can see other pedestrians clearly	+0.20	0.49	Not significant
I would feel safe while driving	+1.20	0.20	Significant
I would be able to see pedestrians clearly while driving	+0.80	0.58	Not significant
I would be able to see other vehicles clearly while driving	+1.40	0.40	Significant
I would be able to see where the road is going while driving	+1.40	0.24	Significant
The lighting here looks better than along other roads	+1.40	0.40	Significant
The color of the lighting on the road is acceptable	+2.00	0	Significant
The color of vegetation looks natural	+1.00	0.45	Not significant
The color of the traffic signs are clear	+1.40	0.24	Significant
The road looks bright	+1.60	0.24	Significant
The road looks gloomy	-1.40	0.24	Significant
The lighting is comfortable	+1.40	0.24	Significant

Participants also asked to provide comments about the lighting, and the comments are paraphrased here:

- Crosswalk was dark
- Whole area looks much brighter and better and feels more comfortable
- Need to increase lighting at crosswalks/approaches, possibly moving interior lights to periphery
- Whiter lighting is clearer, improves contrast of lane markings and curbs
- Aprons may be overlighted
- Approaches need additional light
- "White" lights are preferred to "yellow/orange" ones

Discussion

Although there were relatively few questionnaire responses to the LED demonstration, there were many statistically significant average responses that differed from zero and all were in the positive direction indicating preferred conditions under the LED lighting than what would be expected under HPS illumination. The primary exceptions were the ability of pedestrians and drivers to see pedestrians, which were not significantly different from zero (i.e., no difference from HPS). No question yielded a negative result, except for the question "The road looks gloomy" which was expected to achieve a negative result compared to HPS. Although it was a much smaller sample than the initial ecoluminance demonstration under this project, the statistical tests account for this by requiring a higher threshold difference to achieve statistical significance, so the results are still useful.

The results are consistent with previous literature that white roadway illumination is generally judged to be more visually effective and safer than yellower HPS illumination at roadway lighting levels (Rea et al., 2009).

Section 3
FINAL ECOLUMINANCE LIGHTING DEMONSTRATION

LIGHTING SYSTEM LAYOUT

The layout planned for the final ecoluminance lighting demonstration builds upon the observations and data gathered during short-term demonstrations at the Slingerlands roundabout at the intersection of State Routes 85 and 140. The concept provides some illumination along or adjacent to the sidewalks and part of the roadway that surround the roundabout. There are three primary lighting elements in the layout:

1. LED landscape lighting (9 W LED fixtures, Kichler) is suggested for the trees that are located in the center of the roundabout. In the first demonstration it was noticed that the brightness of the traffic signs, such as the chevrons, was brighter than the landscape lighting that was illuminating the juniper and inkberry shrubs in the central island. However it was noticed that providing landscape lighting to the trees was a better solution, since the trees are bigger in size and have a higher reflectance than the shrubs.
2. Bollards with fluorescent lighting (48 W fluorescent, Forms + Surfaces) to provide vertical illumination on the crosswalks. Although it was noticed that the bollards were excessively bright during the first mock up, with some modifications to the fixture, such as covering the rear part of the fixture and adding some baffles, this light source could still be a good lighting solution for the crosswalks. A total of eight bollards, two per roundabout entrance, were used on the splitter traffic islands at each entrance.
3. Reflectors on the perimeter of the roundabout’s central island could be used with the purpose of delineating the inner curve of the roundabout when a car approaches.

In addition to these lighting elements (illustrated in the renderings shown in Figures 21 and 22), chevron signs in the central island have been added to the simulation of the roundabout, with the purpose of better illustrating the brightness of these signs and how they can compete with the landscape lighting inside the roundabout. To make the renderings more realistic, they include cars, light coming from the car headlamps, and a pedestrian crossing one of the crosswalks.

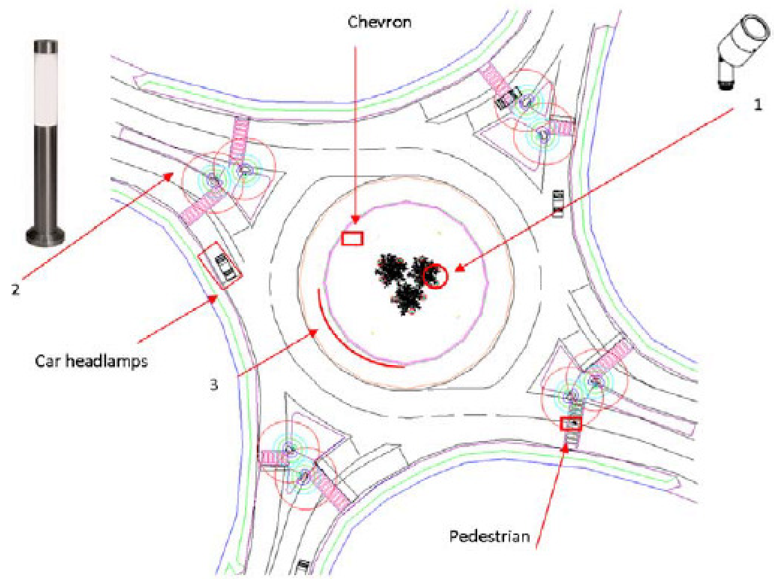


Figure 21. Lighting elements that are used in the final lighting system.

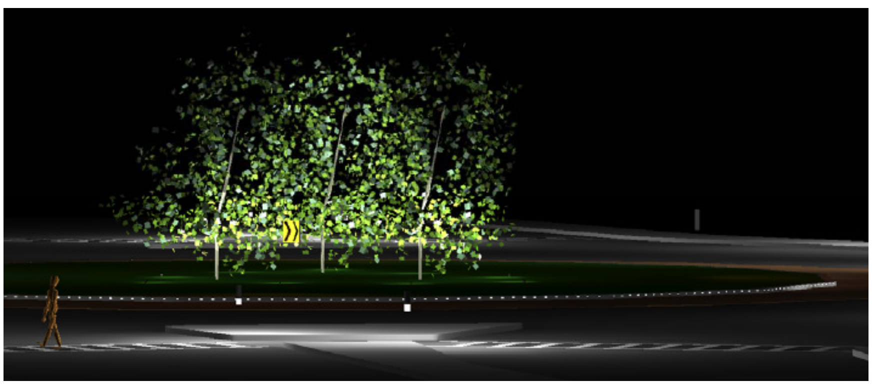


Figure 22. Isometric view of the roundabout showing the lighting on the crosswalks, the landscape lighting aimed toward the trees inside the roundabout, reflectors attached to the surface of the roundabout's border, a pedestrian crossing the crosswalk and the chevron sign.

<u>Overhead Lighting Equipment</u>

The overhead lighting component of the installation uses four 30 watt LED area light fixtures (Bega, labeled fixture A) with a Type II light distribution, mounted 15 ft above the ground, to provide light on the sidewalks and part of the roadway, as shown in Figure 23. Each fixture provides a total of 1944 lumens, considering a total light loss factor of 0.72. For practical purposes, these LED area light fixtures have been located on the same location were current cobra head light poles are located on the Slingerlands roundabout. Ideally these fixtures would be located in the center of those sidewalks, like the fixture that is circled with a blue ring on Figure 23.

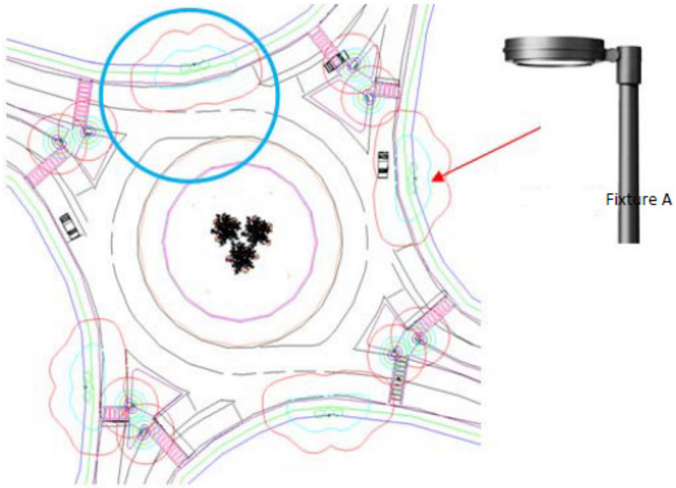


Figure 23. Top view drawing of the roundabout with the four 30W LED area fixtures.

Figure 24. Retroreflective glass markers used in the central island perimeter.

<u>Retroreflective Markers</u>

The project team selected 1-inch glass diameter curb markers (U.S. Reflector) to be installed along the perimeter of the central island. These were clear (white) glass, but were sprayed with a yellow lacquer since the inner traffic line was painted yellow, and this color was required for compliance with the Manual on Uniform Traffic Control Devices (MUTCD). The markers were inserted into 2-inch diameter PVC tube about 1 foot long, cut at one end at approximately 45^{o} so they could be inserted like stakes into the grass covered turf in the central island (Figure 24), spaced 6 ft apart.

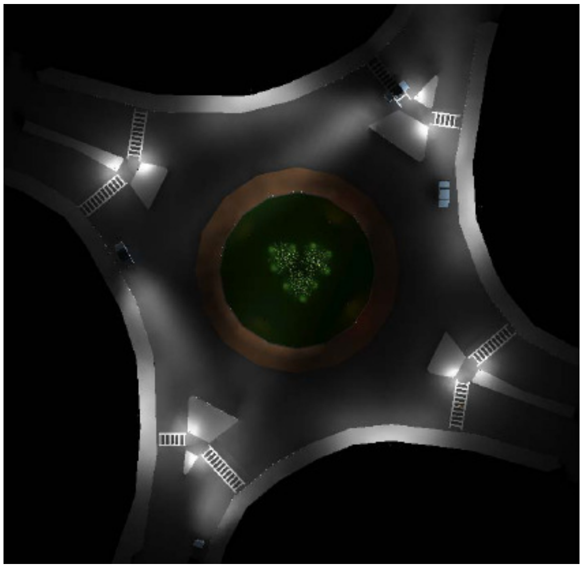


Figure 25. Plan view of the lighting layout.

Renderings of Installation

In Figures 25 through 27 it is noticeable how the four A fixtures, located near the sidewalks that surround the perimeter of the roundabout, provide an even light distribution on the sidewalks and some light in the roadway. Much of the light that is noticeable on the pavement is also coming from the car headlamps. The lighting installation uses a total of 612 W to illuminate the roundabout.

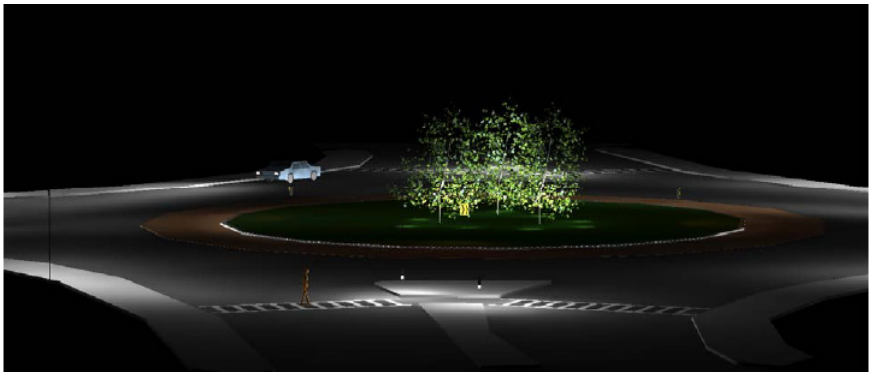


Figure 26. Isometric view of the roundabout. Notice the light on the sidewalks.

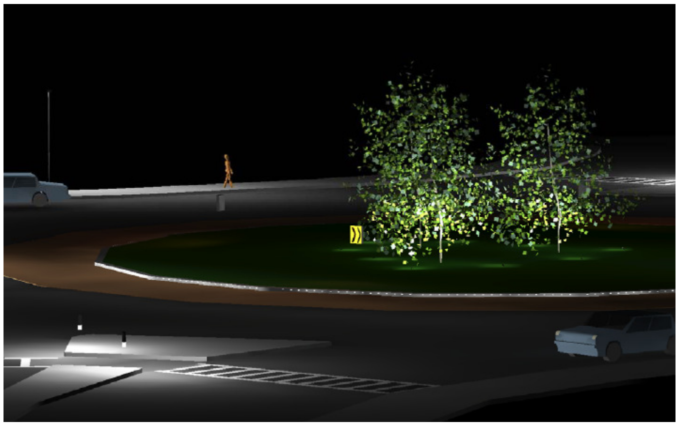


Figure 27. Isometric view of the roundabout rendering with pedestrian walking on the sidewalk. Notice that the pedestrian and sidewalk are well illuminated.

INSTALLATION

The installation was conducted during the week of June 18th, 2012. In the first half of the week, the equipment and materials were installed, and the existing HPS lights were de-energized by NYSDOT Region 1. The lighting system was powered up at sunset on Wednesday night and turned off at sunrise on Thursday morning. It was then re-powered at sunset on Thursday night and turned off on Friday morning. On Friday, all of the vegetation and lighting equipment was removed from the location. Two existing HPS luminaires, at the eastern- and western-most ends of the roundabout, remained on during the nights of the demonstration.

<u>Power Supply</u>

During the initial ecoluminance lighting demonstration, which was only scheduled to occur for a couple of hours during a single evening, luminaires were powered using batteries. The final demonstration was planned for a duration of at least two nights, from sunset to sunrise, and therefore battery power was not practical. Nor was it possible to use existing power for the HPS streetlights already present at the location. The means for powering the lighting equipment was through gasoline generators, each equipped with an extended run fuel tank (Figure 28) to permit long term operation over the course of each night. A total of nine generators were used: one for each overhead LED luminaire, one for each pair of bollard luminaires at each entrance, and one in the central island for the landscape lighting. In the crosswalk locations, electrical power cords that crossed the crosswalk were covered with cable protecting covers and taped to the concrete sidewalk to permit wheelchair or stroller access. To address safety and security concerns, generators and fuel tanks were removed from the location during the daytime when not in use.

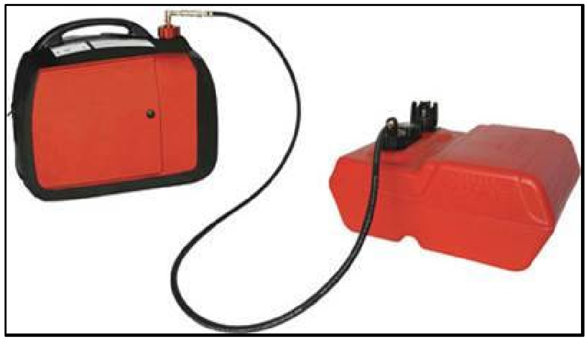


Figure 28. Generator and extended run fuel tank used to power the lighting installation.

Mounting for LED Overhead Fixtures

With cooperation from NYSDOT Region 1, the LED overhead fixtures were mounted directly to the existing street light poles for the HPS system, at a height of 15 ft above the ground. A mounting bracket was customized and fabricated (Figure 29), that could use a ratchet strap to tighten around the pole and create a stable, fixed mounting location. Rubber sheets were placed between the pole and the contact surfaces of the bracket to avoid scratching or damaging the poles.

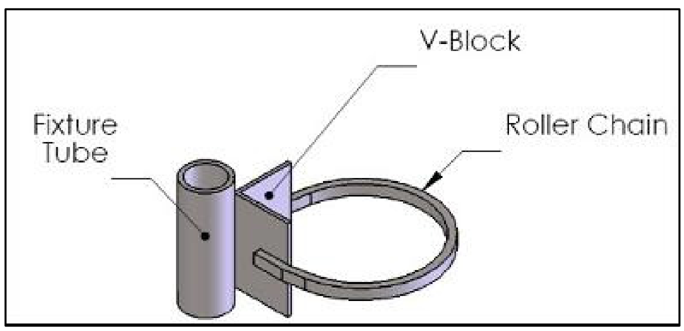


Figure 29. Mounting bracket for overhead LED luminaires.

Photographs of Installation

Figure 30 shows the appearance of the landscape lighting and vegetation (Inkberry, a total of 12 shrubs) in the central island of the roundabout. Also visible in the foreground of Figure 30 are the glass retroreflective markers in the perimeter of the central island. Figure 31 shows one of the pedestrian bollard luminaires, which were all fitted with opaque louvers in the front opening of the fixture to help reduce brightness and direct light mainly in the forward direction. Figure 32 shows the LED overhead light fixture.

Figure 30. Vegetation, landscape lighting and retroreflective markers.

Figure 31. Pedestrian bollard luminaire with louvers.

Figure 32. LED overhead luminaire mounted on existing HPS pole.

EVALUATION

Unlike the initial demonstrations, individual participants were not invited to provide survey feedback about the final lighting installation. Rather, the project team made observations of the traffic behavior, primarily through approaching vehicle speeds, during the two nights of the installation. (Vehicle speeds were also measured before and after the installation was conducted, to obtain baseline data.) Photometric measurements of light levels were also made in order to compare the predicted performance from the calculation and rendering stage of the layout design to the actual conditions at the roundabout.

<u>Photometric Measurements</u>

Table 9 summarizes the photometric measurements made for the site. The two crosswalk locations at New Scotland Ave. (the northern-most entrance) and Cherry Ave. (the eastern-most entrance) of the roundabout were measured for vertical illuminances 3 ft from the ground (toward oncoming traffic), and for the horizontal illuminance in the center of the crosswalk. The illuminances for the crosswalk facing traffic entering the crosswalk included some contribution from the HPS street light that remained on during the demonstration. The measured values were close to those predicted by the simulation software in the calculation and design stage.

Table 9. Photometric measurements for two crosswalk locations.

<table>
<tr><th>Location</th><th>Minimum vertical illuminance (lx) furthest from bollard</th><th>Maximum vertical illuminance (lx) closest to bollard</th><th>Vertical illuminance (lx) in center of driving lanes</th><th>Horizontal illuminance (lx) in center of crosswalk</th></tr>
<tr><td>New Scotland Ave. (entering roundabout, two lanes)</td><td>1.7</td><td>17.7</td><td>7.8</td><td rowspan="2">5.2</td></tr>
<tr><td>New Scotland Ave. (exiting roundabout, one lane)</td><td>3.5</td><td>13.7</td><td>10.6</td></tr>
<tr><td>Cherry Ave. (entering roundabout, two lanes)</td><td>7.3</td><td>18.0</td><td>10.0</td><td rowspan="2">10.0</td></tr>
<tr><td>Cherry Ave. (exiting roundabout, two lanes)</td><td>2.4</td><td>13.5</td><td>5.0</td></tr>
</table>

Horizontal illuminance measurements were made under one of the LED overhead lights as well as 30 ft toward each direction along the sidewalk. The illuminance directly under the luminaire was 8 lx, and the illuminance 30 ft away in each direction was 4 lx. In comparison. Bullough (2010) suggested that a minimum illuminance of 2 lx would be needed to ensure visibility of tripping hazards.

Vehicle Speeds

At each entering leg of the roundabout, vehicle speeds were measured using a Bushnell Velocity radar speed gun with an accuracy of +/- 1 mph. Vehicle speeds were measured between the hours of 10 p.m. and 12 midnight for all legs, both during the installation as well as before and after the installation when the conventional HPS lighting system was operating. Vehicles were measured when they were approximately 200 ft from the crosswalk for each entrance. If a train of vehicles approached, only the speed for the first vehicle in the train was measured since the following vehicles' speeds could be influenced by the speed of the leading vehicle. Between 100 and 110 vehicles were measured at each approach leg and under each lighting condition.

Figure 33 shows a histogram of the measured speeds for the northern entrance (New Scotland Ave.) with the conventional lighting and during the ecoluminance demonstration. Figure 34 shows the corresponding data for the eastern entrance (Cherry Ave.), Figure 35 shows the data for the southern entrance (Rte. 85), and Figure 36 shows the data for the western entrance (the Slingerlands bypass).

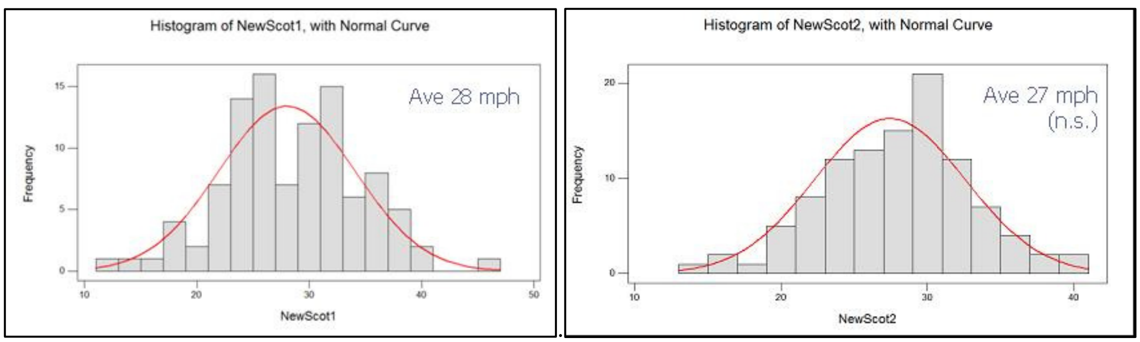


Figure 33. Histograms of vehicle speeds (in mph) for New Scotland Ave. under conventional lighting (left) and during the ecoluminance demonstration (right). No statistically significant difference (p>0.05) was found.

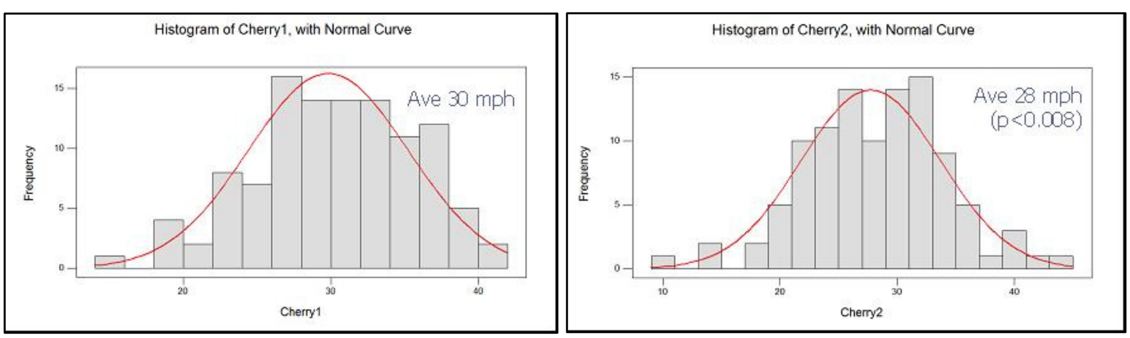


Figure 34. Histograms of vehicle speeds (in mph) for Cherry Ave. under conventional lighting (left) and during the ecoluminance demonstration (right). A statistically significant reduction (p<0.05) was found.

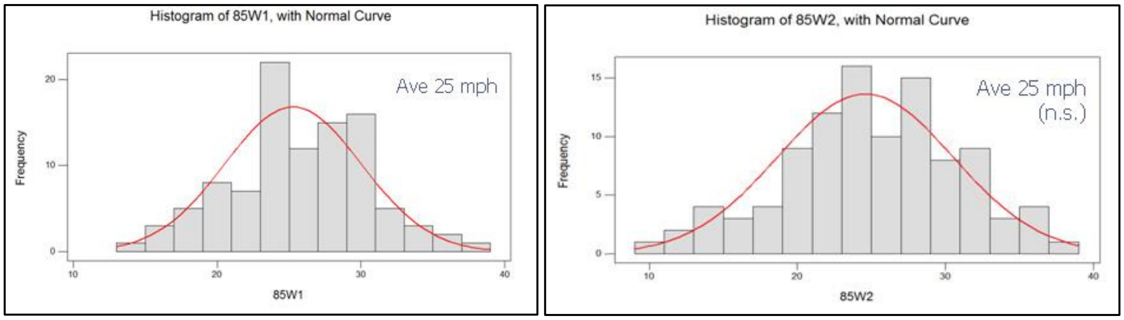


Figure 35. Histograms of vehicle speeds (in mph) for Rte. 85 under conventional lighting (left) and during the ecoluminance demonstration (right). No statistically significant difference (p>0.05) was found.

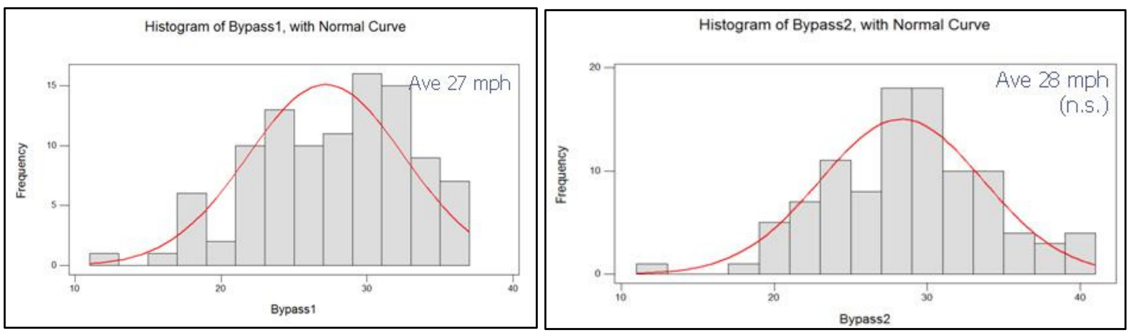


Figure 36. Histograms of vehicle speeds (in mph) for the Slingerlands bypass under conventional lighting (left) and during the ecoluminance demonstration (right). No statistically significant difference (p>0.05) was found.

In general the differences in speeds were very small (on the order of 0-2 mph different). For only one entrance, along Cherry Ave., was a statistically significant difference found, a reduction from 30 to 28 mph. Of interest, the existing HPS luminaire at this location remained on during the demonstration, so it is not entirely clear whether its presence contributed to the change in speed or not. Further, since the demonstration only occurred over a period of two nights, some drivers may have noticed the novel lighting and adjusted their behavior accordingly. However, since the speeds for the conventional and ecoluminance lighting approaches were so similar, it would be expected that the speeds might become even more similar after a longer duration. In general, at least as far as approaching vehicle speed is relevant to safety at this location, the change in lighting configurations had little measurable impact.

Section 4
DISCUSSION

MAINTENANCE ISSUES

The ecoluminance lighting demonstration used several different types of lighting fixtures including fluorescent bollards, LED landscape lighting, and LED overhead luminaires. In comparison, the existing HPS system uses only a single lamp and luminaire type, 250 W HPS lamps and cobrahead style luminaires. Despite the substantially lower power of just over 600 W for the ecoluminance concept (or 1100 W, including the two HPS luminaires that remained on during the demonstration) compared to about 2360 W for the existing system (295 W per luminaire including ballast power), maintenance of the system could be complicated by a need to keep a larger number of lamps and luminaires in stock.

Another point that was brought up during the initial ecoluminance demonstration was the potential interference of the landscape lighting in mowing operations in the central island. Mowing equipment could also damage or at a minimum, knock luminaires out of alignment with the potential of reducing efficacy of the landscape lighting, or possibly creating glare if the luminaires happened to point toward oncoming traffic. The particular roundabout location where the demonstration occurred was rather large, with a 100-ft diameter central island. Smaller roundabouts might be able to avoid the need for landscape lighting, since vehicles would be closer to the central island and headlamp illumination could be sufficient for illuminating the vegetation, as pointed out by Bullough et al. (2009) in the earlier ecoluminance report.

One approach that was not implemented in the present demonstration could be the used of a larger number of lower-wattage and lower-mounted LED overhead lights. Typically, mounting heights for street lights are at 30 ft or higher, in order to place the fixtures far from drivers' and pedestrians' line of sight and reduce the potential for glare. It was observed during the final demonstration that the 30-W LED overhead luminaires were not particularly glaring even though they were only mounted 15 ft high. These could be located along the crosswalk areas, perhaps even using multiple luminaires on either side of the crosswalk, in addition to the locations between the roundabout entrances, to reduce the need for the bollard luminaires at the crosswalk locations. Such an approach would benefit from reduced energy use, allow substantially lower poles with reduced cost and mass, and minimize the number of different fixture types needed to illuminate the roundabout. The use of "white" illumination compared to the "yellowish" light from HPS lamps also would provide additional brightness perception (Rea et al., 2009).

ECONOMIC ANALYSIS

In addition to the reduction in energy, it is worth considering the potential long-term economic costs of the ecoluminance system in comparison with the conventional HPS lighting system (Table 10). The approximate initial cost of the HPS system is $34,624 whereas the initial cost of the ecoluminance system is $35,704. The annual operating cost for the HPS is $1130, and it is slightly lower, $1055, for the ecoluminance system, although the energy use is only 2681 kWh/year, compared to 10,337 kWh/year for the HPS system. As a result the total annualized cost for each system is similar, nearly $4700/year.

Table 10. Economic cost analysis for conventional and ecoluminance lighting systems.

Location	**Roundabout**			
Lamp type	*HPS*	*Landscape*	*Ped. Bollard*	*LED Overhead*
Initial costs				
Number of luminaires	8	12	8	4
Cost per luminaire	$210	$105	$986	$1,600
Total luminaire cost	$1680	$1260	$7888	$6400
Lamps per luminaire	1	1	2	1
Total number of lamps	8	12	16	4
Total lamp cost	$432	$0	$224	$0
Number of poles	8	12	8	4
Pole cost	$1900	$0	$0	$520
Total pole cost	$15200	$0	$0	$2080
Total equipment cost	$17312	$1260	$8112	$8480
Labor	$17312	$1260	$8112	$8480
Total installation cost	$34624	$2520	$16224	$16960
Annual costs				
Capital recovery factor (8% discount/20 years)	0.10185	0.10185	0.10185	0.10185
Annualized installation cost	$3526	$257	$1652	$1727
Average daily use (hours)	12	12	12	12
Annual operating time (hours)	4380	4380	4380	4380
Average rated lamp life (hours)	24000	50000	20000	50000
Lamps used per year	1.46	1.05	3.50	0.35
Relamping labor per lamp	$23	$23	$10	$23
Lamp replacement cost per lamp	$66	$128	$24	$1,623
Annual maintenance cost	$96	$135	$84	$569
Input power (watts)	295	9	24	30
Annual energy use (kWh)	10337	473	1682	526
Electricity cost per kWh	$0.10	$0.10	$0.10	$0.10
Annual energy cost	$1034	$47	$168	$53
Annual operating cost	$1130	$182	$252	$621
Total annualized cost	$4656	$439	$1905	$2349

Looking at the initial and maintenance costs, one of the primary reasons that the ecoluminance system has such a high initial and operating cost is that the LED overhead luminaires used had a high initial cost ($1600). As reported by Radetsky (2010, 2011), the high initial costs of LED luminaires for street lighting are a substantial part of the total cost of ownership, because LEDs are a relatively new technology with high cost margins. LED luminaire costs are decreasing, and will be expected to continue to do so for several years. As a comparison, if the LED overhead luminaires had an initial cost of $600 (still a relatively high cost compared to HPS luminaires, but substantially lower than $1600), the initial system cost would be reduced to $27,704 (from $35,704) and the annual operating cost would be reduced to $705 (from $1055). This would reduce the total annualized system cost to $3500, rather than $4700. Thus, not only would the initial cost be lower, the annual operating cost would be lower as well.

The reduction in annual energy use of 7656 kWh/year corresponds to reductions in greenhouse gas emissions. The U.S. Environmental Protection Agency (2009) estimated that on average nationwide, each kilowatt hour (kWh) of electricity saved corresponds to reductions of 0.9 grams (g) of nitrogen oxide (NO_X), 2.4 g of sulfur dioxide (SO_2) and 603 g of carbon dioxide (CO_2). Thus a single roundabout with the ecoluminance lighting approach would reduce emissions of 6.9 kg of NO_X, 18.4 kg of SO_2, and more than 4600 kg of CO_2 each year, compared to the conventional HPS lighting system.

CONCLUSIONS

In general, the ecoluminance approach was demonstrated to provide attractive lighting that was judged favorably by individuals from transportation agencies as well as members of the public concerned with pedestrian safety. The configuration used in the final demonstration was derived from the knowledge gained in the earlier demonstrations, and resulted in substantial energy savings compared to the conventional HPS lighting approach, while having no observed negative impacts on traffic or pedestrian safety. Of course, the installation was in place for a short period of time only, and the true effects on safety are not fully understood. Each of the ecoluminance elements (pedestrian bollards, landscape lighting, LED overhead lights, and retroreflective markers) could be considered for use in other roundabout locations. For smaller roundabouts, landscape lighting may not be necessary as discussed by Bullough et al. (2009) in their earlier ecoluminance concept report. Bollard luminaires might be used in conjunction with push-button controls to use a lower light output and only use full light output when pedestrians are present and waiting to use the crosswalk, which would reduce energy use and potential glare. NYSDOT might also consider evaluating the use of lower-wattage, and lower-mounted LED overhead lights to illuminate roundabout locations and other types of intersections in order to reduce operating and installation costs, especially as costs for LED luminaires continue to decrease.

Section 5
REFERENCES

Bullough JD. 2010. Lighting Answers: Dynamic Outdoor Lighting. Troy, NY: National Lighting Product Information Program.

Bullough JD, Rea MS, Snyder JD, Radetsky LC, Zhang X, Skinner NP. 2009. Lighting and Vegetation for Energy-Efficient and Safe Roadway Travel, C-08-03. Albany, NY: New York State Department of Transportation.

Illuminating Engineering Society. 2008. Design Guide for Roundabout Lighting. New York, NY: Illuminating Engineering Society.

Radetsky LC. 2010. Specifier Reports: Streetlights for Collector Roads. Troy, NY: National Lighting Product Information Program.

Radetsky LC. 2011. Specifier Reports: Streetlights for Local Roads. Troy, NY: National Lighting Product Information Program.

Rea MS, Ouellette MJ. 1991. Relative visual performance: A basis for application. Lighting Research and Technology 23(3): 135-144.

Rea MS, Bullough JD, Freyssinier-Nova JP, Bierman A. 2004. A proposed unified system of photometry. Lighting Research and Technology 36(2): 85-111.

Rea MS, Bullough JD, Akashi Y. 2009. Several views of metal halide and high pressure sodium lighting for outdoor applications. Lighting Research and Technology 41(4): 297-320.

Rea MS, Radetsky LC, Bullough JD. 2011. Toward a model of outdoor lighting scene brightness. Lighting Research and Technology 43(1): 7-30.

U.S. Environmental Protection Agency. 2009. How Clean is the Electricity I Use: Power Profiler. Washington, DC: U.S. Environmental Protection Agency.