



## TRANSPORTATION RESEARCH SYNTHESIS

Local Road Research Board  
Minnesota Department of Transportation  
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TRS 1413  
Published November 2014

# New Approaches for Roundabout Lighting to Enhance Pedestrian Safety

*The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of CTC & Associates, MnDOT or LRRB.*

### Introduction

Roundabouts are rapidly gaining in popularity as an intersection treatment across the United States. As the number of roundabouts in Minnesota continues to grow, local road authorities are interested in new approaches to roundabout lighting to enhance pedestrian safety while reducing ongoing energy costs.

One emerging approach is ecoluminance, a lighting concept that incorporates light reflected from plants, low-height bollard-based lighting, and retroreflective elements to light roundabouts while reducing power consumption. LRRB was interested in more information about this and other approaches to lighting roundabouts effectively but efficiently to improve pedestrian safety, and more generally in a synthesis of information that could serve as a starting point for review of several topics in roundabout lighting. These topics include:



- Current design standards and best practices for roundabout lighting to enhance pedestrian safety.
- The role of lighting in enhancing the visibility and safety of pedestrians at roundabouts.
- The impacts of lighting placement, height and fixture type, particularly low-height fixtures (such as bollards that are a few feet tall, rather than mounted overhead).
- Energy considerations related to lighting systems, including the incorporation of ecoluminance elements.
- Challenges related to maintenance of lighting systems and equipment durability, especially during the winter.

To gather this information, CTC & Associates conducted a literature search to identify design guidance, research and best practices. We also conducted interviews with researchers and practitioners who have extensive experience in this area.

## **Summary of Findings**

While many state and local agencies offer guidelines or policies on roundabout design, most of these guides do not offer unique guidelines for lighting but instead cite federal guidance or the Illuminating Engineering Society's *Design Guide for Roundabout Lighting*. The state and local guidelines cited in this report offer additional lighting guidance unique to their own agencies.

### **General Principles**

*NCHRP Report 672: Roundabouts: An Informational Guide* (2010) recommends lighting at all roundabouts, although the report acknowledges that lighting may be cost-prohibitive if there is no power supply nearby. The report notes that drivers in a roundabout may not expect the geometry and channelization unless it is visible at all times, and that the effectiveness of vehicle headlights is reduced because of the curve of the roundabout. The report includes recommendations on lighting in potential conflict areas and transition lighting on the approach to the roundabout.

### **Lighting Levels**

Widely cited as the fundamental roundabout lighting standard, the IES *Design Guide for Roundabout Lighting* makes recommendations for both horizontal and vertical illuminance levels in a roundabout crosswalk. These recommendations vary based on the functional classification of the roads that enter the roundabout and the expected pedestrian usage of the roundabout; recommended levels range from 8 to 34 lux.

A 2008 conference paper from the city of Noblesville, Indiana, outlined several methods for evaluating whether a luminaire layout will effectively meet these recommended illuminance levels. These strategies include obtaining advice and input from professional design consultants, manufacturers and the power utility, and using computer modeling software or lighting photometric charts to generate illumination contours.

### **Lighting Equipment and Layout**

While crosswalks are traditionally lit from directly above, recent FHWA guidance and other research recommend positioning lights ahead of crosswalks in order to improve visibility of pedestrians to drivers. This approach provides positive contrast for the pedestrians against a darker background. The 2010 MnDOT Roadway Lighting Design Manual recommends placing light poles 1 to 30 feet before the crosswalk and lighting roundabouts from the outer edge of the roadway to aid in providing this positive contrast.

Illumination can be provided from the interior of the roundabout circle or from its perimeter. *NCHRP Report 672* notes that the IES *Design Guide for Roundabout Lighting* recommends perimeter lighting, augmented by lighting on the approach side of crosswalks. The report notes that both lighting options have advantages:

- **Perimeter illumination** allows the strongest lighting around critical bicycle and pedestrian areas, provides good visual guidance on the circular roadway, makes approach signs clearly visible and makes luminaires easier to maintain.
- **Central illumination** improves perception of the roundabout at a distance, requires fewer poles to achieve the same illumination, keeps the central pole clear of critical conflict areas, and makes the exit guide signs clearly visible.

Roundabouts have several conflict areas where run-off-the-road crashes are most prevalent. The 2014 Kansas DOT Roundabout Guide offers detailed guidance about lighting in these areas, recommending that light poles should be placed as far from the curb as possible.

Other key guidance includes:

- MnDOT's 2010 Roadway Lighting Design Manual recommends illumination on the approach nose of all splitter islands, at all exit and entry points, and for at least 400 feet along each road that connects to the roundabout. To improve visibility of the central island and circulating vehicles, lighting the roundabout from the outside in is preferred. The MnDOT Roundabout Lighting Guidelines, which is a separate document offered as a handout, offer more detailed guidance.
- The FHWA Manual on Uniform Traffic Control Devices notes that the use of post-mounted delineators and reflective chevrons is common practice for helping drivers recognize the geometry of a roadway, particularly at curves.

### **Safety Impacts of Lighting**

A forthcoming Georgia DOT study found that roundabout lighting in Minnesota has a safety benefit. (The study is using crash data from Minnesota, a state with a more established roundabout program, to estimate safety effects in Georgia.) In the study, which used crash data from 2003 to 2010, Minnesota roundabouts with no illumination had an average observed crash rate of 0.458 crashes per million vehicles, compared with 0.285 for roundabouts with partial illumination and 0.193 for roundabouts with full lighting. This analysis involved only vehicle collisions and did not evaluate pedestrian safety.

### **Ecoluminance and Energy Considerations**

Ecoluminance is an emerging concept that incorporates multiple features that combine to provide adequate roundabout illumination: lights mounted on bollards (posts typically approximately three to four feet tall) for pedestrian crossings, overhead LED lamps, retroreflective elements, and a central island with landscape lighting and vegetation that can reflect light. Developed by a team at Rensselaer Polytechnic Institute's Lighting Research Center, this approach focuses on providing luminance (the amount of light reflected or emitted by a surface) rather than illuminance (the amount of light falling on a surface). Several short-term demonstration projects have used this approach. In these projects, researchers found that this approach provided adequate luminance, and observers generally felt that the lighting was an improvement compared to conventional overhead lighting.

In one study, the relative costs of an ecoluminance-based system compared to one based on high-pressure sodium overhead lamps were similar on an annualized basis. These annualized costs factored in initial installation cost and annual energy usage. However, the ecoluminance approach uses LED bollards that have high initial costs and low energy consumption. If LED lamp costs drop as expected, annualized costs for the ecoluminance approach will also drop.

### **Pedestrian Visibility Under Low-Height Lighting**

Research on bollard luminaires at crosswalks has concluded that they improve pedestrian visibility. While the tests in these studies took place at mid-block crosswalks or intersections, the researchers expect that the results would apply to roundabout crosswalks as well.

### **Winter Maintenance of Low-Height Lighting**

Those we interviewed said that while deicers would likely have minimal impact on bollard fixtures, plowing operations could impede bollard effectiveness by piling snow in front of them. This could be addressed, at least in existing roundabouts where traditional lighting is being replaced by low-height lighting, by taking current plowing operations into consideration when planning the lighting layout, aiming to avoid placing bollards in spots that typically get blocked by snow piles.

# Detailed Findings

## Definitions

Several technical terms and concepts that are widely used in lighting design appear in this report. The following definitions are adapted from FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* unless otherwise noted (see <http://www.fhwa.dot.gov/publications/research/safety/08053/>, pages 2 to 9 and page 14).

**Illuminance:** A measurement of the quantity of light that falls on a surface, measured in lux or footcandles. *Vertical illuminance* refers to the illuminance on a vertical surface. Vertical illuminance of a pedestrian is typically measured at a point 1.5 meters above the road surface. The mounting height of a luminaire (and therefore the angle at which the light hits the object) has a significant impact on vertical illuminance.

**Luminance:** A measurement of the quantity of light emitted by a surface, whether directly emitted by an object or reflected by it. Luminance is what an observer perceives, and it is an approximate description of how bright an object appears. (However, brightness can vary depending on an object's surroundings; for example, a full moon has the same luminance during day or night, but appears brighter at night.)

**Contrast:** The visual difference between an object and its background, typically reported as the difference between the luminance of the object and the background luminance, divided by the background luminance. Contrast can be negative, which indicates that the object is darker than the background and appears in silhouette. There are two aspects: *color contrast*, the difference in color between the two, and *luminance contrast*, the difference in brightness between the two. Luminance contrast is far more important to pedestrian visibility at night.

**Pedestrian visibility:** Reported as the distance at which a pedestrian is visible enough for a driver to react appropriately.

**Glare:** Glare is caused when the luminance of an object is significantly higher than what the human eye is adapted for. There are two types of glare: *discomfort glare*, which causes discomfort or pain, and *disability glare*, which actually impedes the ability of the observer to perform a visual task (such as detecting pedestrians).

**Uniformity:** As described in the Kansas Roundabout Guide, uniformity is the ratio of the average illuminance to the minimum illuminance in a roundabout. (See page 8-2 of [https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeng/Roundabouts/Roundabout\\_Guide/KansasRoundaboutGuideSecondEdition.pdf](https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeng/Roundabouts/Roundabout_Guide/KansasRoundaboutGuideSecondEdition.pdf).)

**Bollard:** A bollard is a short vertical post, which can be used in transportation to direct or control traffic, and which may or may not include a light installed.

**Lux and Footcandles:** Two measurements of light levels. One lux is equal to one lumen (a measure of the total amount of visible light emitted by a source) per square meter. According to [Wikipedia](#), a night illuminated by a full moon is 0.27 to 1.0 lux, twilight is at least 3.4 lux, and a home living room is typically about 50 lux. One footcandle is equal to approximately 10.8 lux.

## Key Guidance Documents and Research

Through our research and interviews, we identified two key national guidance documents that address roundabout lighting, as well as four documents from state DOTs and local agencies. This section lists these six documents for reference. Detailed guidance from each document is included in the appropriate sections of this report.

## **National Guidance and Resources**

**Design Guide for Roundabout Lighting**, Illuminating Engineering Society, 2008.

Summary at <http://www.ies.org/store/product/design-guide-for-roundabout-lighting-1037.cfm>

This guide is widely cited as the fundamental roundabout lighting standard. *NCHRP Report 672* describes it as “the primary resource that should be consulted in completing a lighting plan for a roundabout.” MnDOT’s Roadway Lighting Design Manual uses the guide’s recommended lighting values.

**NCHRP Report 672: Roundabouts: An Informational Guide**, Second Edition, Lee Rodegerdts, Justin Bansen, Christopher Tiesler, Julia Knudsen, Edward Myers, Mark Johnson, Michael Moule, Bhagwant Persaud, Craig Lyon, R. Barry Crown, Bernard Guichet and Andrew O’Brien, 2010.

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_672.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf)

In addition, three FHWA guidance documents are referenced in specific sections of this report:

- Informational Report on Lighting Design for Midblock Crosswalks, 2008.
- Technical Summary on Mini-Roundabouts, 2010.
- Manual on Uniform Traffic Control Devices, 2009 with 2012 updates.

## **State and Local Guidance and Resources**

We identified guidance and research on roundabout lighting from four agencies: Minnesota DOT; Kansas DOT; the city of Bend, Oregon; and the city of Noblesville, Indiana.

### **Minnesota DOT**

**MnDOT Roadway Lighting Design Manual**, May 2010.

[http://www.dot.state.mn.us/trafficeg/lighting/2010\\_Roadway\\_Lighting\\_Design\\_Manual2.pdf](http://www.dot.state.mn.us/trafficeg/lighting/2010_Roadway_Lighting_Design_Manual2.pdf)

- MnDOT Roundabout Lighting Guidelines (see [Appendix A](#))

### **Kansas DOT**

**Kansas Roundabout Guide**, Second Edition, Kittelson & Associates, 2014.

[https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeg/Roundabouts/Roundabout\\_Guide/KansasRoundaboutGuideSecondEdition.pdf](https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeg/Roundabouts/Roundabout_Guide/KansasRoundaboutGuideSecondEdition.pdf)

Previous version of the guide:

**Kansas Roundabout Guide**, Kittelson & Associates, 2003.

[http://safety.fhwa.dot.gov/Intersection/resources/fhwasa09027/resources/Kansas\\_Roundabout\\_Guide.pdf](http://safety.fhwa.dot.gov/Intersection/resources/fhwasa09027/resources/Kansas_Roundabout_Guide.pdf)

### **Bend, Oregon**

**City of Bend Roundabout Evaluation and Design Guidelines**, Kittelson & Associates, April 2010.

<http://www.ci.bend.or.us/modules/showdocument.aspx?documentid=2512>

### **Noblesville, Indiana**

**“Developing Effective Standards and Strategies for Roundabout Lighting,”** John Beery and Andrew Rodewald, City of Noblesville, Indiana, *Institute of Transportation Engineers Annual Conference*, August 2008.

<http://www.ite.org/Membersonly/annualmeeting/2008/AB08H0202.pdf>

# **Roundabout Lighting Standards and Best Practices**

## **General Principles**

**NCHRP Report 672: Roundabouts: An Informational Guide**, Second Edition, 2010.

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_672.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf)

Chapter 8 of *NCHRP Report 672* defines the primary purposes of roundabout lighting as providing visibility for users approaching the roundabout and providing visibility of key conflict areas to help users see other users in the roundabout. It notes that drivers in a roundabout may not expect the geometry and channelization unless it is visible at all times, and that the effectiveness of vehicle headlights is reduced because of the curve of the roundabout. The report recommends lighting at all roundabouts, although it acknowledges that lighting may be cost-prohibitive if there is no power supply nearby.

The report makes several general recommendations regarding roundabout lighting design:

- Overall roundabout illumination should be approximately equal to the sum of the illumination levels of the intersecting roadways.
- Lighting design should include transition lighting that extends along the approach to the roundabout if continuous roadway lighting is not present. This allows drivers' vision to adjust from the lit roundabout back to the dark roadway.
- Adequate illumination should be provided on the approach nose of roundabout splitter islands, at every location where traffic enters the roundabout and could conflict with traffic already in the roundabout, and at every location where traffic streams separate (roundabout exits).
- Adequate illumination should be provided for pedestrian crossing and bicycle merging areas.
- The impact of the lighting on adjacent properties and ambient lighting zones should be considered. Efforts should be made to minimize glare and misdirected light.
- Raised channelization and curbing should be illuminated.

## **Lighting Levels**

**Design Guide for Roundabout Lighting**, Illuminating Engineering Society, 2008.

Summary at <http://www.ies.org/store/product/design-guide-for-roundabout-lighting-1037.cfm>

As reported in *NCHRP Report 672* (Section 8.3), the *Design Guide for Roundabout Lighting* makes recommendations for the average horizontal illuminance on the pavement based on the functional classifications of the roads (major, collector or local) that enter the roundabout and the expected pedestrian usage of the roundabout during the average annual peak hour of darkness (typically 6 to 7 p.m.). These recommendations vary from 8 to 34 lux. The standards specify that vertical luminance in the crosswalk should be equal to these horizontal illuminance levels. Finally, the standards also specify uniformity based on road classification, ranging from 3:1 to 6:1.

Additional resource:

**Technical Summary on Mini-Roundabouts**, FHWA, L.A. Rodegerdts, W.E. Scarbrough, J.A. Bansen, February 2010.

<http://safety.fhwa.dot.gov/intersection/roundabouts/fhwasa10007/fhwasa10007.pdf>

This FHWA Technical Summary on mini-roundabouts states that the principles outlined in the IES *Design Guide for Roundabout Lighting* apply to mini-roundabouts.

**MnDOT Roadway Lighting Design Manual**, May 2010.

[http://www.dot.state.mn.us/trafficeng/lighting/2010\\_Roadway\\_Lighting\\_Design\\_Manual2.pdf](http://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway_Lighting_Design_Manual2.pdf)

In addition to using the IES lighting level recommendations, MnDOT's Roadway Lighting Design Manual (Section 1.4.9) suggests that light intensity of a roundabout should be 1 footcandle (10 lux) greater than between

intersections where there is continuous lighting, or double the light intensity if there is low illumination between intersections.

**“Developing Effective Standards and Strategies for Roundabout Lighting,”** John Beery and Andrew Rodewald, City of Noblesville, Indiana, *Institute of Transportation Engineers Annual Conference*, August 2008. <http://www.ite.org/Membersonly/annualmeeting/2008/AB08H0202.pdf>

While many agencies’ guidelines reference the IES recommended illuminance values for intersections, this paper by City of Noblesville staff offers additional guidance, outlining several methods for evaluating whether a luminaire layout will effectively meet these recommended illuminance levels. These methods include:

- Obtaining advice from a professional design consultant.
- Considering manufacturers’ recommendations and input.
- Obtaining advice from the power utility providing the lighting.
- Using computer modeling software to produce illumination contour intervals.
- Manually generating illumination contours using lighting photometric charts.

**City of Bend Roundabout Evaluation and Design Guidelines**, Kittelson & Associates, April 2010.

<http://www.ci.bend.or.us/modules/showdocument.aspx?documentid=2512>

While the city recommends using the IES guidelines for illumination, its guidelines also specify a minimum horizontal illumination of 1.0 footcandles (10 lux) and a uniformity of 3:1 or better (see page 12). The guidelines also note that recent studies recognize the importance of vertical illuminance, and recommend that it meet the same minimum standard as horizontal illuminance.

We spoke with city Transportation Engineer Robin Lewis, who said the city ensures that the noses of short splitter islands are well lit if they are present. Lewis said bike and pedestrian conflict areas are also areas of focus. The city tries to light in advance of pedestrian crossings so pedestrians in the crossings are well lit.

**FHWA Lighting Handbook**, Paul Lutkevich, Don McLean, Joseph Cheung, August 2012.

[http://safety.fhwa.dot.gov/roadway\\_dept/night\\_visib/lighting\\_handbook/](http://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/)

This handbook specifically recommends against the use of adaptive lighting, which allows the lighting level to be reduced during off-peak hours, in roundabouts because of their geometry and the effectiveness of fixed headlights within the roundabout circle.

### **Additional Resources**

We interviewed Bastian Schroeder, assistant director of highway systems at the Institute for Transportation Research and Education (housed at North Carolina State University), who has published research on many aspects of roundabouts. Regarding lighting levels, Schroeder suggested that the principles outlined in FHWA’s *Informational Report on Lighting Design for Midblock Crosswalks* would be applicable to roundabout pedestrian crossings as well.

For studies on pedestrian visibility in crosswalks using low-height bollard lighting, see “Pedestrian Visibility Under Low-Height Lighting” on page 17 of this report.

**Informational Report on Lighting Design for Midblock Crosswalks**, FHWA, Ronald B. Gibbons, Chris Edwards, Brian Williams and Carl K. Anderson, April 2008.

<http://www.fhwa.dot.gov/publications/research/safety/08053/>

This report recommends a vertical illuminance of 20 lux in crosswalks at a height of 1.5 meters. This lighting should extend the entire width of the roadway to ensure that pedestrians are visible before they step into the roadway.

The report describes the importance of both luminaire height and angle in achieving the necessary illuminance. Using a vertical illuminance plot, the report demonstrates that a 250-watt high-pressure sodium luminaire mounted at a height of 8.5 meters will produce a vertical illuminance of 20 lux at a (horizontal) distance of 4.25 to 6 meters from the luminaire. Mounting height has a significant impact on vertical illuminance; the same luminaire mounted at a height of 10 meters will never produce a vertical illuminance of 20 lux at pedestrian height.

Similarly, while many agencies traditionally light crosswalks from directly above, the report recommends lighting them from ahead of the crosswalk to make pedestrians more visible.

## **Lighting Equipment and Layout**

**NCHRP Report 672: Roundabouts: An Informational Guide**, Second Edition, 2010.

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_672.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf)

Chapter 8 of this report describes common lighting equipment types, including cobra-style, ornamental and high-mast lighting, but suggests that agency staff select equipment based on the needs of a specific roundabout.

The report discusses pole location options including lighting in the central island or around the perimeter of the roundabout, noting that the IES *Design Guide for Roundabout Lighting* recommends perimeter lighting, augmented by lighting on the approach side of crosswalks. Both options have advantages and disadvantages. Perimeter illumination allows the strongest lighting around critical bicycle and pedestrian areas, provides good visual guidance on the circular roadway, makes approach signs clearly visible and makes luminaires easier to maintain. Central illumination improves perception of the roundabout at a distance, requires fewer poles to achieve the same illumination, keeps the central pole clear of critical conflict areas, and makes the exit guide signs clearly visible.

**MnDOT Roadway Lighting Design Manual**, May 2010.

[http://www.dot.state.mn.us/trafficeng/lighting/2010\\_Roadway\\_Lighting\\_Design\\_Manual2.pdf](http://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway_Lighting_Design_Manual2.pdf)

Section 1.4.9 of MnDOT's Roadway Lighting Design Manual cites *NCHRP Report 672*'s guidance on roundabout lighting. Additionally, for pedestrian lighting at roundabouts, it states: "Crosswalks at roundabouts should typically be lit with the pedestrians in positive contrast. Light poles placed 1 to 30 feet before the crosswalk [are] recommended for this purpose. Roundabouts should be lit from the outer edge of the roadway to aid in providing this positive contrast to pedestrians."

The manual recommends illumination on the approach nose of all splitter islands, at all areas where traffic enters or exits the circulation stream of the roundabout, and for at least 400 feet along each road that connects to the roundabout. It also states: "It is preferable to light the roundabout from the outside in towards the center. This improves the visibility of the central island and the visibility of circulating vehicles to vehicles approaching the roundabout."

The MnDOT Roundabout Lighting Guidelines (included as [Appendix A](#) to this TRS), which are a separate document from the MnDOT Roadway Lighting Design Manual but offered as a handout accompanying it, specify that roundabouts should be illuminated in all urban conditions, and in suburban conditions when one or more approaches are lit, when competing (non-roadway) illumination in the vicinity could distract drivers, when heavy nighttime traffic is expected, or when pedestrian or bicycle traffic is expected. In rural conditions, illumination is recommended but allowances for enhanced signing and markings are allowed if illumination is impossible.

The Roundabout Lighting Guidelines specify at least 8 light poles in a 4-leg roundabout: 1 light in advance of the crosswalk at each approach and exit in order to provide positive contrast lighting for pedestrians and yielded vehicles. Additional light poles may be needed when there are high-speed approaches or sight constraints, and in rural conditions. While lighting should extend at least 400 feet along each road connected to the roundabout, transition lighting can be used to help drivers adjust their vision back to dark conditions. If transition lighting is used, full lighting should begin 250 feet from the roundabout.



In clear zones, light pole locations relative to curbs are governed by the potential speeds of vehicles that run off the road; the document recommends referring to the AASHTO *Roadside Design Guide* and the ANSI/IESNA *American National Standard Practice for Roadway Lighting* for details. Specific practices to avoid include placing poles in splitter islands, placing poles on the right-hand perimeter just downstream of an exit point, and lighting from the central island outward.

**“Developing Effective Standards and Strategies for Roundabout Lighting,”** City of Noblesville, Indiana, *Institute of Transportation Engineers Annual Conference*, August 2008.

<http://www.ite.org/Membersonly/annualmeeting/2008/AB08H0202.pdf>

In this paper, staff detail the city’s process for establishing standards and policies for roundabout lighting, noting that “traditional and conventional methods for luminaire spacing and placement along linear roadways do not address the need to illuminate critical areas associated with the unique geometrics of roundabouts.”

For pedestrian crossings, the paper recommends initially planning to place luminaires approximately 10 feet ahead of the crossing in both entry and exit lanes (see page 8 of the paper). The authors acknowledge, however, that lighting or infrastructure needs may require the luminaire placement to be adjusted. The paper also encourages designers to anticipate future crosswalk locations through splitter islands at roundabouts that are designed without crosswalks, and to use this planning to determine light placement. If this is not feasible, the authors recommend placement of the first street light at least 75 feet or three car lengths in advance of the inner circle.

The paper notes that lighting fixture selection is one of the most important aspects of effective roundabout lighting. “It cannot be over-emphasized that implementing effective illumination begins with understanding the type of luminaire used for the desired application,” the authors write. “The most common error when considering the installation of street lighting is selecting a luminaire and pole based solely on aesthetics.” The paper provides lighting contours for four luminaire types: decorative structural cut-off, old-English-style decorative non-cut-off, traditional cobra head and post-top decorative.

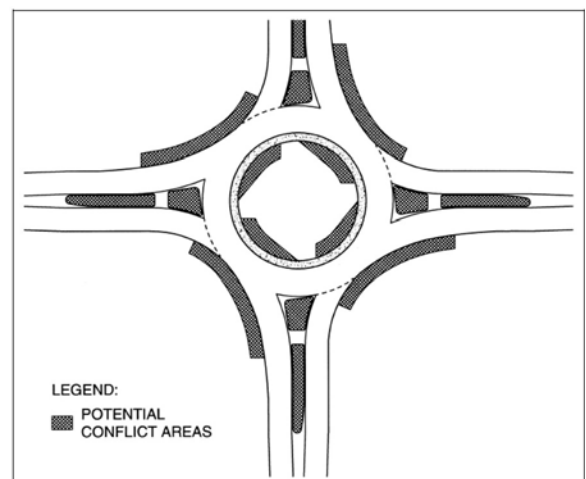
The authors recommend against placing light poles in splitter islands due to safety concerns, particularly in roundabouts that have mountable curbs to permit large trucks to turn. All light locations should be analyzed to ensure that they will not be affected by vehicle turning movements, and poles placed in the clear zone should be installed with breakaway transformer bases or breakaway foundation bolts for safety.

**Kansas Roundabout Guide**, Second Edition, Kittelson & Associates, 2014.

[https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeng/Roundabouts/Roundabout\\_Guide/KansasRoundaboutGuideSecondEdition.pdf](https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burtrafficeng/Roundabouts/Roundabout_Guide/KansasRoundaboutGuideSecondEdition.pdf)

The guide offers detailed guidance about the critical conflict areas in a roundabout where run-off-the-road crashes are most prevalent (see Figure 1, from page 8-4 of the guide). Light poles in these areas, which include the outer curves of the roundabout, the medians between the approach and exit lanes and most of the central island, should be placed as far away from the curb as practical.

The guide states: “In rural areas, KDOT prefers locating light poles at least 2 feet from the edge of the shoulder, or at least 8 feet from the edge of the pavement in the absence of a shoulder.” In urban areas, the guide recommends poles be at least 6 to 8 feet behind the curb, and it specifies a minimum



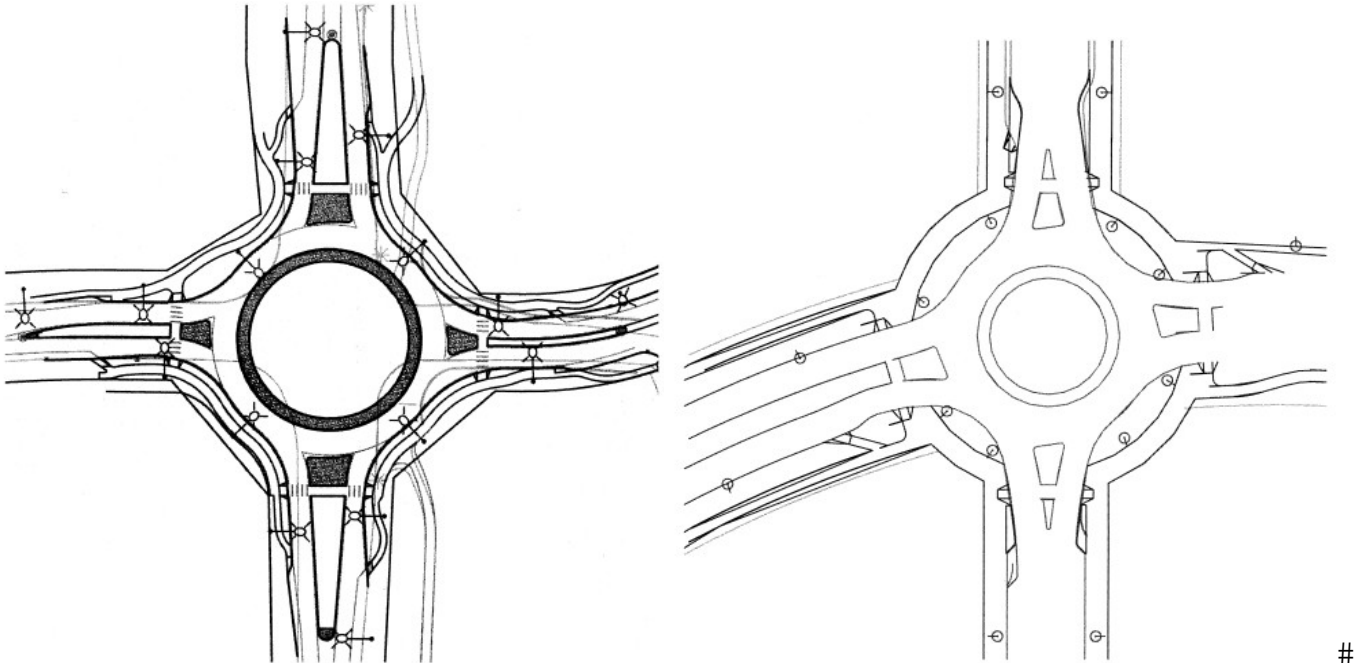
**Figure 1: Conflict areas where run-off-the-road crashes are most common (from the *Kansas Roundabout Guide*, Second Edition).**

offset distance of 3 feet for areas in or approaching the roundabout where the overhang of a turning truck could hit a pole.

The first edition of the Kansas Roundabout Guide

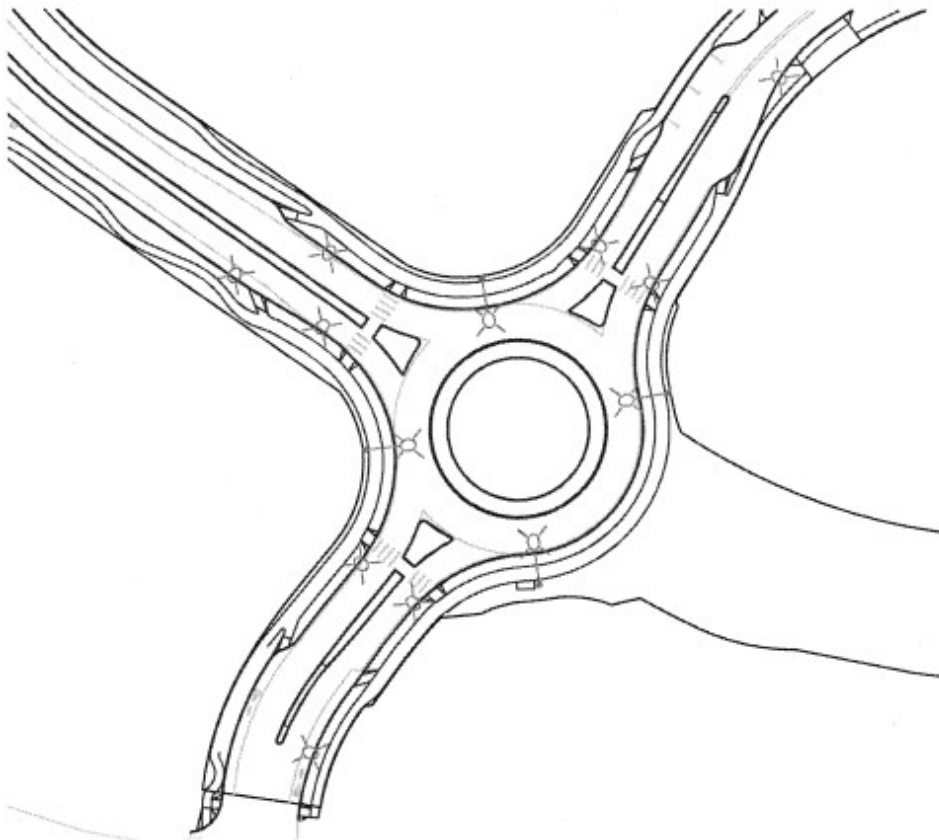
[http://safety.fhwa.dot.gov/Intersection/resources/fhwasa09027/resources/Kansas Roundabout Guide.pdf](http://safety.fhwa.dot.gov/Intersection/resources/fhwasa09027/resources/Kansas_Roundabout_Guide.pdf)

provides lighting layout diagrams for three roundabouts (see Figures 2 and 3, from pages 134-136 of the guide). These examples include one using cobra-style luminaires mounted 37 feet (11.2 meters) high, one using pedestrian-level luminaires mounted 18 feet (5.5 meters) high and one using a combination of the two. The report, however, urges caution in adapting the designs to another location.



**Figure 2: Examples of illumination using cobra-style luminaires (left) and pedestrian-level (18-ft.) luminaires (right), from *Kansas Roundabout Guide* (First Edition).**

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**Figure 3: Example of illumination using a mix of cobra-style and pedestrian-level luminaires (from *Kansas Roundabout Guide, First Edition*).**

**City of Bend Roundabout Evaluation and Design Guidelines**, Kittelson & Associates, April 2010.

<http://www.ci.bend.or.us/modules/showdocument.aspx?documentid=2512>

These guidelines from the City of Bend, Oregon, recommend starting the design “by placing luminaires along the perimeter of the roundabout in advance of each pedestrian crossing” (see page 12). The guidelines note that lighting from both the interior and exterior of the roundabout may be necessary, depending on roundabout size, and they stress the importance of a photometric analysis to ensure that light levels and uniformity are appropriate.

**Manual on Uniform Traffic Control Devices for Streets and Highways**, FHWA, 2009 Edition with May 2012 Revisions.

<http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf>

The use of post-mounted delineators and reflective chevrons is common practice for helping drivers recognize the geometry of a roadway, particularly at curves. The Manual on Uniform Traffic Control Devices provides a standard for these devices in Section 3F.02, although this standard is fairly broad: “Delineators shall consist of retroreflective devices that are capable of clearly retroreflecting light under normal atmospheric conditions from a distance of 1,000 feet when illuminated by the high beams of standard automobile lights. Retroreflective elements for delineators shall have a minimum dimension of 3 inches.” The MUTCD says delineators “are particularly beneficial at locations where the alignment might be confusing or unexpected, such as at lane-reduction transitions and curves. Delineators are effective guidance devices at night and during adverse weather. An important advantage of delineators in certain locations is that they remain visible when the roadway is wet or snow covered.”

## **Safety Impacts of Lighting**

**“Roundabout Illumination and Safety,”** Michael Rodgers, Michael Hunter, Alexander Samoylov, Franklin Gbologah, Georgia DOT Project 12-01, September 2013.

[http://www.gti.gatech.edu/sites/default/files/u51/Evaluation\\_of\\_Roundabout\\_Illumination\\_and\\_Safety\\_-\\_Franklin\\_Gbologah\\_%281%29.pdf](http://www.gti.gatech.edu/sites/default/files/u51/Evaluation_of_Roundabout_Illumination_and_Safety_-_Franklin_Gbologah_%281%29.pdf)

This poster describing a forthcoming study of the impact of roundabout lighting on safety in Minnesota found that roundabout illumination has a safety benefit. (This Georgia DOT study is using crash data from Minnesota, a state with a more established roundabout program, to estimate safety effects in Georgia.) In the study, which used crash data from 2003 to 2010, Minnesota roundabouts with no illumination had an average observed crash rate of 0.458 crashes per million vehicles. With partial illumination (four luminaires in the roundabout circle), that figure dropped to 0.285 crashes per million vehicles, while full lighting (four luminaires in the roundabout circle plus two luminaires on each approach) reduced the rate to 0.193 crashes per million vehicles.

We contacted authors Michael Rodgers and Franklin Gbologah to discuss the study. They noted that while initial results suggested that continuous lighting (which further increases the lighting on approaches) reduced safety compared to full lighting, they believe this result was due to errors in analysis and is probably not valid. Additionally, this analysis looked only at vehicle collisions and did not evaluate pedestrian safety.

**The Design of Interurban Intersections on Major Roads,** Service d’Etudes Techniques des Routes et Autoroutes, 1998.

[http://www.setra.developpement-durable.gouv.fr/IMG/pdf/US\\_ACI-P\\_GB.pdf](http://www.setra.developpement-durable.gouv.fr/IMG/pdf/US_ACI-P_GB.pdf)

This translation of a report from the French organization Service d’Etudes Techniques des Routes et Autoroutes argues that rural roundabouts generally do not require illumination unless there is an illuminated leg or another brightly lit area nearby (see page 99). Disadvantages of lighting roundabouts include high investment costs, maintenance and power costs that can equal up to 1.5 times the initial investment costs (over 15 years), and the fact that light poles are hazardous obstacles. The report recommends “staging” of the roundabout—indirectly lighting approaches or the central island—if there is a need to improve the roundabout’s nighttime visibility. It recommends avoiding placing light poles in the center island if possible, and never placing luminaires on the edges of the center island or on the splitter islands.

## **Ecoluminance and Energy Considerations**

Ecoluminance is an approach to roundabout lighting that uses lower light mounting heights, retroreflective elements and light reflected from plants to illuminate a roundabout while reducing power consumption.

Developed by a team at Rensselaer Polytechnic Institute’s Lighting Research Center, this approach is first described in the following 2009 report.

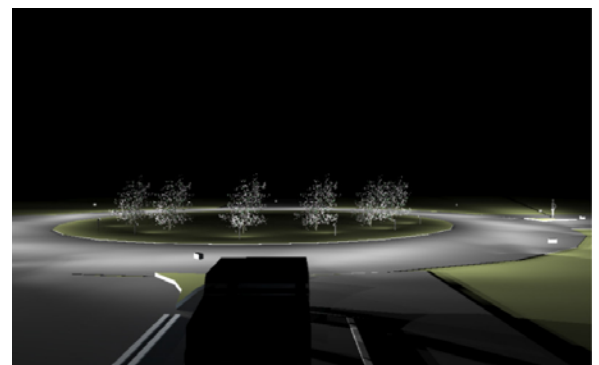
### **Concept Development**

#### **Lighting and Vegetation for Energy-Efficient and Safe**

**Roadway Travel,** John D. Bullough, Mark S. Rea, Jeremy D. Snyder, Leora C. Radetsky, Xin Zhang, Nicholas P. Skinner, New York State Energy Research and Development Authority/New York State DOT, April 2009.

<https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/LightingVegetation-C-08-03-10628.pdf>

This report proposed a conceptual shift for roadway lighting. Typical roadway lighting uses high-wattage lamps on tall poles (10 to 15 meters) to minimize glare and light level fluctuations. These



**Figure 4: Preliminary rendering of a roundabout illuminated using the ecoluminance strategy.**

lights provide high levels of illuminance, whereas the ecoluminance concept focuses on providing luminance instead.

The general design proposed in this report includes four elements: vegetation, retroreflective delineators, landscape lighting directed toward vegetation to help delineate road edges, and luminaires with controlled optical systems to provide localized luminance at locations where potential hazards must be lit, such as crosswalks or merging zones. A concept sketch for a roundabout includes vegetation in the roundabout's center island to help delineate the inner edge of the roadway and reduce glare from oncoming vehicles, low-level landscape lighting to augment the visibility of the vegetation if vehicle headlights are not sufficient, and cutoff-type luminaires to light travel lanes within the roundabout and make vehicles in those lanes appear brighter than the background. (Figure 4, from page 1-2 of the 2012 report summarized below, is a preliminary rendering of the ecoluminance concept.)

Chapter 4 of the report lays out criteria for evaluating the success of a lighting system. First among these is the lighting system's impact on safety, but energy use and the cost of the system are also important considerations. Given that crashes are relatively uncommon events, most studies use visibility and visual performance as surrogate indicators for safety. Luminance is one indicator of an object's visibility, and the report also uses the Relative Visual Performance model, which also takes into account the size of the target, the luminance of the background, the contrast in luminance between the object and its background, and the age of the observer.

The report proposed ecoluminance-based lighting designs for roundabouts, highway exit ramps and urban boulevards, and compared the designs to current lighting practices. For each design, researchers simulated the lighting performance and initial and operational costs. Based on these simulations, researchers decided that roundabouts offered the best potential of the three site types for using the ecoluminance approach to improve visibility while reducing energy consumption. They proposed a demonstration project, which received funding and is described below.

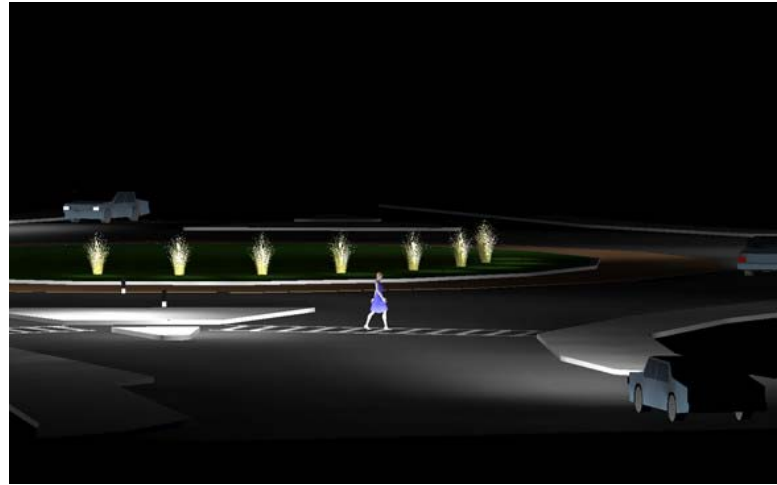
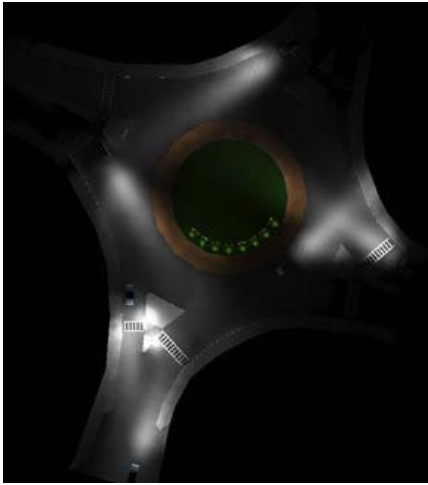
## **Initial Demonstrations**

**Demonstration of Roundabout Lighting Based on the Ecoluminance Approach.** John D. Bullough, Mark S. Rea, Jeremy D. Snyder, Nicholas P. Skinner, Rosa I. Capó, Patricia Rizzo, Uta Besenecker, New York State Energy Research and Development Authority/New York State DOT, August 2012. <https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-08-03FinalReport-Project18233-C0803.pdf>

This demonstration project was installed at a newly constructed two-lane roundabout in Bethlehem, New York. Two initial demonstrations lasted for one night each. The first demonstration showed the ecoluminance concept at one entrance by illuminating vegetation in the center island to alert drivers to the presence of the center island and installing bollards in pedestrian islands to light pedestrians in the crosswalks (see Figure 5, from page 2-4 of the report, and Figure 6, from page 2-6). The second demonstrated white overhead lighting, rather than the typical yellow light emitted by high-pressure sodium lamps.



**Figure 5: Pedestrian crosswalk bollard.**



**Figure 6: Overhead and perspective renderings of the initial ecoluminance demonstration.**

For the first one-night demonstration, two bollards mounted in the pedestrian islands illuminated the crosswalks at one entrance to the roundabout (see Figure 7, from page 2-7 of the report). Landscape lighting for this demonstration was provided by an in-ground luminaire, although researchers noted that in winter these could be covered by snow. Another option would be adjustable lighting on 2-foot stakes.

The demonstration reduced power consumption by about 75 percent. Bollards and vegetation lighting used 220 watts, while three high-pressure sodium lamps totaling 885 watts were turned off.

In the crosswalks, the research team measured illuminance values 3 feet above the ground. In the portion exiting the roundabout, illuminances started at 20 lux near the pedestrian island, but dropped off quickly to 7 lux at the far end of the crosswalk. On the entry side, illuminance started at 40 lux near the pedestrian island, dropping quickly to 5 lux at the far end of the crosswalk. The lowest illuminance values were greater than design values.

Researchers also compared the illumination from bollards to the illumination from existing HPS streetlights, which ranged from 6 to 8 lux over the entire length of the crosswalk.

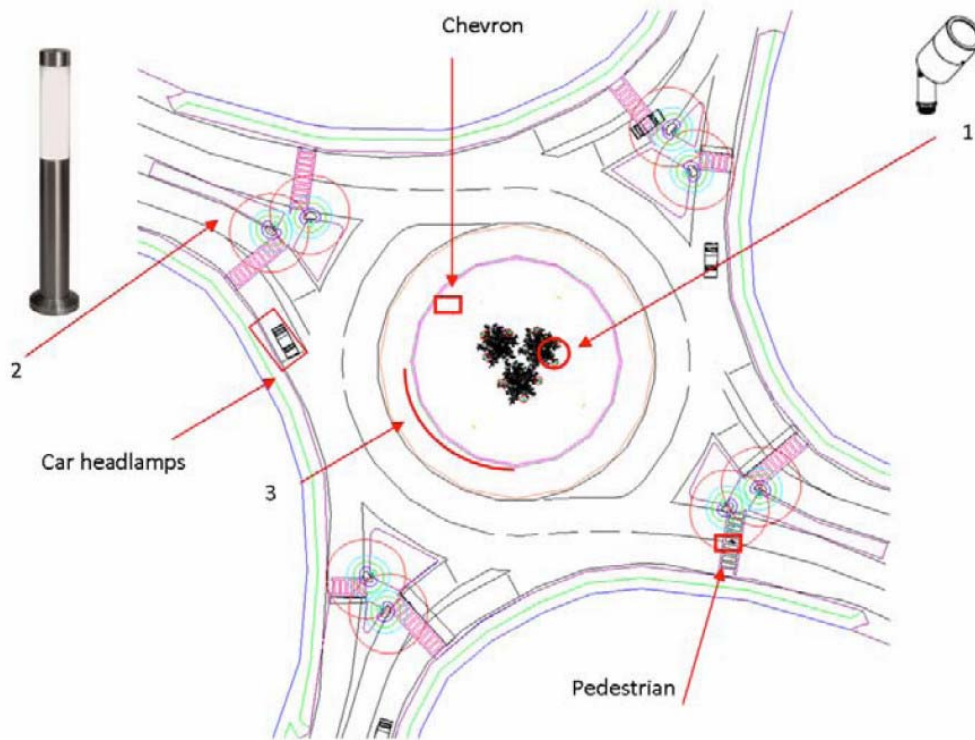
The research team surveyed 16 people who observed the roundabout on foot. Respondents generally considered the demonstration project to be an improvement over the original overhead lighting in terms of perceived safety. However, many of the respondents offered comments that the bollard lighting was too bright.

The second one-day demonstration temporarily installed LED streetlights to replace most of the existing HPS streetlights (two of the eight existing streetlamps were left on for safety reasons.) These lights reduced power consumption by nearly 50 percent, reducing it from more than 2,300 watts to 1,256 watts. Illuminance values closely matched predicted values, and five survey respondents strongly preferred the LED lights.



**Figure 7: Installed crosswalk bollards at initial ecoluminance demonstration.**

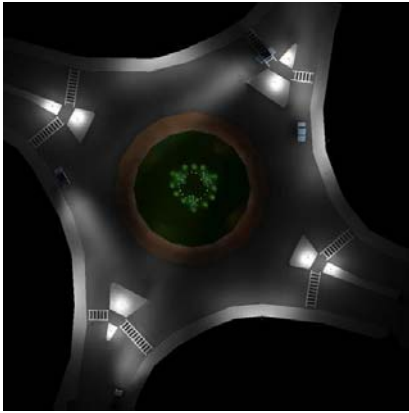
Researchers refined the concept and installed another demonstration at the site for two days. It incorporated 9-watt LED lighting fixtures to illuminate trees in the center of the roundabout, bollards with 48-watt fluorescent lights to illuminate crosswalks, and reflectors on the perimeter of the roundabout to help delineate the inner curve of the roundabout (see Figure 8, from page 3-2 of the report, and Figure 9, from page 3-4 of the report). To reduce the excessively bright illumination observed at crosswalks in the first demonstration, the researchers added baffles and covered the rear part of the fixture (see Figure 10, from page 3-7 of the report). Overhead lighting was provided by four 30-watt LED area light fixtures mounted 15 feet above the ground at the center of the sidewalks around the roundabout. The research team also installed 1-inch retroreflective curb markers, placed into 1-foot-long sections of PVC tube and staked into the grass of the center island at 6-foot intervals.



**Figure 8: Layout of chevrons, bollards and landscaping lighting in the follow-up ecoluminance demonstration. The system also used four 30-watt LED overhead luminaires along the sidewalks between each roundabout entrance.**

Researchers measured illuminance at crosswalk locations and observed vehicle speeds to serve as an indicator of safety, both during the two nights of the installation as well as before and after the installation to collect baseline data. Vertical illuminances in the crosswalks ranged from 1.7 to 7.3 lux furthest from the bollards, and 13.5 lux to 18.0 lux closest to the bollards. Average vehicle speeds during the demonstration varied by less than 2 mph from speeds under normal circumstances; researchers suggested that if the lights were installed for a longer period and drivers became accustomed to them, speeds might become even more similar.





The research team did identify some maintenance concerns with this system. Due to the greater variety of lighting fixtures the ecoluminance-based system uses, the agency would need to keep a greater number of lamps and luminaires on hand. Mowing operations in the center island could damage landscape lighting or knock it out of alignment, potentially reducing its effectiveness or even creating glare if the lights were to become aimed toward traffic.

Finally, an economic analysis found that costs were similar for an HPS system (\$4,656 on an annualized basis) versus an ecoluminance-based one (\$4,693 on an annualized basis). These figures take into account installation costs and annual energy costs. However, LED lamps are an emerging technology with a high initial cost that is expected to decrease for the next

**Figure 9: Overhead and isometric rendering of the follow-up ecoluminance demonstration.**

several years. If the cost of an overhead LED luminaire drops from \$1,600 to \$600 (which is still high compared to HPS luminaires), annualized costs of the LED-based system would drop to \$3,500.

### **Follow-up Demonstration**

**“Demonstration and Evaluation of New Approaches for Roundabout Lighting,”** John D. Bullough, Jeremy D. Snyder, Nicholas P. Skinner, Rosa I. Capó, Patricia Rizzo, Ute C. Besenecker, *Transportation Research Board 93rd Annual Meeting Compendium of Papers*, Paper 14-1134, 2014.

Citation at <http://trid.trb.org/view/2014/C/1287659>

Presentation materials available with TRB login at <http://amonline.trb.org/trb-55856-2014a-1.823612/t-1139-1.865354/341-1.869451/14-1134-1.869463/14-1134-1.869471>

Researchers used knowledge gained from the demonstrations described above to refine the system for a longer-term demonstration, which they described in a presentation at the 2014 TRB Annual Meeting. This installation consisted of:

- 9-watt LED landscape lighting for trees and vegetation in the center of the roundabout.
- Eight bollards with 48-watt fluorescent lights to provide vertical illumination of the crosswalks. To reduce the excessive brightness observed in prior demonstrations, the research team added louvers to the fixture.
- Chevron reflectors on the perimeter of the center island to delineate the inner curve of the roundabout.
- Four 30-watt LED overhead luminaires with Type II distributions mounted 15 feet above the ground on existing light poles along the sidewalks between each roundabout entrance.
- 1-inch-diameter glass curb markers, installed in angled 2-inch-diameter PVC pipe installed at 6-foot intervals along the perimeter of the center island. The markers were clear glass painted yellow, as required by the MUTCD.

Photometric measurements found satisfactory light levels that were similar to the previous demonstration. Directly under the overhead luminaires, illuminance was 8 lux, while 30 feet away in each direction the illuminance was 4 lux. A minimum of 2 lux is necessary to ensure visibility of tripping hazards. In the crosswalks, vertical illuminance ranged from 1.7 lux at a point farthest from the bollards to 18.0 lux closest to them.



**Figure 10: Louvered bollard used in the follow-up ecoluminance demonstration.**



Researchers also measured the speeds of approaching vehicles as a measure of safety; the installation had minimal impact.

Researchers acknowledged that these tests occurred only during warm, clear weather. In addition, due to the short installation periods, the true safety impacts of this approach are not fully understood. They also suggested that at smaller roundabouts, the landscape lighting may not be necessary, and it may be appropriate to use bollard luminaires with push-button controls that would produce lower light output unless a pedestrian pressed the button to produce the full light output.

## **Pedestrian Visibility Under Low-Height Lighting**

We interviewed John Bullough, senior research scientist at Rensselaer Polytechnic Institute's Lighting Research Center and leader of the research team that developed the ecoluminance approach. His team has done several studies on low-height/bollard lights at mid-block crosswalks, and Bullough said the results of that research would likely be applicable to roundabouts as well. "By putting fixtures at ground level, it's easier to produce vertical illumination" that is necessary to make pedestrians visible, he said. "It's also not spreading as much light, so it produces contrast and minimizes 'visual noise' to help objects stand out."

Recent research in this area by Bullough and his team is presented below.

**"Evaluation of Visual Performance from Pedestrian Crosswalk Lighting,"** John D. Bullough, Mark S. Rea and Xin Zhang, *TRB 91st Annual Meeting Compendium of Papers DVD*, Paper 12-3348, 2012.

Citation at <http://trid.trb.org/view/2012/C/1130243>

Presentation materials available with TRB login at <http://amonline.trb.org/2012-1,498485/t-12-032-1.522360/652-1.522801/12-3348-1.522839/12-3348-1-1.522842>

This study evaluated four configurations of pedestrian lighting at crosswalks for their impact on the visibility of pedestrians in the crosswalk for drivers at night. This research found that a bollard-based system allowed for the fastest driver identification of human-shaped cutouts in a crosswalk.

Researchers based these conclusions on the Relative Visual Performance model, which was developed through laboratory experiments to predict the speed and accuracy with which observers can process visual information. Variables that this model considers include the size of the target, contrast of the target, background luminance and observer age. RVP values typically range from 0 (the minimum threshold for being able to recognize an object) to 1 (described as "the visibility of a retroreflective traffic sign illuminated by headlights on a clear night"). When RVP values are low, small improvements in any of the variables make it possible for observers to process a visual stimulus faster and more accurately. Once RVP values reach a moderate level, approximately 0.8, further improvements do not improve processing of the stimulus. As a result, "A useful lighting design objective is to create a lighting system that places pedestrians in a crosswalk on the RVP plateau without incurring higher electric energy or capital costs than necessary."

The paper notes that modeled RVP levels have been found to accurately predict real-world visual performance.

The research demarcated a simulated crosswalk across a four-lane roadway in an unlit asphalt parking lot. The approaching vehicle was located 100 feet from the crosswalk (which would provide approximately 2.5 seconds of response time in real-world conditions.) Four lighting configurations were evaluated:

- Low-beam vehicle headlamps only.
- Overhead lighting from a cobra-style 60-watt metal halide luminaire mounted 18 feet directly above the crosswalk, plus vehicle headlamps.
- The same overhead lighting mounted 20 feet ahead of the crosswalk, plus vehicle headlamps.
- Two 28-watt bollard luminaires positioned 7 feet ahead of the crosswalk, plus vehicle headlamps.

In the experiment, four groups of four subjects sat in chairs facing the crosswalk behind the vehicle headlamps. Each subject looked down at a laptop screen while the researchers placed black plywood silhouettes of adult- or child-sized pedestrians at one of three locations in the crosswalk. When the subject looked up, they were timed as they identified whether the silhouette was facing left or right. Each target was tested three times at each location in random order under each of the lighting conditions.

Average identification times were shortest for both adult- and child-sized silhouettes when they were illuminated by bollards. Identification times correlated strongly with calculated RVP values.

**“Design and Demonstration of Pedestrian Crosswalk Lighting,”** John D. Bullough, Xin Zhang, Nicholas P. Skinner, Nazhat Aboobaker and Mark S. Rea, *TRB 89th Annual Meeting Compendium of Papers DVD*, Paper 10-0315, 2010.

Citation at <http://trid.trb.org/view/2010/C/909408>

This research also compared crosswalk lighting systems, including a bollard-based approach to crosswalk lighting. The lighting systems evaluated included conventional pole-mounted luminaires directly above the crosswalk, overhead pole-mounted luminaires mounted 5 meters ahead of the crosswalk, two strings of LEDs hung over the crosswalk, and bollard-based luminaires at the corners of the crosswalk. The comparison was performed in a computer model of a mid-block crosswalk. In the model, researchers compared the relative visual performance of the configurations based on luminous intensity distributions that they obtained from manufacturers of commercially available outdoor luminaires.

In this model, only the hanging LEDs and the bollard-based luminaires lit dark-clothed pedestrians in positive contrast regardless of where in the crosswalk they were located. Economic analysis found the bollards to be significantly less expensive than the hanging LEDs both in installation costs (\$4,794 vs. \$13,738) and annual operating costs (\$248 vs. \$1,016).

Researchers conducted a temporary field demonstration of the bollard system at the intersection of US Route 9 and Texas Road in New Jersey. In this test, horizontal illuminances at 1 meter above the pavement ranged from 20 to 28 lux, and vertical illuminance in the crosswalk ranged from 10 lux in the center of the crosswalk to 50 lux near the edges.

Observers provided comments about the system. While there were too few participants to analyze these comments statistically, the observers generally had no concern about glare from the system. However, some felt that the luminaires were close enough to the edge of the roadway to create glare that would adversely affect drivers turning onto the cross road.

**Demonstration and Evaluation of Pedestrian Crosswalk Bollard Lighting,** John D. Bullough, City of Aspen, Colorado, December 2013.

[http://aspen.siretechnologies.com/sirepub/view.aspx?cabinet=published\\_meetings&fileid=14115](http://aspen.siretechnologies.com/sirepub/view.aspx?cabinet=published_meetings&fileid=14115)

This report (see page 4 of the PDF) describes a two-night demonstration of bollard-based pedestrian lighting at a crosswalk in Aspen, Colorado. Surveys of observers found they felt the system improved visibility and made them feel more secure than the existing lighting did.

**Design and Evaluation of Effective Crosswalk Illumination,** John D. Bullough, Xin Zhang, Nicholas P. Skinner and Mark S. Rea, New Jersey DOT, March 2009.

<http://www.nj.gov/transportation/refdata/research/reports/FHWA-NJ-2009-003.pdf>

This New Jersey DOT report similarly recommended bollards for crosswalk lighting. The research conducted simulations of a variety of lighting configurations, including traditional pole-based luminaires and bollard-based luminaires, using the AGI32 lighting calculation software package. For each lighting configuration, researchers evaluated the visual conditions created and documented installation costs and ongoing costs.

The most promising configuration was demonstrated for one night at a real-world New Jersey intersection. At this installation, researchers installed luminaires with two 40-watt fluorescent biax (twin-tube) lamps. Baseline

conditions at the site included horizontal illuminances ranging between 20 and 28 lux, and vertical illuminances ranging from 5 to 12 lux in the center and edges of the road, respectively. When the lighting system was on, vertical illuminances increased to 10 lux in the center of the crosswalk and 40 to 50 lux at the edges.

Observers reported that the bollard-based system made visibility of pedestrians easier, produced fewer shadows that could obscure pedestrians and was brighter than the baseline, and observers believed crossing the street would be more comfortable with the system. Observers also believed it produced more glare than the baseline, although not to an excessive level.

Researchers noted the possibility of incorporating a signal function into crosswalk lighting—either dimming the crosswalk lighting unless a pedestrian pressed a signal button or synchronizing crosswalk lighting to pedestrian signal timing.

## **Related Research**

### **Evaluation of the Safety and User Response to Embedded Roadway Lighting Systems on an FDOT Demonstration Project**, Ralph Ellis and Scott Washburn, Florida DOT, March 2003.

[http://www.dot.state.fl.us/research-center/Completed\\_Proj/Summary\\_EMO/FDOT\\_BC354\\_31rpt.pdf](http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT_BC354_31rpt.pdf)

This 2003 Florida DOT report suggested that roadway users may be accepting of low-level lighting. The project involved a demonstration at a site in Boca Raton, Florida, where existing overhead roadway lights were replaced with embedded lighting systems on the roadway and low bollard-mounted luminaires along pedestrian and bike paths. The change in lighting was motivated by the road's proximity to beaches where sea turtles nest; overhead lights can disorient hatchlings as they cross the beach from nest to ocean.

The existing lights were 150-watt cobra-head HPS luminaires, mounted 25 feet tall at approximately 200-foot intervals. (Note that this system was intended primarily to light the pedestrian path and roadside on the western side of the road, rather than the road itself.) These were supplemented by 10-foot-tall pole-mounted HPS luminaires on the pedestrian pathway. There was little ambient lighting due to the lack of development near the roadway.

The demonstration project deactivated the cobra-head roadway lights, replaced clear lenses on the pedestrian luminaires with amber ones that reduced the light output and changed the light color, installed embedded pavement lighting (the Smartstud system from Harding Traffic Systems) to delineate lanes and other features and installed bollard-mounted luminaires along bike lanes and along the sidewalk at one intersection.

In general, the reconfigured lighting pattern reduced light output, although different parts of the roadway experienced different impacts. The embedded pavement lights provided marking, rather than illumination, but the average light levels in the travel lanes increased slightly. Bike lane light levels increased significantly due to the bollard lighting, although these served more to delineate the lane rather than improve bicyclist visibility. Lighting in pedestrian pathways and crosswalks decreased.

A survey of 255 roadway users found that users generally considered the lighting levels adequate for motor vehicles, pedestrians and bicyclists. They largely concurred that sea turtle safety should be a primary concern on the roadway.

## **Winter Maintenance of Low-Height Lighting**

We were unable to identify guidance documents addressing winter maintenance issues related to low-level lighting. We asked the researchers and practitioners that we interviewed for their input on this topic.

Rensselaer Polytechnic Institute's John Bullough said that the use of deicing chemicals would likely have no impact on lighting fixtures, including bollard-style fixtures. "The manufacturers are accustomed to having fixtures close to the action," he said. "They anticipate some chemical exposure and the fixtures are designed for it."

While his team's eoluminance demonstrations took place during the summer, he acknowledged that planning would be required for plowing. "It's important to work with the people who do the plowing and find out what their patterns are," he said. Any flexibility that plow operators have in these patterns should also be learned before positioning lights in the roundabout, and lights should not be positioned in locations where snow has to be deposited. Bullough said that the demonstrations (which replaced lighting in existing roundabouts rather than new roundabouts) were designed to be compatible with plowing operations, but that the design process for every roundabout would need to take plowing into consideration.

He also noted that bollards produce light at the top of the fixture, and there is some clearance above the ground where no light is emitted. As a result, low levels of snow will not have any negative impact on their light output.

Robin Lewis, transportation engineer for the City of Bend, Oregon, said that the city has had issues with pedestrian-scale decorative lighting (14 to 18 feet tall) in roundabouts, because they are frequently hit by vehicles. In particular, the light installed immediately prior to the crosswalk as vehicles were exiting was often hit. As a result, the city now requires standard overhead poles (at least 30 feet tall) that are maintained by the power company. The city has not experienced any issues plowing around these overhead poles; they have long (10-foot) horizontal arms so the poles can be set back as far as possible while still illuminating the roadway.

## **Contacts**

During the course of our research, we interviewed or corresponded with the following researchers and practitioners:

**John Bullough**, Senior Research Scientist, Rensselaer Polytechnic Institute Lighting Research Center, 518-687-7100, [bulloj@rpi.edu](mailto:bulloj@rpi.edu).

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**Michael Rodgers** and **Franklin Gbologah**, Georgia Institute of Technology, [michael.rodgers@ce.gatech.edu](mailto:michael.rodgers@ce.gatech.edu).

**Bastian Schroeder**, Assistant Director, Highway Systems, North Carolina State University Institute for Transportation Research & Education, 919-515-8565, [bastian\\_schroeder@ncsu.edu](mailto:bastian_schroeder@ncsu.edu).