University Transportation Research Center - Region 2

Final Report

Demonstrating Urban Outdoor Lighting for Pedestrian Safety and Security

Performing Organization: Renssealaer Polytechnic Institute

December 2015

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

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16. Abstract

Pedestrian safety is a critical element of urban transportation. A review of published literature, as well as real-world demonstration activities, indicate that bollard-level crosswalk lighting has excellent potential for enhancing pedestrian visibility and improving safety at crosswalks, particularly where the presence of a crosswalk might not be expected by approaching drivers. Such locations include midblock crossings, roundabouts and locations near schools and other public venues that might experience high levels of pedestrian traffic at sporadic or unexpected times. The light levels produced by the system and measured during a nighttime demonstration installation were sufficient to achieve high levels of visual performance. The push button control used by the prototype bollard system allowed the luminaires to produce a relatively low, glare-free light level when not in use, while still making them highly visible to pedestrians and drivers. The temporary cycling between low and high light levels that occurred when the button was pressed could act as a visual alert to warn drivers that a pedestrian is present and waiting to cross the street, and the higher light level of at least 10 vertical lux in the crosswalk resulted in high levels of visibility.

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ABSTRACT

Pedestrian safety is a critical element of urban transportation. A review of published literature, as well as real-world demonstration activities, indicate that bollard-level crosswalk lighting has excellent potential for enhancing pedestrian visibility and improving safety at crosswalks, particularly where the presence of a crosswalk might not be expected by approaching drivers. Such locations include midblock crossings, roundabouts and locations near schools and other public venues that might experience high levels of pedestrian traffic at sporadic or unexpected times. The light levels produced by the system and measured during a nighttime demonstration installation were sufficient to achieve high levels of visual performance. The push button control used by the prototype bollard system allowed the luminaires to produce a relatively low, glare-free light level when not in use, while still making them highly visible to pedestrians and drivers. The temporary cycling between low and high light levels that occurred when the button was pressed could act as a visual alert to warn drivers that a pedestrian is present and waiting to cross the street, and the higher light level of at least 10 vertical lux in the crosswalk resulted in high levels of visibility.

1. INTRODUCTION

Outdoor urban pedestrian lighting serves multiple purposes, and should do so in the most efficient and economic manner. Among the purposes of outdoor urban pedestrian lighting are:

- To support the safety of pedestrians, particularly those who interact with adjacent vehicle traffic
- To enhance pedestrians' perceptions of personal safety and security
- To assist pedestrians in identifying the appropriate locations for crossing the street and other aids to wayfinding

Lighting at pedestrian crosswalks in urban areas is critical to addressing the aforementioned purposes. Prior demonstration studies and experiments involving pedestrian crosswalk lighting (Bullough et al., 2009, 2012a, 2012b; Bullough, 2013) have indicated that illumination using bollard level luminaires located at the ends of a crosswalk (see Figure 1) provides good contrast between pedestrians in the crosswalk and surrounding terrain. Higher contrast results in greater visibility, and shorter pedestrian identification times for approaching drivers. This in turn increases the safety margins between approaching vehicles and pedestrians in the crosswalk (Bullough and Skinner, 2012), which is especially critical for midblock crosswalks positioned in less-expected locations.

A midblock crosswalk located between a pedestrian plaza and a nearby parking garage served as the evaluation location for a demonstration of urban pedestrian lighting in the present study. Project partners 3M and Intrigue Lighting developed a prototype bollard luminaire (Edmonds et al., 2015) that met performance specifications previously developed by the Lighting Research Center (LRC) in studies of crosswalk lighting conducted for the New Jersey Department of Transportation (Bullough et al., 2009), the New York State Department of Transportation (Bullough et al., 2012b), and the City of Aspen (Bullough, 2013). Measurements of light levels confirmed the potential of the bollard lighting system to improve safety, and judgments of safety, visibility and aesthetics of the fixture from pedestrians were also collected.

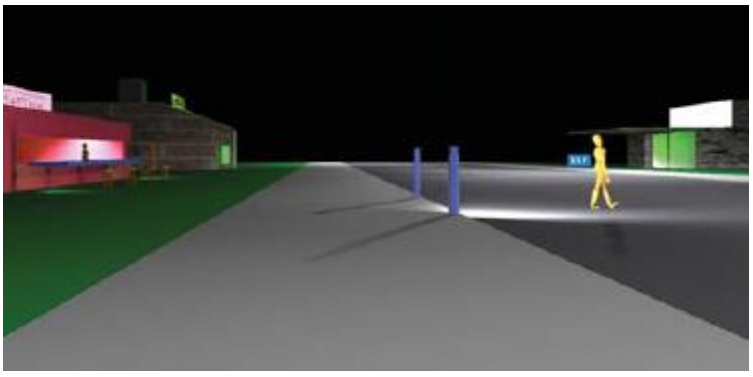

Figure 1. Rendering of a bollard based crosswalk lighting system providing vertical illumination on pedestrians crossing the street.

2. BACKGROUND

As described in the previous section of this report, outdoor urban pedestrian lighting serves multiple purposes. In this section, the effects of lighting reported in the published literature are reviewed with respect to three aspects: visibility of pedestrians, perceptions of safety and security, and wayfinding characteristics.

2.1. Lighting and the Visibility of Pedestrians

An important objective of lighting is to make objects, hazards and pedestrians in and near the road visible to drivers at a range that exceeds the distance at which vehicle headlights can do so. In urban areas, because of the relatively higher traffic density than in rural locations, low beam headlights are almost exclusively used (Mefford et al., 2006), and low beams do not provide more than a couple hundred feet of forward visibility (Bullough et al., 2008). Overhead street lighting (IES, 2014) is commonly used for visibility of both vehicles and pedestrians. Overhead lighting is primarily designed to produce a particular level of roadway surface luminance, which serves as a background against which potential hazards are seen. Producing roadway luminance is achieved through horizontal illumination on the road surface, and the distributions of street lighting luminaires are optimized to achieve horizontal illuminances while maximizing spacing to reduce system and operating (energy and maintenance) costs.

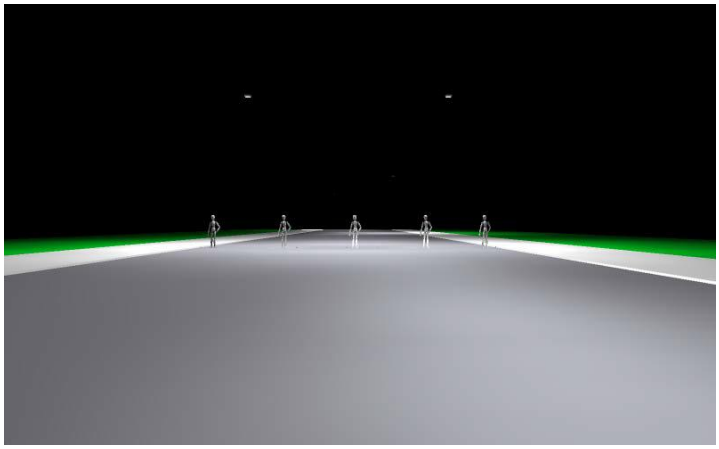

Figure 2. Under overhead street lighting, some pedestrians are brighter than the background and some are darker.

It has been demonstrated that the combination of street lighting and low beam headlight illumination can reduce the visibility of objects (such as pedestrians) along the roadway below the levels of visibility produced by either of these systems alone (Oya et al., 2000). In their analysis of pedestrian midblock crosswalk lighting, Bullough et al. (2009) found that street lighting located over the crosswalk resulted in transitions between positive (pedestrian brighter than the background) and negative (pedestrian darker than the background) contrast where the visibility of pedestrians could be low (Figure 2). Some studies (Hasson et al., 2002; Gibbons et al., 2008) have advocated offsetting street lights to be located 10 to 15 ft ahead of the crosswalk in the direction of travel, which improves

pedestrian visibility by making positive contrast more prevalent, but even this technique can result in negative contrast (Bullough et al., 2009) and thus, reduced visibility of pedestrians.

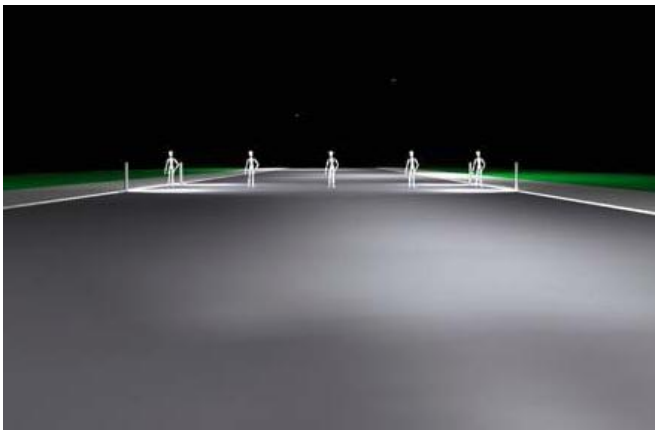

Figure 3. Bollard level crosswalk lighting provides consistent levels of vertical illumination in the crosswalk, maintaining positive contrast.

To overcome these shortcomings, Bullough et al. (2009) analyzed several different crosswalk lighting solutions, and identified bollard-level crosswalk lighting (Figure 3; see also Figure 1) as a promising solution for producing sufficient vertical illuminance levels in the crosswalk to maintain positive contrast throughout the crosswalk. Prototype bollard fluorescent floodlight luminaires were tested in Middlesex County, New Jersey and judged by participants from the local police department, the New Jersey Department of Transportation, and New Jersey Transit to be beneficial for safety.

Figure 4. Bollard crosswalk lights evaluated for use in New Jersey.

Visual performance improvements from the bollard-based approach were studied more systematically in a field experiment conducted by Bullough et al. (2012a) and found to be consistent with the previous demonstration participants' comments. Subsequently, other

bollard luminaires using fluorescent lamps were evaluated along roundabout crosswalks (Bullough et al., 2012b) in Albany County, New York (Figure 5), and bollards using light emitting diodes (LEDs) were tested in a field evaluation (Bullough, 2013) conducted in Aspen, Colorado (Figure 6). In each case, responses to the bollard lighting system were positive. This approach to illuminating pedestrian crosswalks was featured in the Transportation Research Board's *Human Factors Guidelines for Road Systems* (Campbell et al., 2012) and in a Minnesota Department of Transportation research synthesis entitled *New Approaches for Roundabout Lighting to Enhance Pedestrian Safety* (CTC and Associates, 2014).

Figure 5. Fluorescent bollard luminaires tested in New York State.

Figure 6. LED bollard luminaires tested in Colorado.

2.2. Lighting and Perceptions of Safety and Security

There are several aspects of outdoor lighting, particularly bollard-level lighting, that can influences pedestrians' perceptions of safety and security in the illuminated exterior

environment. Several authors have investigated the role that the scale of bollard luminaires and elements can play in reinforcing these perceptions. For example, Vogel and Pettinari (2002) reported that bollard luminaires can assist in providing "people-scaled illumination in dark corners" of areas around transit stations. Paskovic (2012) found that bollard luminaires in pedestrian areas reinforced "an inviting public realm."

The color of illumination can also play a role in impacting pedestrian perceptions of personal security. A number of studies of "white light" for outdoor use have been made in which the white illumination from such light sources as mercury vapor (MV) lamps, metal halide (MH) lamps, fluorescent lamps or LEDs was compared to the yellowish illumination from high pressure sodium (HPS) lamps. HPS lamps are the most commonly used light source for outdoor lighting in the U.S. (Navigant, 2012). Daley (1995) reported that individuals judged outdoor college campus lighting using MH lamps as producing brighter illumination that reinforced safety more than lighting using HPS lamps. Belcher et al. (1999) compared the responses of residents to MH and HPS street lighting, finding preferences for MH over HPS. Rea et al. (2009) performed a series of field experiments under MH and HPS lighting; under MH, streets were judged as brighter (Figure 7) and safer (Figure 8) than under HPS. Color identification was also improved under the white MH illumination relative to the yellowish HPS light. Knight (2010) also reported that neighborhoods illuminated by MH lamps were judged as brighter, safer and more comfortable than those lighted by HPS.

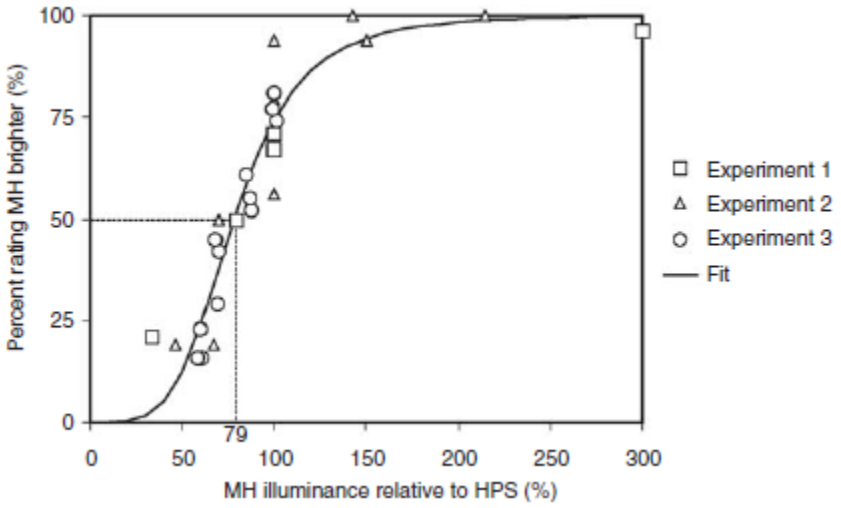

Figure 7. Percentage of time observers judged a street illuminated by MH to appear brighter than one illuminated by HPS, as a function of the relative illuminance from the MH to the HPS system.

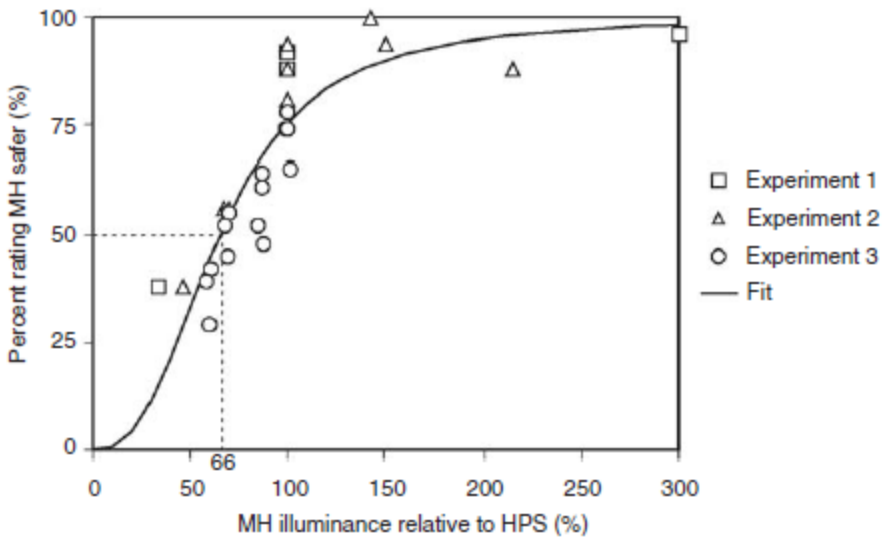

Figure 8. Percentage of time observers judged a street illuminated by MH to appear safer than one illuminated by HPS, as a function of the relative illuminance from the MH to the HPS system.

Taken together, these results confirm the notion that white light for outdoor lighting is likely to appear brighter, and consequently safer, than yellowish light such as that from HPS lamps.

2.3. Lighting, Street Furniture and Pedestrian Wayfinding

The impacts of bollards and bollard-level lighting elements on wayfinding and navigation by pedestrians have also been investigated.

Vogel and Pettinari (2002) stated that bollards can provide cues about where pedestrians should stand and about the locations of pathways while moving through a transit station. Stoloff (2005) reported that participants in a workshop on pedestrian wayfinding at roadway intersections stated that bollards could serve a wayfinding function for pedestrians at these locations. Reiss et al. (2014) found that bollards used on a transit station platform served as impromptu wayfinding aids, especially for transit passengers with visual impairments. Richards (2014) described the use of decorative bollards to provide visual cues to patrons of an outdoor zoo to assist in identifying different parts of the facility. Adams and Cavill (2015) reported that the presence of pedestrian-level bollards in conjunction with other infrastructure improvements resulted in long-term increases in the use of certain pedestrian routes. Taken together, these results suggest that using bollard luminaires for pedestrian crosswalks, particularly at midblock crossings where crosswalks might otherwise not be expected, could assist in identifying appropriate street crossing locations.

3. LIGHTING DEMONSTRATION: METHOD

In cooperation with the Schenectady County Metroplex Development Authority, 3M and Intrigue Lighting, the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute demonstrated a novel prototype pedestrian crosswalk lighting system during October and November 2015. The project team initially demonstrated the lighting system inside the Broadway Parking Garage for the City of Schenectady Mayor and Traffic Signal Control Superintendent.

The final nighttime demonstration location was at a midblock crosswalk across Broadway in downtown Schenectady during an evening in which a performance at nearby Proctor's Theatre was held. The lighting system (Figure 9) used LED (correlated color temperature of 4000 K) bollard luminaires to illuminate the crosswalk and provide vertical illumination onto pedestrians crossing the street. The system was equipped with push button control so that the output was reduced until a push button was activated and then the luminaires increased to full output (producing a vertical illuminance of 12 lux, meeting the performance specification of at least 10 lux) after briefly flashing for several seconds (Figure 10). The reduced output level from the luminaires was between 2 and 3 lux in the center of the crosswalk. The luminaires were aimed across the roadway so that they did not serve as glare sources for oncoming traffic (Figure 11). It can also be seen from Figure 11 that the location was illuminated by a mix of light sources including HPS and MH post-top luminaires, and by LED floodlights mounted on the wall of the adjacent parking garage.

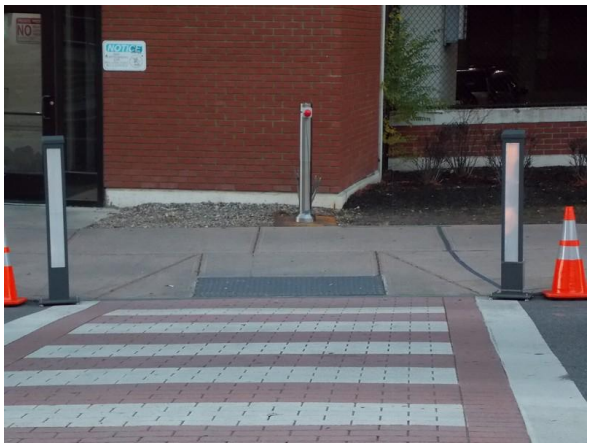

Figure 9. Daytime appearance of the bollard crosswalk luminaires. On the post in the center of the photograph is a red button used for pedestrian activation of the lighting system.

Figure 10. Illuminated appearance of bollard crosswalk lighting system at night.

Figure 11. Nighttime view of the crosswalk lighting system from down the road (taken from the sidewalk).

Researchers from the LRC observed the lighting installation and asked members of the public who were walking along or across Broadway to complete a short questionnaire asking about several aspects of the lighting system. Questions related to perceptions of safety, comfort, appearance, glare, visibility and color. A total of 40 individuals completed the survey questionnaire between 5:00 and 9:00 p.m.

4. LIGHTING DEMONSTRATION: RESULTS

The average responses to the survey questionnaire (shown in Figure 12) indicated the level of agreement or disagreement with each statement on a five-point scale ranging from +2 (agree completely) to -2 (disagree completely). Statistical analyses were conducted using two-tailed, one-sample Student's t-tests. These analyses revealed that all of the average responses differed significantly ($p<0.05$) from a value of zero, indicating that participants exhibited a reliable level of agreement or disagreement with every question. The mean numerical responses for most questions were *greater* than zero, indicating positive assessment of the lighting system. The mean numerical responses for two of the questions (specifically, the questions about glare and about the presence of dark areas) were *less* than zero, indicating disagreement with the statements that the lighting was glaring or that there were dark areas. These responses also indicated a positive overall assessment of the lighting.

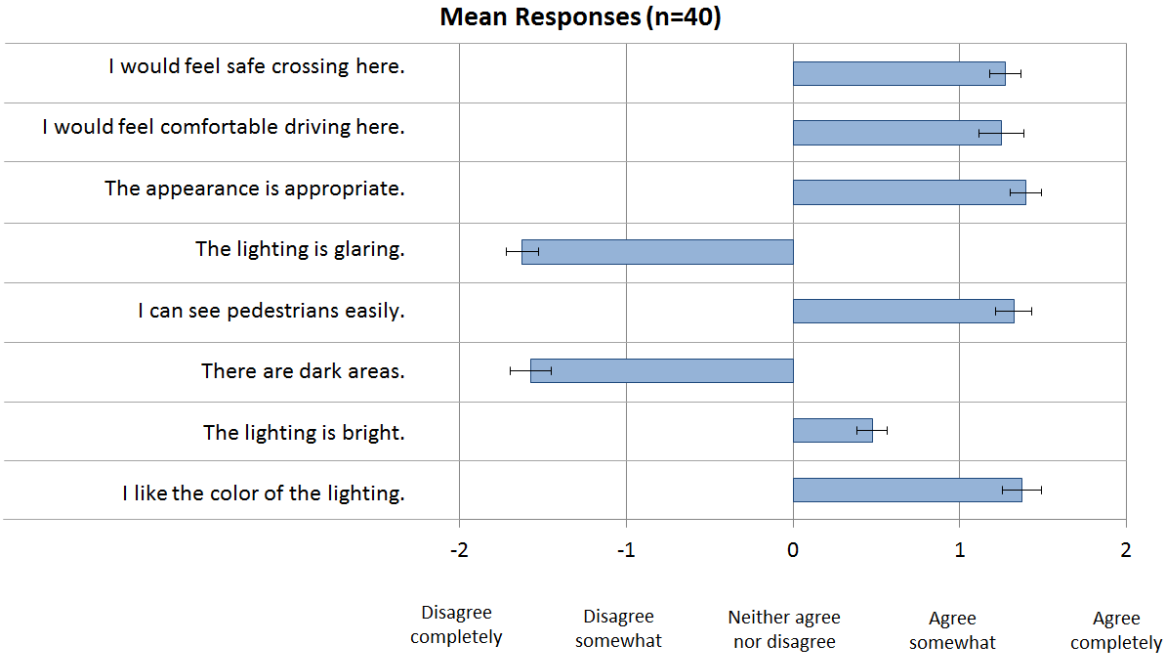

Figure 12. Average (mean) responses to each of the survey questionnaire items. Also shown as error bars are the standard error of the mean for the responses to each question.

The responses to the statement "The lighting is bright" had the lowest positive mean rating value. In combination with the less-than-zero mean response to the statement "The lighting is glaring," this suggests that the brightness of the luminaires was not excessive but that respondents felt that the lighting produced an adequate light level within the crosswalk. Based on the research results reviewed in an earlier section of this report, the perceptions of the brightness of the lighting were likely influenced both by the light level and by the spectral (color) content of the lighting, which was white in appearance. As described previously and illustrated in Figure 11, the ambient lighting in the test location was generated by a mixture of (white) MH, (white) LED and (yellowish) HPS light sources.

Responses about the appearance of the bollard lighting luminaires (see Figure 9) were also positive, suggesting that the luminaires' aesthetic appearance was appropriate for a downtown urban area, and reinforcing their potential value as architectural wayfinding elements for locations like the midblock crossing at which they were installed.

5. DISCUSSION AND CONCLUSIONS

The demonstration of pedestrian crosswalk lighting in downtown Schenectady attracted press coverage from the local newspaper, the *Daily Gazette* (Barber, 2015).

The review of published literature as well as the demonstration activities summarized in this report indicate the potential for bollard-level crosswalk lighting to enhance pedestrian visibility and improve safety at crosswalks, particularly at locations where the presence of a crosswalk might not be expected by approaching drivers. Such locations include midblock crossings, roundabouts and locations near schools and other public venues that might experience high levels of pedestrian traffic at sporadic or unexpected times.

The light levels produced by the system are sufficient to achieve high levels of visual performance (Bullough et al., 2009, 2012a). The pushbutton control used by the prototype bollard luminaires in the present demonstration allow the system to produce a relatively low, glare-free light level when not in use, while still making the luminaires highly visible to pedestrians and drivers. The temporary cycling between low and high light levels can act as a visual alert to drivers that a pedestrian wishes to cross the street, and the higher light level of at least 10 vertical lux results in high levels of visibility.

Subjective judgments of the test lighting system in downtown Schenectady were very positive, reinforcing previous findings that the light levels needed for visibility can be achieved without excessive glare or other negative consequences.

The lighting system used no more than 7 W of electrical power when operating at full light output, and less than 2 W when operating at the reduced output level. In comparison, outdoor overhead luminaires use much higher wattages, mainly because the higher mounting heights they use to produce long pole spacings requires the power to increase approximately with the square of the mounting height (the so-called inverse square law). By locating luminaires close to the pedestrians they are intended to illuminate, and keeping illumination within the confines of the pedestrian crosswalk area, power levels and the resulting energy use can be greatly reduced relative to convention overhead lighting approaches.

6. ACKNOWLEDGMENTS

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The authors dedicate this report to the memory of Joseph O'Connor from TW&A Construction Management, who passed away recently after a heroic battle with cancer. Joe's participation in this project was helpful and constructive, and he was a supportive advocate and catalyst for many positive developments in downtown Schenectady.

7. REFERENCES

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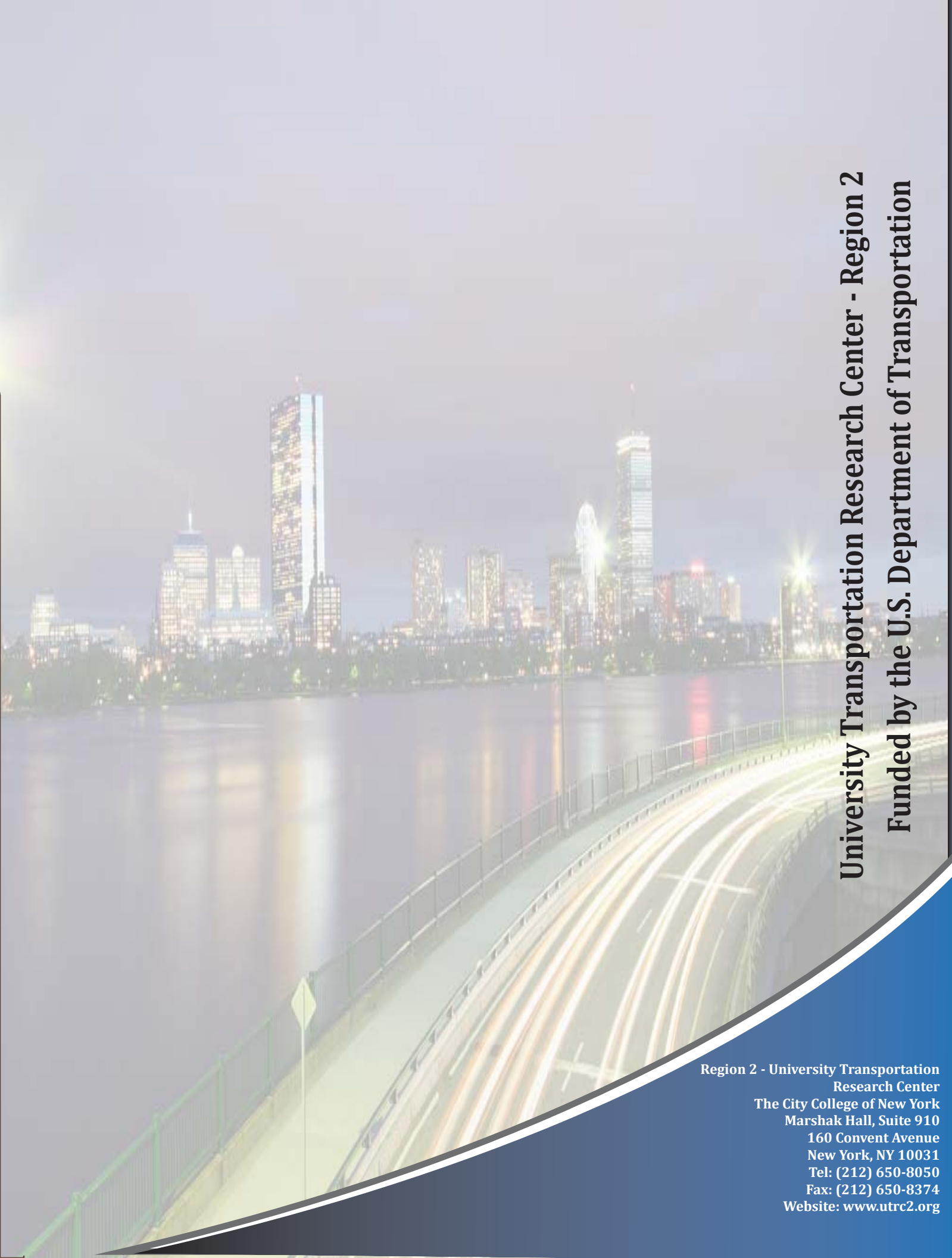

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