Evaluation of the Cost Effectiveness of Illumination as a Safety Treatment at Rural Intersections

F. Gbologah, A. Guin, M. Hunter, M.O. Rodgers
Civil & Environmental Engineering
&
R. Purcell
Middle Georgia State College
Motivation

- Street lighting is a proven countermeasure for reduction of nighttime crashes but recurring maintenance and utility costs have limited its application in rural areas.
- Most safety studies that have looked at the impact of illumination have treated lighting as a yes/no variable without considering the effectiveness of alternative lighting schemes
  - Partial or Limited Lighting Schemes
  - Solar Powered LED Lighting
- No existing studies regarding illumination of rural roundabouts
Motivation (cont.)

- Illumination is one of the most important contributors to roadway operating costs.
  - Current practice for rural uncontrolled and stop-controlled intersections is to keep them unlit
  - Current U.S. national guidelines on roundabouts are to illuminate all
    - A recent review of international roundabout lighting policies and standards from 45 countries show no requirement for systematic illumination of roundabouts.
    - Countries without any requirement include France, Germany, Holland, UK, New Zealand, and Canada (except in Quebec)

- Study is to determine the relative cost effectiveness of intersection illumination as a safety treatment
  - Intersection type
  - Operational characteristics
Previous Research

- Previous research has shown that fixed intersection lighting can provide significant safety benefits through the reduction in nighttime crashes:
  - Bruneau and Morin (2005) – non-standard and standard light can reduce accident rates at rural intersections by 29 percent and 39 percent respectively.
  - Hallmark et. al. (2008) – expected mean of nighttime accidents is about 2.0 times higher for unlit intersections than lighted intersections.
  - Isebrands et. al. (2010) – fixed lighting can reduce nighttime crash rates by about 37 percent.
  - Donnell et. al (2010) – about 7.6 percent reduction in nighttime crash frequency with normalization for other factors and about 28 percent reduction without normalization for other factors.
  - Bhagavathula et al. (2015) – one lux increase in average horizontal illuminance corresponds to 9 and 21 percent reduction in night/day crash ratio for lighted intersections and unlighted intersections respectively.
Objectives

The main objectives are:

- To provide a better understanding of the relationship between illumination levels and crash occurrence at intersections
- To synthesize this understanding into a guidance for transportation agencies to determine when or how an intersection should be illuminated or if safety requirements can be met with reduced or unlit illumination levels
### IES Intersection Lighting Design Criteria

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Average Maintained Illumination at Pavement by Pedestrian Area Classification (lux/fc)</th>
<th>$E_{avg}/E_{min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Major/ Major</td>
<td>34.0/3.4</td>
<td>26.0/2.6</td>
</tr>
<tr>
<td>Major/ Collector</td>
<td>29.0/2.9</td>
<td>22.0/2.2</td>
</tr>
<tr>
<td>Major/ Local</td>
<td>26.0/2.6</td>
<td>20.0/2.0</td>
</tr>
<tr>
<td>Collector/ Collector</td>
<td>24.0/2.4</td>
<td>18.0/1.8</td>
</tr>
<tr>
<td>Collector/Local</td>
<td>21.0/2.1</td>
<td>16.0/1.6</td>
</tr>
<tr>
<td>Local/Local</td>
<td>18.0/1.8</td>
<td>14.0/1.4</td>
</tr>
</tbody>
</table>
Roundabout Pilot Study

- GA has no archived intersection illumination data and limited roundabout history
- MN crash data was obtained from HSIS
  - 2003 through 2010
  - About 78,000 crashes per year (state and federal network only)
  - Multilevel intersection illumination data: None, Point, Partial, Full, and Continuous
- Inherent issues with MN HSIS data
  - No information on lighting installation date.
  - Very few MN roundabouts are on the state and federal network
  - Yearly jurisdictional changes affects availability of roundabouts in HSIS data
  - Omits crashes were property damage is less than $1000 or investigating officer is not stated.
Summary Methodology of Roundabout Pilot Study

- Analysis was performed using a cross-sectional approach that compared roundabouts with lighting to those without.

1. Identify daytime/nighttime and urban/rural conditions for crashes
2. Identify crashes within a 325ft buffer from center of each roundabout and tabulate crashes per roundabout
3. Compute the intersection-weighted crash rates (per roundabout per year)
4. Identify roundabouts in HSIS and compute entering volumes.
5. Create a database of roundabouts in MN
6. Compute the volume-weighted crash rates for entire study period
## Effect of Lighting on Total Crash Rates at Lit and Unlit Roundabouts

<table>
<thead>
<tr>
<th></th>
<th>Intersection Weighted</th>
<th>Traffic Volume Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lit</td>
<td>Unlit</td>
</tr>
<tr>
<td>Mean Nighttime Crash Rates</td>
<td>0.745</td>
<td>1.845</td>
</tr>
<tr>
<td>(# of Crashes per MEV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Change from Unlit to Lit</td>
<td>-59.35</td>
<td></td>
</tr>
</tbody>
</table>
Effect of Different Illumination Levels on Total Crash Rates at Roundabouts

<table>
<thead>
<tr>
<th></th>
<th>Intersection Weighted</th>
<th>Traffic Volume Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Partial</td>
</tr>
<tr>
<td>Mean Nighttime Crash Rates (# of Crashes per MEV)</td>
<td>1.845</td>
<td>0.938</td>
</tr>
<tr>
<td>% Change Compared to “None”</td>
<td>N/A</td>
<td>-49.16</td>
</tr>
<tr>
<td>Incremental Change</td>
<td>N/A</td>
<td>-49.16</td>
</tr>
</tbody>
</table>
Nighttime Crash Rates vs. Illumination Level

- Intersection Weighted
- Traffic Volume Weighted

- 0 - None
- 1 - Partial
- 3 - Full

0.5
1.0
1.5
2.0
### Effect of Lighting on Nighttime Crash Severity Rates for Lit and Unlit Roundabouts

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Int. Weighting</th>
<th>Volume Weighting</th>
<th>Fatal Lit</th>
<th>Fatal Unlit</th>
<th>Serious Lit</th>
<th>Serious Unlit</th>
<th>Injury Lit</th>
<th>Injury Unlit</th>
<th>PDO Lit</th>
<th>PDO Unlit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Crash Rate</td>
<td>0</td>
<td>0.084</td>
<td>0</td>
<td>0.089</td>
<td>0</td>
<td>0</td>
<td>0.145</td>
<td>0.444</td>
<td>0.605</td>
<td>1.508</td>
</tr>
<tr>
<td>% Change from Unlit</td>
<td>-100</td>
<td>N/A</td>
<td>-100</td>
<td>N/A</td>
<td>-58.57</td>
<td>-67.61</td>
<td>-57.12</td>
<td>-61.89</td>
<td>1.411</td>
<td>1.508</td>
</tr>
</tbody>
</table>

- PDO: Property Damage Only
Summary Findings from Roundabout Pilot Study

- Illuminated roundabouts experience about 60 – 64 percent lower nighttime crash rates (crashes per MEV) relative to unlit roundabouts based on the Minnesota HSIS data.
- 68 – 83% of safety benefits of “full” illumination could be gained from “partial” illumination alone.
- Lighting can also reduce Injury and PDO crash rates by about 60% at roundabouts.
Benefit/Cost Analysis

• Estimate Safety Benefits
  – Based on AASHTO “Red Book” Methods
  – Estimate Value
    • Avoided Crashes by Severity
    • Safety Benefit by Value of Avoided Crash by Severity

• Estimate Costs
  – Annualized Cost for Typical Installation
    • Illumination Standard to be Met
    • Assumed Lifetime
  – Maintenance and Operations
  – Energy Costs
Annual Costs for Intersection Illumination

Typical Annualized Costs for High Pressure Sodium (HPS) and LED Lighted Urban (Major/Major) and Rural (Local/Local) Roundabouts under Full and Partial (inscribed circle only) Illumination Schemes
Example Benefit/Cost Curve
Data Requirements for Full Study

- **Intersection Crash Data**
- **Historical sunrise and sunset data**
- **Intersection Illumination Data**
  - Very limited data nationally on intersection illumination
  - No existing archive of illumination data for GA or any southeastern state
  - In situ measurements required from selected survey sites

- **Roadway Characteristics Data**
  - Collected from the selected survey sites
Illumination Data – Selection of Survey Intersections

- 60 rural intersections
  - Within 50 miles of Cochran, Atlanta, Brunswick, and Dalton

- Filtered by
  - Only 3 or 4 legged intersections
  - All legs must be paved
  - No signalized intersections

- Stratified Random Grouping
  - Grouped into three illumination schemes; None, Partial, and Full
  - Low and High AADT. High means 5–year AADT is more than 4000
Illumination Data – Maps of Selected of Survey Intersections

Legend
- Intersections
  - Atlanta
  - Brunswick
  - Cochran
Illumination Data – In Situ Measurement Methods

- CIE Recommended Method
- NZ Transit Method
- Photographic Method
Illumination Data – In Situ Measurement Methods

- CIE Recommended Method
  - Luminance spot measurements over gridded area
  - Observer positioned 60 meters from near luminaire with a 1° observation angle
  - Time consuming and difficult to repeat
  - Difficult to measure exact spots due to observer distance

- NZ Transit Method

- Photographic Method
Illumination Data – In Situ Measurement Methods

- CIE Recommended Method
  - Gridded Luminance Measurements

- NZ Transit Method
  - Luminance spot measurements at 8 specified measurement points
  - Simpler than CIE method
  - Observer position 33 meters from first luminaire with 1° or 2° observation angle
  - Luminance distribution in measurement area must have uniform gradient for success
  - Difficult to measure exact spots due to observer distance

- Photographic Method
Illumination Data – In Situ Measurement Methods

- CIE Recommended Method
  - Gridded Luminance Measurements

- NZ Transit Method
  - Transit Luminance Measurements

- Photographic Method
  - Based on pixel Intensities from calibrated camera
  - Quicker than spot measurements and easy to repeat
  - Measures entire scene simultaneously
  - Requires calibrated camera.
Photographic Method - Basis

- Digital Number of pixels in an image is proportional to scene luminance and dependent on camera’s settings in manual mode:
  - Aperture size/F-Stop
  - Exposure Time/Shutter Speed
  - ISO Sensitivity

Mounted Camera on Tripod.
Calibration of Digital Camera - Equipment

- Digital Single Lens Reflex Camera (SLR)
  - Allows manipulation of camera’s settings in manual mode
  - Cannon EOS Rebel T3
- Two different luminance meters for calibration
  - Konica Minolta LS 110 with 1/3° view angle
  - Gossen Starlight 2 meter with 1° and 5° view angles
- Illuminance meter
  - EXTECH HD 450 use in camera calibration process
  - Monitors incident light conditions during calibration
Variability in Road Spot Measurements

- Variability can be significant for gridded measurements on road surface.
  - Surface roughness
  - Uniformity of surface color
  - Luminance distribution
## Luminance Variability Along Transit

Road segment transit on Georgia Tech campus

<table>
<thead>
<tr>
<th>Spot 1</th>
<th>Spot 2</th>
<th>Spot 3</th>
<th>Spot 4</th>
<th>Spot 5</th>
<th>Spot 6</th>
<th>Spot 7</th>
<th>Spot 8</th>
<th>Spot 9</th>
<th>Spot 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.29</td>
<td>7.19</td>
<td>5.64</td>
<td>4.25</td>
<td>2.45</td>
<td>2.46</td>
<td>3.68</td>
<td>7.46</td>
<td>6.62</td>
<td>8.22</td>
</tr>
<tr>
<td>7.27</td>
<td>7.16</td>
<td>5.20</td>
<td>4.10</td>
<td>2.67</td>
<td>2.36</td>
<td>5.79</td>
<td>7.34</td>
<td>7.21</td>
<td>8.77</td>
</tr>
<tr>
<td>7.96</td>
<td>6.90</td>
<td>5.05</td>
<td>4.30</td>
<td>2.25</td>
<td>2.22</td>
<td>5.70</td>
<td>7.99</td>
<td>6.32</td>
<td>9.09</td>
</tr>
<tr>
<td>7.76</td>
<td>6.97</td>
<td>5.87</td>
<td>4.29</td>
<td>2.42</td>
<td>2.92</td>
<td>4.88</td>
<td>7.54</td>
<td>6.24</td>
<td>9.40</td>
</tr>
<tr>
<td>7.89</td>
<td>7.00</td>
<td>5.59</td>
<td>4.50</td>
<td>2.25</td>
<td>2.48</td>
<td>5.06</td>
<td>7.93</td>
<td>6.22</td>
<td>13.45</td>
</tr>
</tbody>
</table>

15.90  
8.64  
11.90  
15.78  
8.43  
8.88  
9.58  

| % Spread | 4.34 | 1.78 | 6.15 | 3.34 | 7.21 | 10.55 | 16.87 | 3.80 | 6.39 | 26.80 |

**NCTSPM**

[Georgia Tech logo]
Camera Response Curve Analysis

- Response curve is not linear across full range. Restrict measurements to Pixel Intensities <10000 to maintain linear response.
- Nonlinearity is associated with image saturation. Higher luminance scenes experience quicker saturation (Right Curve).

\[
RHS = \frac{Shutter Speed \times ISO \times Luminance}{Aperture^2}
\]
Comparison of Konica Minolta and Gossen Meters

- Both meters were used to estimate reflectance of a photographic 18% gray card.
- The meters show almost equal sensitivity at lower luminance typical of rural roadway conditions (0 – 2 cd/m²)
Low Luminance Calibrated Curve for Gossen Meter (0.32 – 2.40) cd/m²

Exposure Level from -2.00 EL to -4.00 EL

Y = 3142.3x

R² = 0.8747

All Pixel Intensities not Greater than 10K

Y = 3190x

R² = 0.8703
Field Test of Calibrated Curve – Test Site

Pixel Measurement Area
Field Test of Calibrated Curve - Approach

- Measured spot areas overlapped due to view angle of the Gossen meter (1°) and the distance between observer and measurement spot.

![Diagram showing measured spot areas overlapped due to view angle and distance.](image-url)
Field Test of Calibrated Curve - Results

- The scene luminance was estimated from the equation:

\[ RHS = \frac{\text{Shutter Speed} \times \text{ISO} \times \text{Luminance}}{\text{Aperture}^2} \]
Next Steps

- Pilot study has been completed and data collection protocols established.
- Initial data collection to be completed by 6/1/2015
- Analysis and recommendations to follow by 10/1/2015