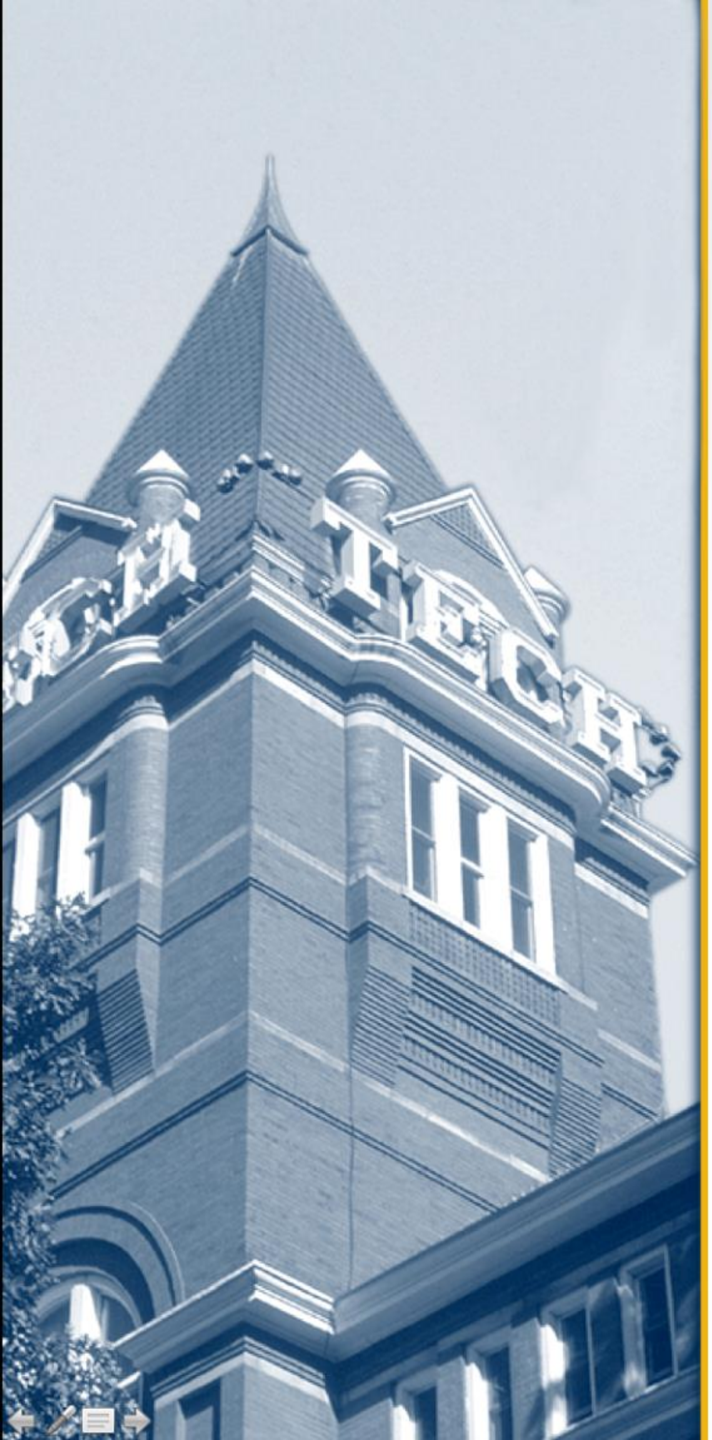

Evaluation of the Cost Effectiveness of Illumination as a Safety Treatment at Rural Intersections

F. Gblogah, A. Guin, M. Hunter, M.O. Rodgers

Civil & Environmental Engineering

&

R. Purcell

Middle Georgia State College

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Georgia Institute of Technology

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 of 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

Functional Classification	Average Maintained Illumination at Pavement by Pedestrian Area Classification (lux/fc)			E_{avg}/E_{min}
	High	Medium	Low	
Major/ Major	34.0/3.4	26.0/2.6	18.0/1.8	3.0
Major/ Collector	29.0/2.9	22.0/2.2	15.0/1.5	3.0
Major/ Local	26.0/2.6	20.0/2.0	13.0/1.3	3.0
Collector/ Collector	24.0/2.4	18.0/1.8	12.0/1.2	4.0
Collector/Local	21.0/2.1	16.0/1.6	10.0/1.0	4.0
Local/Local	18.0/1.8	14.0/1.4	8.0/0.8	6.0

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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.

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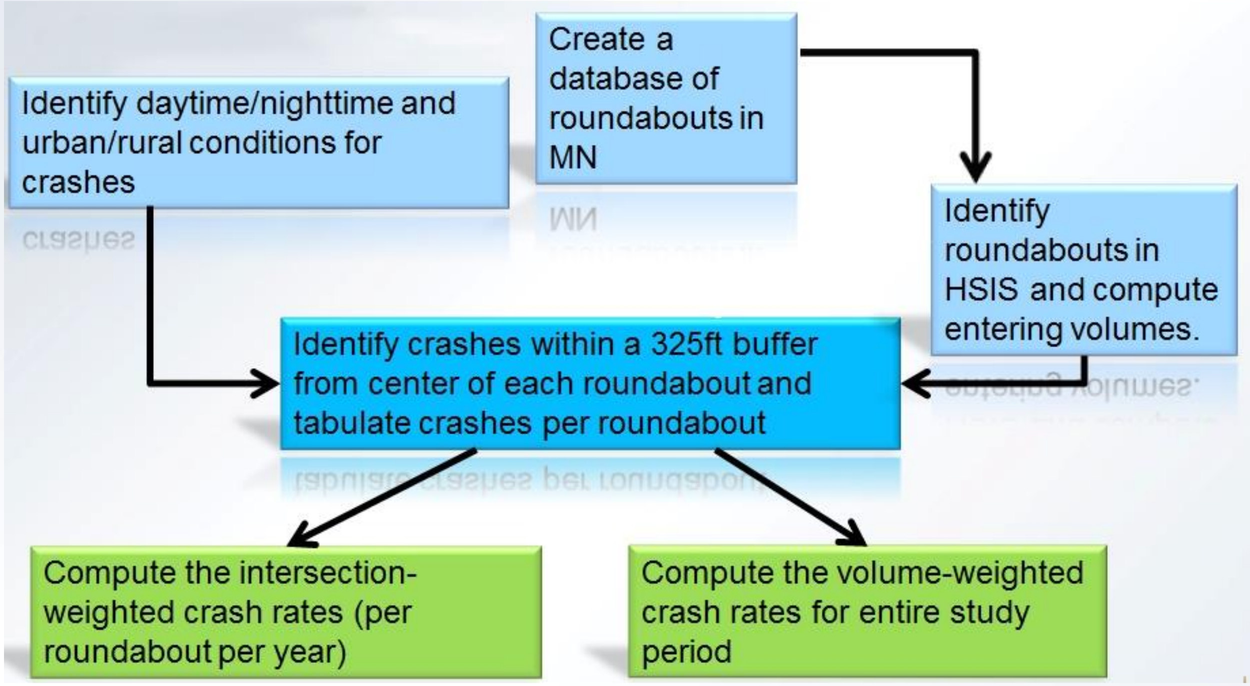
Summary Methodology of Roundabout Pilot Study

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



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Effect of Lighting on Total Crash Rates at Lit and Unlit Roundabouts

	Intersection Weighted		Traffic Volume Weighted	
	Lit	Unlit	Lit	Unlit
Mean Nighttime Crash Rates (# of Crashes per MEV)	0.745	1.845	0.718	2.041
% Change from Unlit to Lit	-59.35		-64.82	

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Effect of Different Illumination Levels on Total Crash Rates at Roundabouts

	Intersection Weighted			Traffic Volume Weighted		
	None	Partial	Full	None	Partial	Full
Mean Nighttime Crash Rates (# of Crashes per MEV)	1.845	0.938	0.515	2.041	0.788	0.537
% Change Compared to “None”	N/A	-49.16	-72.09	N/A	-61.39	-73.69
Incremental Change	N/A	-49.16	-45.10	N/A	-61.39	-31.85

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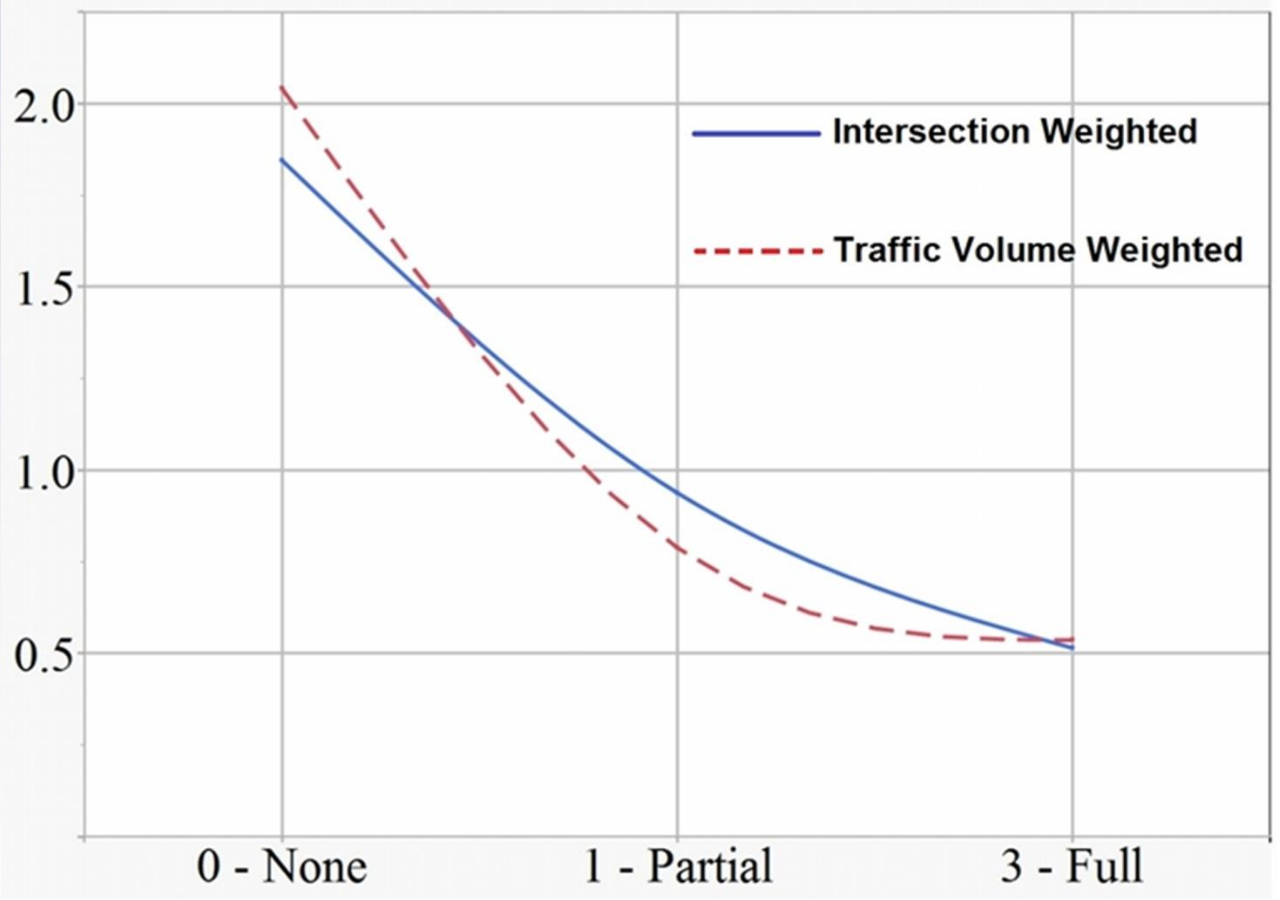
Nighttime Crash Rates vs. Illumination Level



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Effect of Lighting on Nighttime Crash Severity Rates for Lit and Unlit Roundabouts

		Fatal		Serious		Injury		PDO	
		Lit	Unlit	Lit	Unlit	Lit	Unlit	Lit	Unlit
Int. Weighting	Mean Crash Rate	0	0.084	0	0	0.145	0.350	0.605	1.411
	% Change from Unlit	-100		N/A		-58.57		-57.12	
Volume Weighting	Mean Crash Rate	0	0.089	0	0	0.144	0.444	0.575	1.508
	% Change from Unlit	-100		N/A		-67.61		-61.89	

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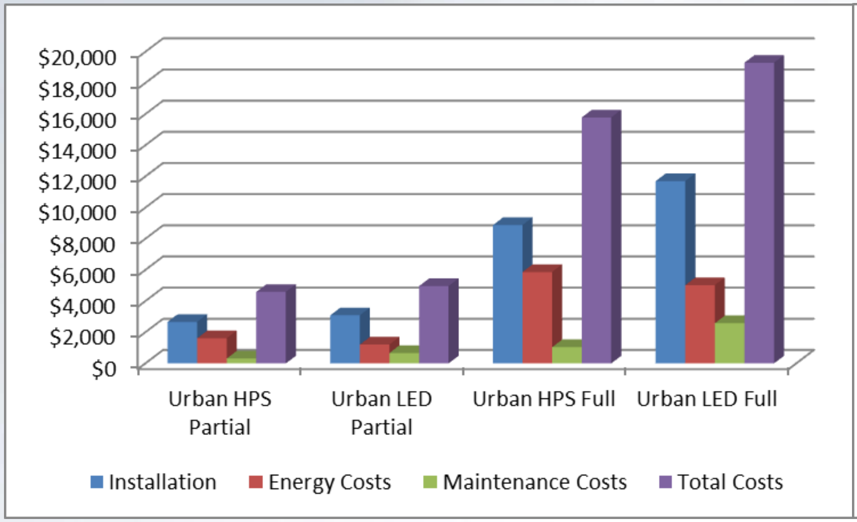
Summary Findings from Roundabout Pilot Study

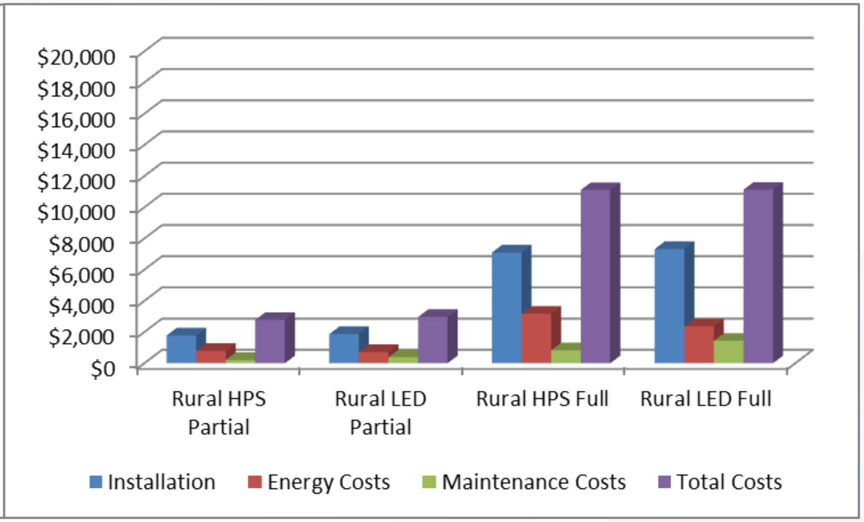
- Illuminated roundabouts experience about 60 – 64 percent lower nighttime crash rates (crashes per MEV) relative to unlit roundabouts based on the Minnesota HSIS data
- 68 – 83% of safety benefits of “full” illumination could be gained from “partial” illumination alone.
- Lighting can also reduce Injury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

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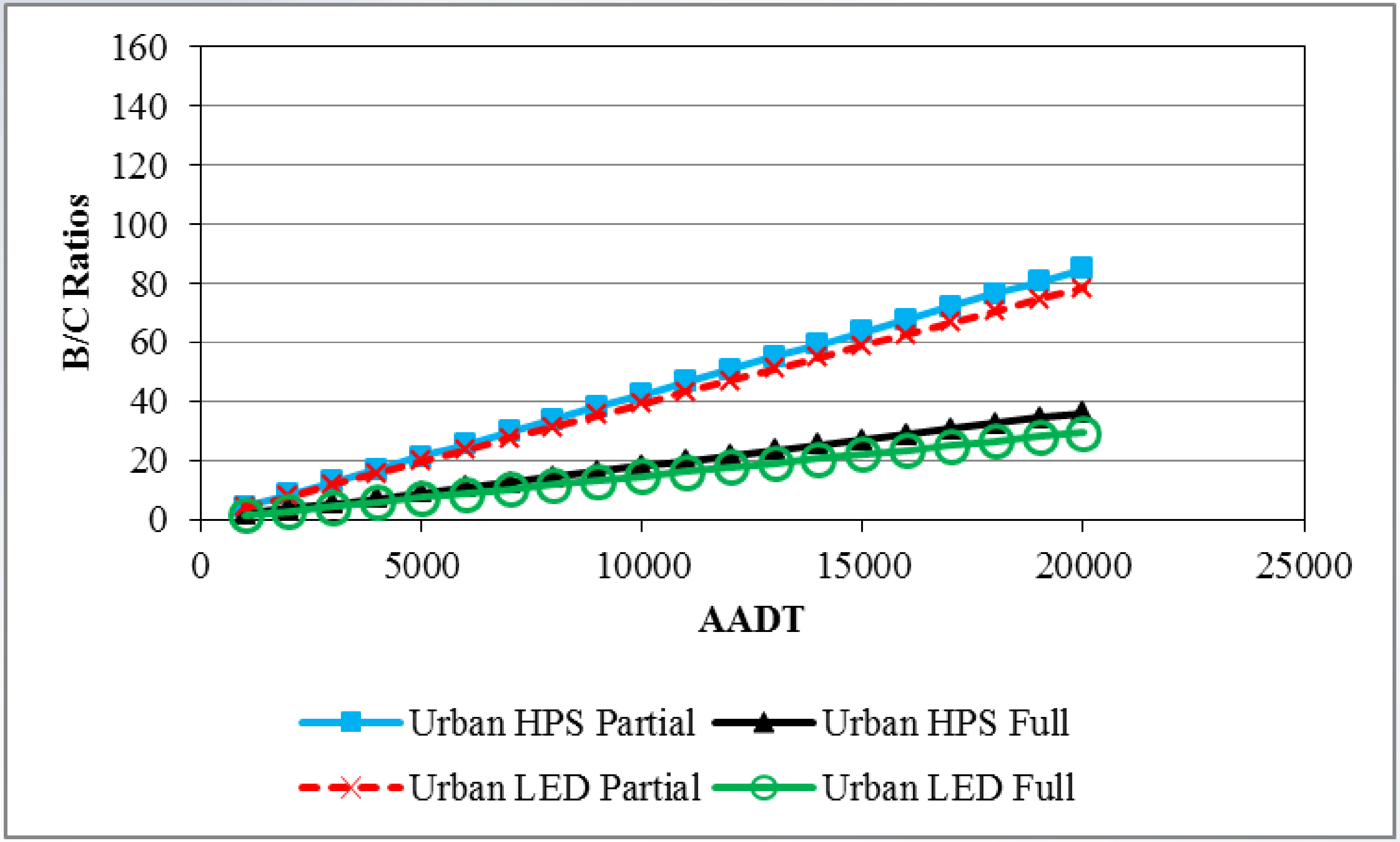
Example Benefit/Cost Curve



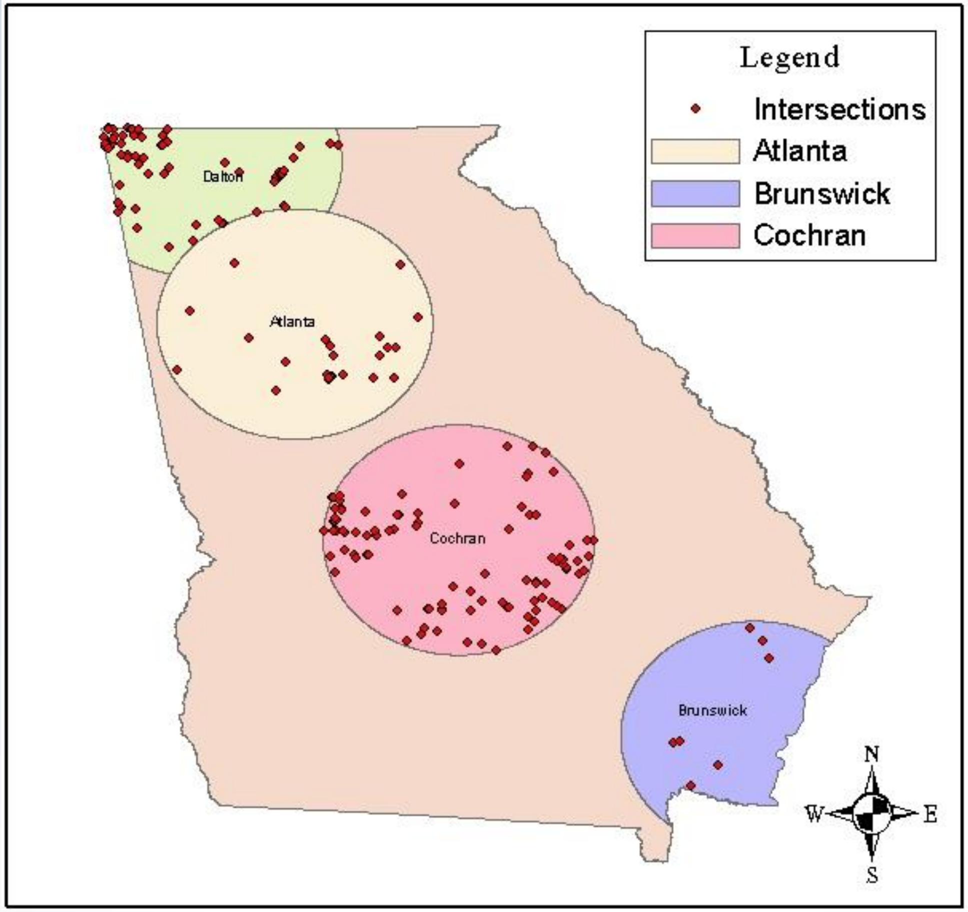
Data Requirements for Full Study

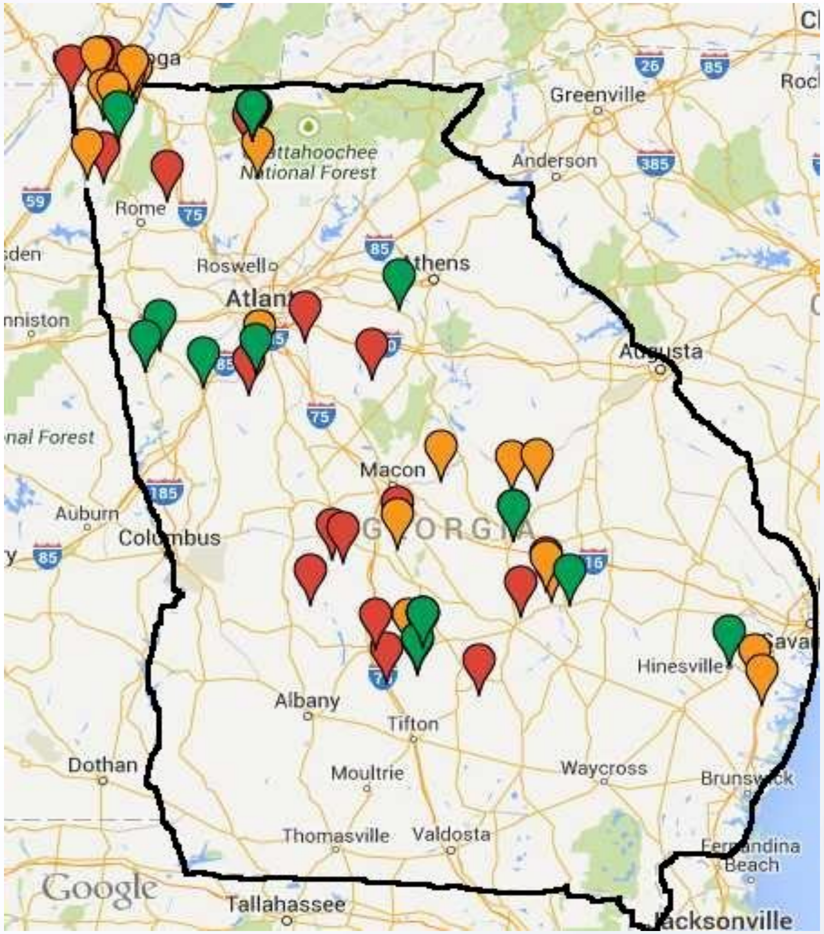
- Intersection Crash Data
- Historical sunrise and sunset data
- *Intersection Illumination Data*
  - Very limited data nationally on intersection illumination
  - No existing archive of illumination data for GA or any southeastern state
  - In situ measurements required from selected survey sites
-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





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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 1º 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^{o} or 2^{o} observation angle
  - Luminance distribution in measurement area must have uniform gradient for success
  - Difficult to measure exact spots due to observer distance
- Photographic Method

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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.

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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 1/3º view angle
  - Gossen Starlight 2 meter with 1º and 5º 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

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Luminance Variability Along Transit

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

Road segment transit on Georgia Tech campus

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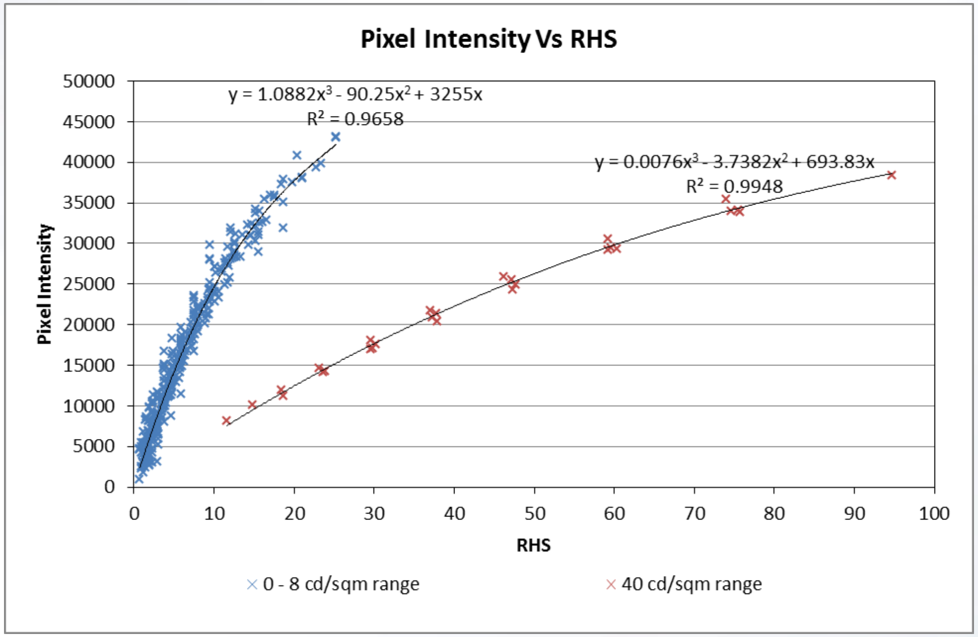
Camera Response Curve Analysis

- 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)



$$RHS = \frac{Shutter\ Speed * ISO * Luminance}{Aperture^2}$$

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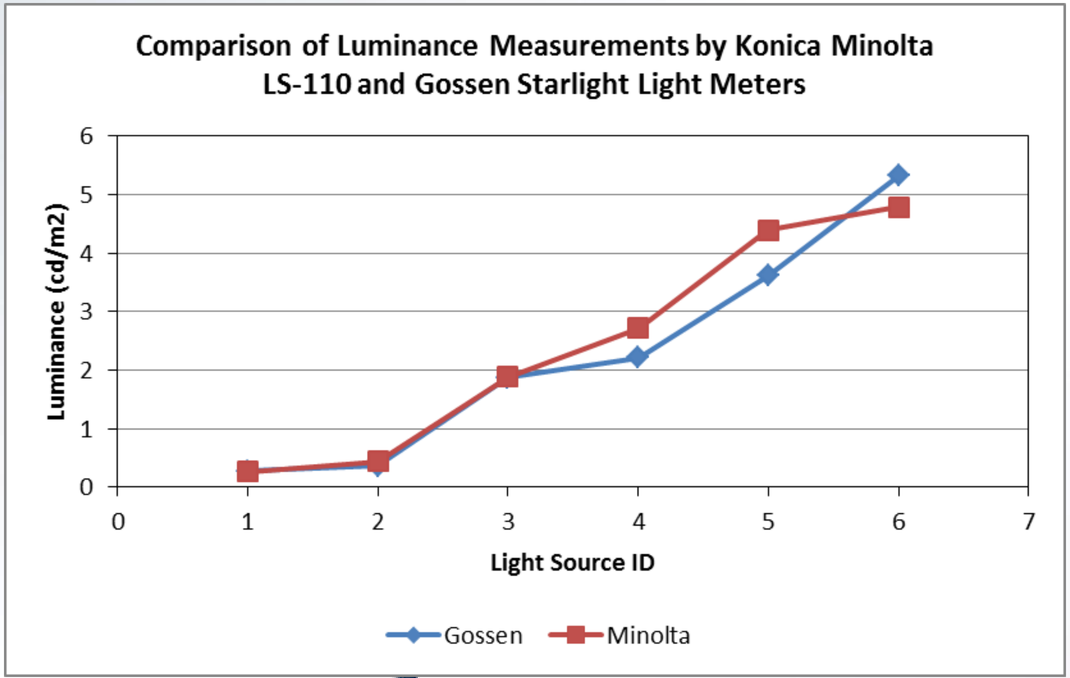
Comparison of Konica Minolta and Gossen Meters

- 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/m^2)



Gossen Starlight 2 meter (left) and Konica Minolta LS-110 meter (right)

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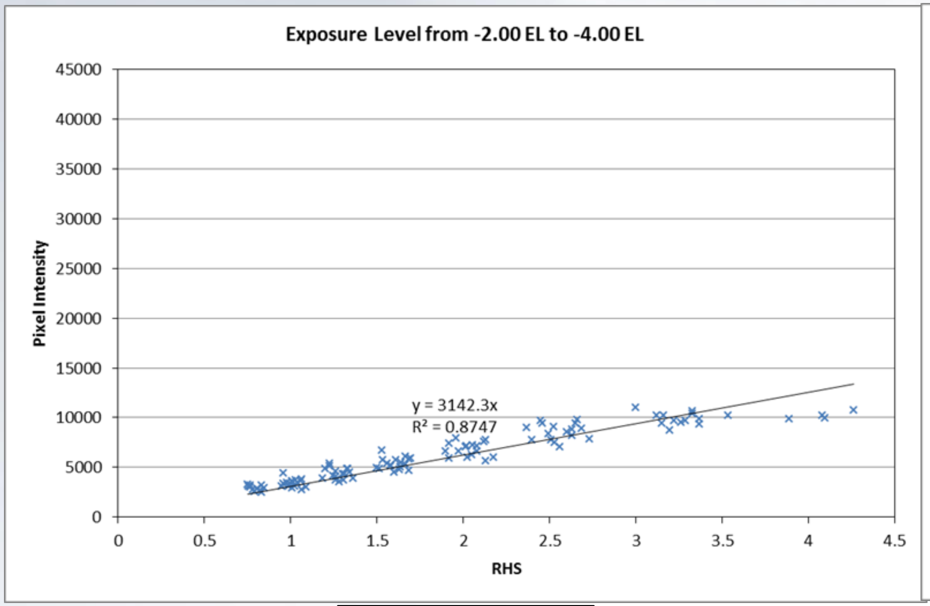
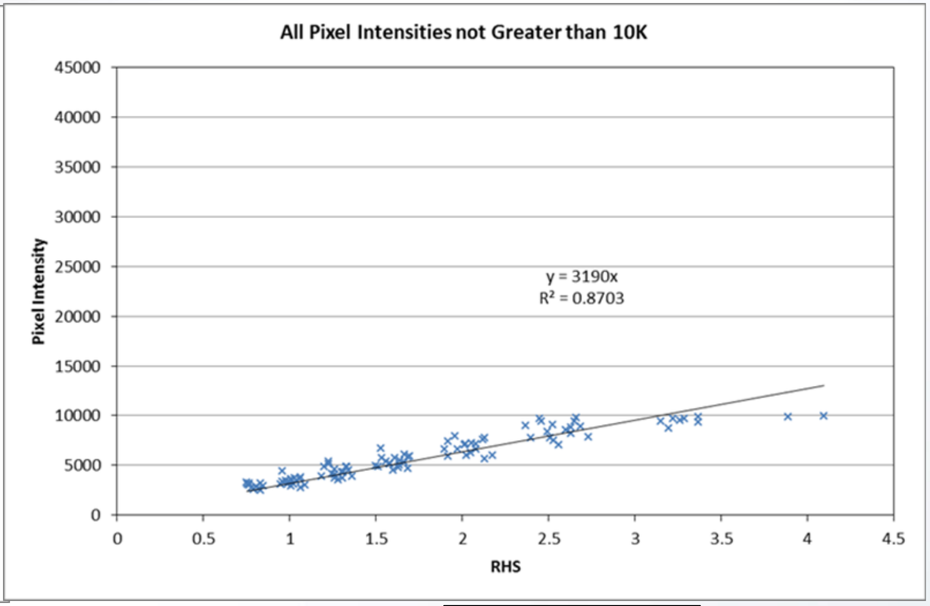
Low Luminance Calibrated Curve for Gossen Meter (0.32 – 2.40) cd/m^2





Y = 3142.3x

Y = 3190x

Field Test of Calibrated Curve – Test Site

Pixel
Measurement Area

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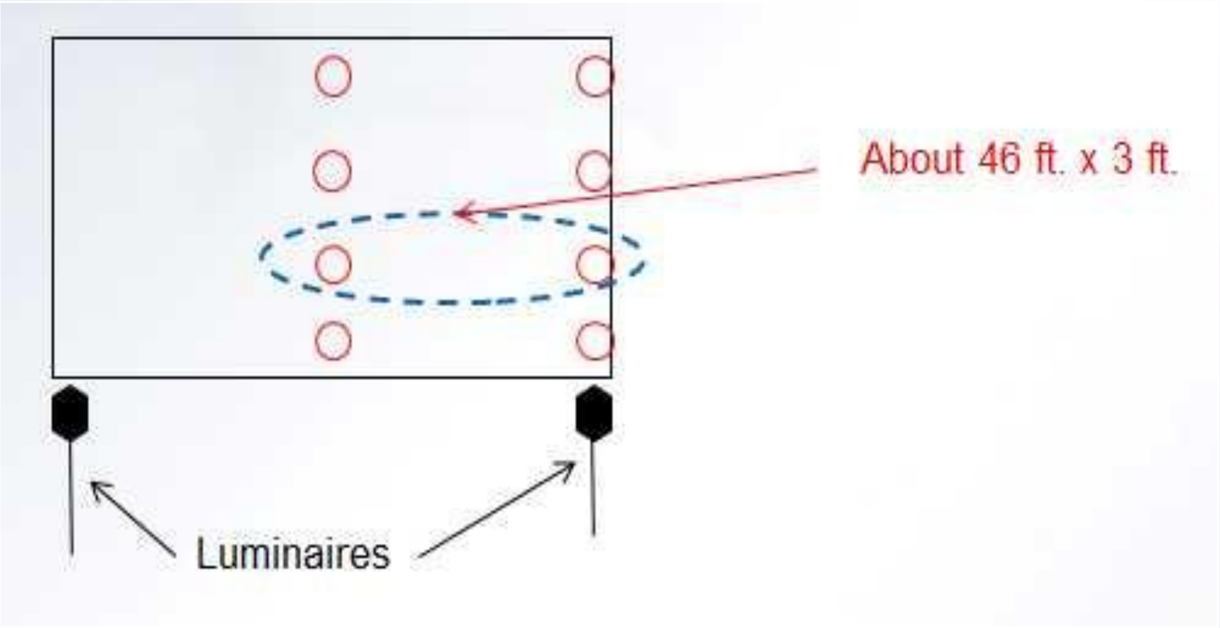
Field Test of Calibrated Curve - Approach

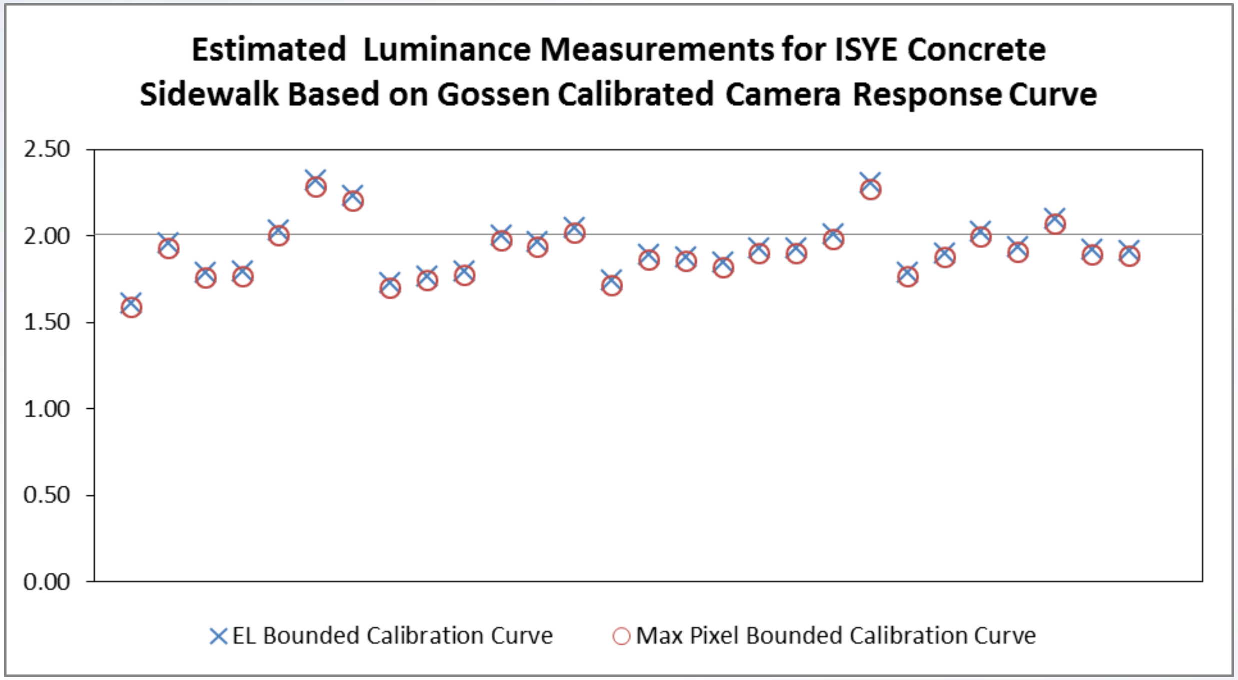
- Measured spot areas overlapped due to view angle of the Gossen meter (1º) and the distance between observer and measurement spot. .



Field Test of Calibrated Curve - Results

- The scene luminance was estimated from the equation;

$$RHS = \frac{Shutter\ Speed * ISO * Luminance}{Aperture^2}$$



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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