Roadway Lighting and Safety: Phase II – Monitoring Quality, Durability and Efficiency

Center for Transportation Research and Education

Final Report
November 2011

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16. Abstract

This Phase II project follows a previous project titled Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections. Based on the results of the previous study, the Iowa Highway Research Board (IHRB) indicated interest in pursuing further research to address the quality of lighting, rather than just the presence of light, with respect to safety.

The research team supplemented the literature review from the previous study, specifically addressing lighting level in terms of measurement, the relationship between light levels and safety, and lamp durability and efficiency.

The Center for Transportation Research and Education (CTRE) teamed with a national research leader in roadway lighting, Virginia Tech Transportation Institute (VTTI) to collect the data.

An integral instrument to the data collection efforts was the creation of the Roadway Monitoring System (RMS). The RMS allowed the research team to collect lighting data and approach information for each rural intersection identified in the previous phase.

After data cleanup, the final data set contained illuminance data for 101 lighted intersections (of 137 lighted intersections in the first study).

Data analysis included a robust statistical analysis based on Bayesian techniques. Average illuminance, average glare, and average uniformity ratio values were used to classify quality of lighting at the intersections.

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ROADWAY LIGHTING AND SAFETY: PHASE II – MONITORING QUALITY, DURABILITY, AND EFFICIENCY

Final Report
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Principal Investigator
Omar Smadi, Research Scientist
Center for Transportation Research and Education
Iowa State University

Co-Principal Investigator
Neal Hawkins, Director
Center for Transportation Research and Education
Iowa State University

Postdoctoral Research Associate
Basak Aldemir-Bektas

Authors
Omar Smadi, Neal Hawkins, and Basak Aldemir-Bektas

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A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103
Fax: 515-294-0467
www.intrans.iastate.edu

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EXECUTIVE SUMMARY

This Phase II project follows a previous project titled Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections. Based on the results of the previous study, the Iowa Highway Research Board (IHRB) indicated interest in pursuing further research to address the quality of lighting, rather than just the presence of light, with respect to safety.

The previous study confirmed that lighting may have an impact on driver safety at rural intersections. The research used lighting as a strictly binary measure during analysis, meaning that the lighting was either present or absent.

Results showed that the ratios of night-to-day and total night crashes were lower at lighted intersections compared to unlighted intersections. While the results showed lighting enhances driver safety, the data did not account for the quality or level of light at intersections. Moreover, lighting levels at a few locations may detract from driver safety or may provide no safety benefit.

The Center for Transportation Research and Education (CTRE) teamed with a national research leader in roadway lighting, Virginia Tech Transportation Institute (VTTI) to collect the data for this phase of the study.

An integral instrument to the data collection efforts was the creation of the Roadway Monitoring System (RMS). The RMS allowed the research team to collect lighting data and approach information for each rural intersection identified in the previous phase.

Data analysis identified specific lighting levels for each of the data collection sites and related this information directly to the crash statistics obtained in the first study. Data analysis included a robust statistical analysis based on Bayesian techniques.

Average illuminance, average glare, and average uniformity ratio values were used to classify quality of lighting at the intersections. Details of this classification are given in the statistical analysis section of the report.

Summary of Key Findings

- As with any study that includes field data and limited resources, there are limitations on the number of available data points, randomness of data, and ranges of data values (number of crashes, light levels, volume, and intersection control).
- For all but nine of the lighted intersections, the measured illuminance levels were below the recommended values and this limits the robustness of the cluster analysis and results in the inability to contrast different illuminance ranges.
- The negative parameter estimates for lower average illuminance and glare and higher average illuminance and glare suggest lower night-to-day crash ratios for both groups of lighted intersections with respect to unlighted intersections.

- Model results suggest a lower number of nighttime crashes for lower average illuminance intersections when compared with unlighted and higher average illuminance intersections. However, a significant relationship cannot be found due to the high standard deviations of the parameter estimates and there was an imbalance between the data sets with 75 lower illuminance intersections as opposed to only 26 higher illuminance intersections.

This project gave the research team an opportunity to determine the impact of illumination levels on safety (nighttime crashes). Based on the findings from both the Phase I and II studies, lighted intersections experience fewer crashes when compared to unlighted conditions.

Even with the far majority of intersections falling below standard illumination levels, the presence of lighting still made a significant impact on safety when compared to non-lighted locations. Identifying optimal lighting levels will likely enhance the detection of relevant driver information and therefore provide a safety benefit.

The results obtained in Iowa suggest a need for further research. Quantifying the safety contribution of light quality remains elusive at best. Specifically, there is a need to identify how intersection infrastructure and geometry influence lighting levels and corresponding crash rates.

INTRODUCTION

Nighttime driving can be particularly problematic. In Iowa, approximately 24 percent of all crashes and 40 percent of fatal crashes in 2003 occurred under dark conditions. The United States Department of Transportation (USDOT) and National Highway Traffic Safety Administration (NHTSA) report that 45 percent of fatalities occur nationally under dark conditions versus fatalities representing 27 percent of all crashes (USDOT 2003). One study indicated that the nighttime fatality rate is three times the daytime rate, while the general nighttime crash rate is approximately 1.6 times the daytime rate (Hasson and Lutkevich 2002; Opiela et al. 2003)

Recent research by Hallmark et al. (2008) has shown that lighting may have an impact on driver safety at rural intersections. This research used lighting as a strictly binary measure during analysis, meaning that the lighting was either present or absent. Crashes were tabulated based on the binary measurement and ratios were created. Results showed that the ratios of night-to-day and total night crashes were lower at lighted intersections compared to unlighted intersections. These results show lighting enhances driver safety; however, the data does not account for the quality or level of light at intersections. Moreover, lighting levels at a few locations may detract from driver safety or may provide no safety benefit. Identifying optimal lighting levels will likely enhance the detection of relevant driver information and therefore provide a safety benefit.

The results obtained in Iowa suggest a need for further research. Specifically, there is a need to identify how intersection infrastructure and geometry influence lighting levels and corresponding crash rates. Furthermore, recommendations can be established based specifically on lighting levels and related crash data.

This Phase II project follows a previous project (TR-540) named Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections) (Hallmark et al. 2008). Based on the results of the previous study, the Iowa Highway Research Board indicated interest in pursuing further research to address the quality of lighting rather than just the presence of light with respect to safety.

Objectives

The project objectives were as follows:

1. Collect field lighting levels for 101 study intersections from Phase I. This gave the research team an opportunity to determine the impact of illumination levels on safety (nighttime crashes). To accomplish this, the Center for Transportation Research and Education (CTRE) teamed with Virginia Tech Transportation Institute (VTTI) to complete the data collection.
2. Analyze these data to establish a relationship between crash performance and illumination at rural unsignalized intersections. This included a robust statistical analysis based on Bayesian techniques.
3. Investigate lighting levels at rural intersections, considering a number of factors (uniformity, glare, lamp durability, and efficiency-energy consumption).

Research Plan

A breakdown of project tasks follows:

Task 1 – Synthesize state of the practice: The research team supplemented the literature review completed for TR-540, specifically addressing lighting level in terms of measurement, the relationship between light levels and safety, and lamp durability and efficiency.

Task 2 – Data collection: The task included all field measurement of lighting levels for all study intersections. Staff and equipment from VTTI assist the CTRE team in this effort.

Task 3 – Data analysis: This task utilized Task 2 data to identify specific lighting levels for each of the data collection sites and relate this information directly to the crash statistics obtained in TR-540. To accomplish this, an extensive analysis of the data collected was completed.

Task 4 – Lighting parameters: This task focused on the relationship between illuminance and glare in terms of their relationship to safety.

Task 5 – Final report: This task was to prepare an IHRB-formatted final report, which includes the findings from all project research tasks, field data, photos, tables, and charts.

QUALITY OF LIGTING AT RURAL UNSIGNALIZED INTERSECTIONS

Literature Review

The safety literature on lighting at intersections typically focuses on before-and-after studies where the effect of presence of lighting on nighttime crash frequency is researched (Wortman et al. 1972; Walker and Roberts 1976; Isebrands et al. 2010; Kim et al. 2006). In general, lighting at rural unsignalized intersections is reported to provide a positive safety benefit and a reduction in nighttime crash frequency. Usually, studies report lower nighttime crash frequencies after installation of lighting.

The earlier Phase I report includes a detailed literature review on the effect of presence of lighting on nighttime crashes (Hallmark et al. 2008). This project evaluated the effect of presence of lighting on safety performance among other intersection-related measures by a cross-sectional analysis. The nighttime model results indicated that locations without lighting had twice as many crashes as locations with lighting. Use of lighting at rural intersections was most likely to be effective when there are two or more nighttime crashes in a three-year period. No statistically-significant relationship could be established between nighttime crashes and non-lighting low costs measures, based on available data.

While numerous before-and-after and cross-sectional analyses on the presence of lighting are available in the literature, only a few studies that address quality of lighting were found. One study by Monsere and Fischer studied 44 interchanges and 5.5 miles of interstate highway where the Oregon Department of Transportation (ODOT) reduced illumination levels for saving energy. This reduction was selective and in response to a forecasted energy shortage.

An increase in reported crashes where the lineal lighting was reduced both in total crashes (28.95 percent) and injury night crashes (39.21 percent) was reported for the lineal sections. For interchanges, however, the study reported an unexpected decrease (35.24 percent) in total crashes and a (39.98 percent) decrease in injury night crashes (Monsere and Fischer 2008). The quality of lighting variable in this before-and-after study was a categorical variable that indicated the change in lighting (e.g., full interchange lighting to partial lighting).

A study by Box (Box 1976) conducted a before-and-after safety evaluation of reducing roadway lighting in Clearwater, Florida. The results indicated that by de-energizing alternate lighting poles, day crashes increased by about four percent, while night crashes increased by 10 times as much.

A later study by Richards (Richards 1981) in Austin, Texas reported a 47 percent increase in nighttime crash frequency on a 7.2 mile stretch of I-35 where continuous freeway lighting was turned off. Some other studies are consolidated in Elvik and Vaa's Handbook of Road Safety Measures (Elvik and Vaa 2004; Monsere and Fischer 2008). The best estimates of safety change following reductions in lighting were reported as a 17 percent increase for injury crashes and a 27 percent increase for property-damage-only crashes.

Other than the study by Monsere and Fischer (Monsere and Fischer 2008), the researchers didn't find any studies that evaluate the quality of lighting on safety performance of interchanges or intersections.

Practice and Guidelines

The Phase I report includes a chapter on lighting warrants for rural roadways and one on lighting standards and practices in Iowa counties and cities. The latter chapter includes a survey that was developed to question Iowa counties and cities as to their lighting standards and practices. The survey is provided in Appendix B of the earlier report.

The American National Standard Practice for Roadway Lighting (IESNA 2005) includes three different criteria for use in continuous roadway lighting design: illuminance, luminance, and small target visibility (STV). This standard practice manual lists recommended design values for these criteria, representing the lowest maintained values for specific roadways and walkways. In this study, the recommended values for the illuminance criteria were used to categorize quality of lighting at rural intersections; in accordance with the availability of the field data.

Illuminance (E), the density of the luminous flux incident on a surface, is the quotient of the luminous flux by the area of the surface (measured in footcandles or lux) (IESNA 2005). The illuminance method determines "the amount of light incident on the roadway surface from the roadway lighting system." Because different pavement characteristics have different reflective properties and the amount of light seen by the driver changes accordingly, different illuminance levels are recommended for each type of pavement. Recommendations for average maintained lux for various road and pavement classifications are listed in the American National Standard Practice for Roadway Lighting. Road surfaces are classified under four categories as follows:

- R1: Portland cement concrete road surface, asphalt road surface with a minimum of 12 percent of the aggregates composed of artificial brightener aggregates
- R2: Asphalt road surface with an aggregate composed of a minimum 60 percent gravel or asphalt surface with 10 to 15 percent artificial brightener in aggregate mix
- R3: Asphalt road surface with dark aggregates; rough texture after some months use
- R4: Asphalt road surface with very smooth texture

Table 1summarizes the recommended maintained values for isolated traffic conflict areas that are the most applicable for the rural unsignalized intersections addressed in this study. Minimum recommended maintained illuminance values are given by pavement classification. Maximum uniformity ratio, which is the ratio of average illuminance (E_{avg}) to minimum illuminance (E_{min}), is another parameter of the illuminance method.

Table 1. Illuminance method – recommended maintained values*

Road Classification	Pavement Classification** R1 lux/fc	R2 & R3 lux/fc	R4 lux/fc	Maximum Uniformity Ratio** E_{avg}/E_{min}	Maximum Veiling Luminance Ratio L_{Vmax}/L_{avg}
Isolated Traffic Conflict Area	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.3

*Table D1 in (IESNA 2005)

** Available for study intersections

DATA COLLECTION

Phase I Data Collection

In the Phase I study, data on 274 intersections (within 33 counties) were selected from around the state as shown in Figure 1.

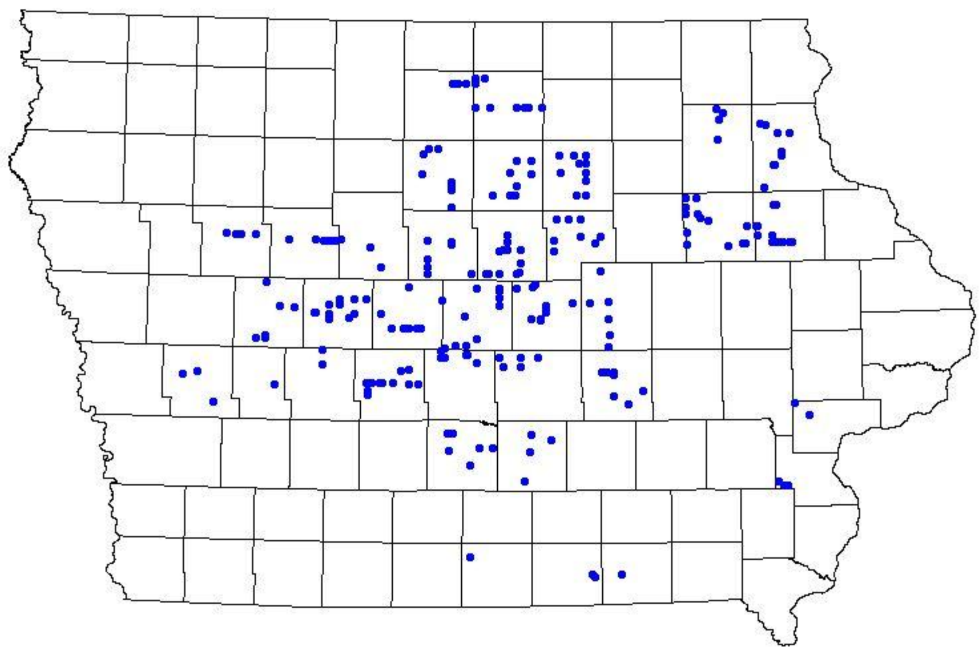

Figure 1. Location of selected rural intersections in Iowa

Selected intersections were in rural locations that were at least 0.5 miles from the nearest urban area. Intersections that were unusual were not included in the data set. For instance, a rural intersection with a gas station or other commercial area was considered unusual, as was an intersection with a severe skew angle on one of the approaches. Intersections had at least three paved approaches (all three approaches at a T intersection or three of four approaches at a standard intersection).

During Phase I data collection, the following data elements were collected at each intersection while in the field:

1. General information
    a. Name and direction of major and minor intersecting roadways
    b. County
    c. Date of data collection
    d. Name of date collector

2. Information by approach
    a. Surface type (asphalt, concrete, gravel)
    b. Number of lanes (left, through, right)
    c. Traffic control (no control, stop, yield)
    d. Channelization (painted right-turn island, raised right-turn island)
    e. Other traffic control (flashing red or yellow beacons, red flags on stop signs)
    f. Number of rumble strips
    g. Median type (undivided, grass, painted)
3. Lighting information
    a. Location
    b. Type of light (cobra head, flood light, other)
    c. Location in relationship to the corresponding approach
        - Perpendicular to inbound lanes
        - Perpendicular to outbound lanes
        - Diagonal between approaches
    d. Type of pole
        - Existing utility (light was placed on existing utility pole without moving the pole to place the light in a particular spot)
        - Wood pole placed for light
        - Metal pole placed for light

The Phase I study analysis period was from 2003 to 2005. After data collection, each intersection was located in a Geographic Information System (GIS) database by locating the two intersecting roadways with the 2003 snapshot of the Iowa Department of Transportation (DOT) Geographic Information Management System (GIMS) line work.

Average Annual Daily Traffic (AADT) reports were extracted for each roadway and one-half of the traffic was assigned to each approach. The total intersection daily entering volume was calculated by summing the total volume for each approach.

The Phase I study analysis was done for the 223 intersections after removing unsuitable intersections such as the ones not following the selection criteria regarding a rural setting or having an unusual configuration. Intersections with railroad tracks crossing an approach within less than 50 feet were also excluded.

Phase II Data Collection

To capture quality of lighting data in the study intersections, CTRE staff arranged to team with a national research leader in roadway lighting, VTTI. VTTI worked with CTRE to complete the objectives of this Phase II work.

An integral instrument to the data collection efforts in this phase of research was the creation of the Roadway Monitoring System (RMS). The RMS allowed the research team to collect lighting data and approach information for each rural intersection identified in the previous phase. To create the RMS, VTTI instrumented a vehicle with data collection equipment. The equipment contained recently-developed hardware that captured luminance data dynamically. The set-up of the RMS is described in more detail below.

To capture illuminance data, the RMS uses a basic network of illuminance meters and a global positioning system (GPS) tied to a data collection system. The illuminance meter network consists of four illuminance meters tied together to a single measurement head. The meters are specifically positioned around the body of the vehicle (e.g., along the center line of the vehicle and in each wheel path) to capture illuminance data from a variety of positions. The specific location of each meter corresponded to the roadway lighting design calculation points as much as possible. The addition of the GPS device provided detailed vehicle positioning data while the vehicle was dynamically collecting lighting data.

The data captured by the illuminance and GPS devices were collected directly onto a laptop hard drive (Figure 2). Additional data could be collected using an in-vehicle Data Acquisition System (DAS) ((Figure 2 and Figure 3). Using the DAS, vehicle variables such as speed, acceleration, and steering behavior could be captured along with the GPS and the illuminance data.

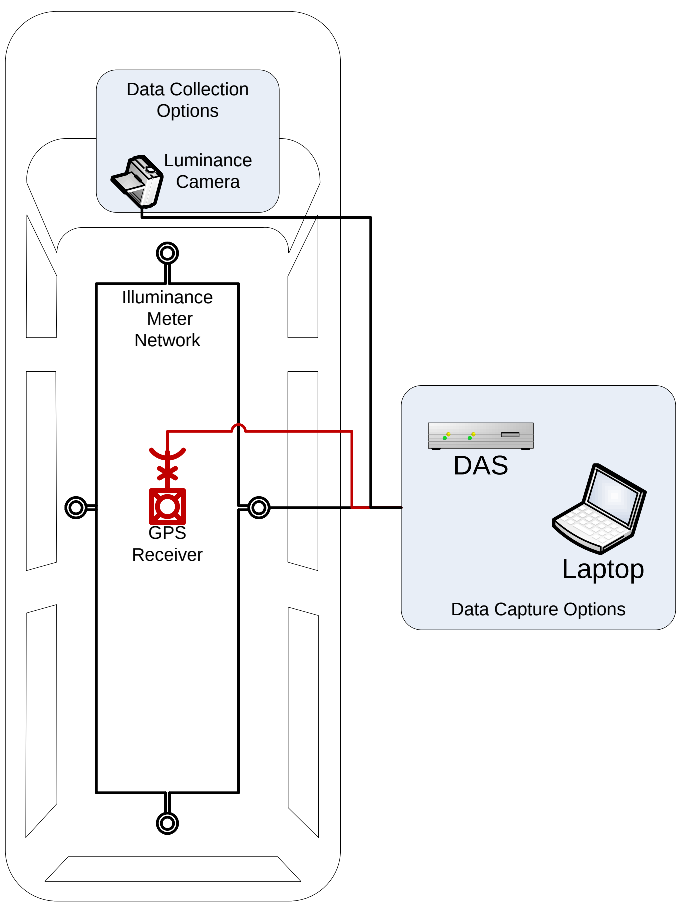

Figure 2. Roadway monitoring system set-up

Figure 3. Mounted cameras and data collection equipment

In addition to the illuminance meters and GPS, the roadway lighting mobile measurement system (RLMMS) was equipped to capture luminance. VTTI had recently developed a luminance camera system that is mounted on the inside of the vehicle windshield as a means to dynamically capture driver viewpoint luminance (Figure 3).

The entire RMS was synchronized such that information collected at any location contained illuminance, GPS, DAS, and luminance data. The combination of all elements would provide a rich data source, which could then be transferred for further data analysis. However, luminance data were only collected for 39 intersections and an analysis of luminance data was not feasible.

After the RMS was developed and installed in a suitable vehicle, rigorous pilot testing was done. Intersection locations around VTTI, both lit and unlit, were tested to verify data synchronization and collection.

CTRE and VTTI worked together to establish an efficient route for the study intersections in Iowa so that RMS data collection could be completed in a pre-defined time. The equipped vehicle drove the route and approached each intersection location from various positions in an effort to capture total lighting level based on approach metrics.

Figure 4 presents the plotted GPS coordinates for the lighting data records collected to achieve representative lighting information for one intersection. This collection method insured that data obtained in the field could be related to exact crash information provided and identified in the second phase of the research project. As a final step in this phase of the research project, the collected data were cleaned in preparation for analysis.

Figure 4. Plot of lighting data records for a study intersection

After data cleanup, the final data set contained illuminance data for 101 lighted intersections (of 137 lighted intersections in the first study). Average illuminance, average glare, and average uniformity ratio values were used to classify quality of lighting at these intersections. Details of this classification are given in the statistical analysis section of the report.

Crash Data for Phase II

The crash database included crashes from January 2006 through March 2011 from the Iowa DOT crash database. Crashes within 150 ft of the intersections were selected. The crashes were then categorized as day and night crashes based on the time of day and the sunrise and sunset times, which were downloaded from the U.S. Naval Observatory web site.

Dawn or dusk crashes were omitted from the study due to the difference of natural light conditions and any possible effect of natural light to lighting level at time of crash. The final crash database included 300 crashes for the 187 intersections (101 lighted and 86 unlighted) in the study.

The next section includes information on the characteristics of the crashes. Other statistics on crash counts are provided in the statistical analysis section.

CRASH CHARACTERISTICS

Over the analysis period (January 2006 through March 2011), 300 crashes occurred at the 187 study intersections. This section presents the crash characteristics analysis, which was based on crash severity, first harm in the crash, and type of crash counts by day and night crashes.

The majority of the crashes occurred during daytime. Table 2 indicates crash severity comparing day and night crashes.

Table 2. Day and night crashes by severity

All Intersections **Crash Severity**	**Day**	**Night**	**Total**
Fatal	0.7%	0.0%	0.7%
Major Injury	6.3%	0.3%	6.7%
Minor Injury	14.7%	2.7%	17.3%
Possible/Unknown	17.0%	3.3%	20.3%
Property Damage Only	37.0%	18.0%	55.0%
Total number of crashes	**227**	**73**	**300**
Overall %	**76%**	**24%**	**100%**

Only two fatal crashes occurred during day in the analysis period. While 22 percent of the fatal and injury crashes occurred during day, only three percent of such crashes occurred during nighttime. Approximately 25 percent of all crashes were fatal or injury crashes and 55 percent of the crashes were property damage only.

The overall day to night crash ratio was approximately 3:1. When comparing day and night crashes, this overall ratio is considered as a reference for comparing frequencies. The total percentages by crash severity were similar when lighted and unlighted intersections were compared (Table 3 and Table 4).

Table 3. Day and night crashes by severity for unlighted intersections

Unlighted Intersections **Crash Severity**	**Day**	**Night**	**Total**
Major Injury	9%		7%
Minor Injury	19%	18%	19%
Possible/Unknown	23%	14%	21%
Property Damage Only	49%	68%	54%
Total number of crashes	**79**	**28**	**107**
Overall %	**74%**	**26%**	**100%**

Table 4. Day and night crashes by severity for lighted intersections

Lighted Intersections Crash Severity	Day	Night	Total
Fatal	1%		1%
Major Injury	8%	2%	7%
Minor Injury	20%	7%	17%
Possible/Unknown	22%	13%	20%
Property Damage Only	49%	78%	55%
Total number of crashes	**148**	**45**	**193**
Overall %	**77%**	**23%**	**100%**

Day and night crash percentages for unlighted and lighted intersections by crash severity were also similar, with the exception of minor injury crashes. For unlighted intersections; the ratios of minor injury crashes to all crashes during day (19 percent) and during night (18 percent) were quite close, although the overall day to night crash ratio was 2.84. Nighttime major injury crashes were twice as common at unlighted intersections (18 percent) than lighted intersections (nine percent).

The majority of the crashes were collision crashes and almost 70 percent of all crashes were collision with another vehicle (Table 5).

Table 5. Crash counts by first harm in the crash

First Harm in the Crash	Day	Night	Total	Day/Night
Collision with fixed object:				
Bridge/bridge rail/overpass	0.7%	0.0%	0.7%	
Culvert	0.3%	0.0%	0.3%	
Curb/island/raised median	1.0%	0.0%	1.0%	
Ditch/embankment	4.0%	1.7%	5.7%	2.4
Guardrail	0.0%	0.3%	0.3%	
Poles (utility/light/etc.)	1.3%	0.3%	1.7%	4
Sign post	1.0%	0.0%	1.0%	
Collision with:				
Animal	3.0%	10.7%	13.7%	0.3
Other non-fixed object (explain in narrative)	0.3%	1.3%	1.7%	0.25
Vehicle in traffic	39.3%	7.0%	46.3%	5.6
Vehicle in/from other roadway	20.7%	1.7%	22.3%	12.4
Non-collision event:				
Jackknife	0.7%	0.0%	0.7%	
Other non-collision (explain in narrative)	0.3%	0.7%	1.0%	0.5
Overturn/rollover	3.0%	0.7%	3.7%	4.5
Total	**227**	**73**	**300**	**3.1**

Vehicle collision crashes were more common during day when total day to night ratio is considered. Day to night ratio for collisions with another vehicle in traffic was 5.6 while the overall day to night ratio is 3. Collisions with a vehicle in/from another roadway were much more common during daytime given the day to night ratio for such crashes was 12.2; three times the overall day to night ratio. Animal crashes, however, were more almost three times more common during night and constituted 11 percent of all nighttime crashes.

Table 6 represents statistics on types of crashes compared by day and night.

Table 6. Crash counts by type of crash

Type of Crash	Day	Night	Total	Day/ Night
Animal	3.3%	10.7%	14.0%	0.3
Cargo/equipment loss or shift	0.3%	0.0%	0.3%	
Crossed centerline	1.7%	0.0%	1.7%	
Driving too fast for conditions	6.0%	0.3%	6.3%	18.0
Equipment failure	0.3%	0.0%	0.3%	
Exceeded authorized speed	0.3%	0.0%	0.3%	
Followed too close	5.0%	0.7%	5.7%	7.5
FTYROW: From driveway	0.3%	0.0%	0.3%	
FTYROW: From stop sign	20.7%	1.7%	22.3%	12.4
FTYROW: Making left turn	4.0%	1.0%	5.0%	4.0
FTYROW: Other (explain in narrative)	1.3%	0.3%	1.7%	4.0
Lost Control	1.3%	0.7%	2.0%	2.0
Made improper turn	2.3%	0.0%	2.3%	
Operating vehicle in an erratic/reckless/careless/negligent/aggressive manner	2.0%	0.3%	2.3%	6.0
Other (explain in narrative): No improper action	1.3%	1.0%	2.3%	1.3
Other (explain in narrative): Other improper action	3.7%	1.0%	4.7%	3.7
Other (explain in narrative): Vision obstructed	0.3%	0.0%	0.3%	
Ran off road - left	1.7%	0.3%	2.0%	5.0
Ran off road - right	2.0%	0.3%	2.3%	6.0
Ran off road - straight	1.0%	0.3%	1.3%	3.0
Ran Stop Sign	11.0%	4.3%	15.3%	2.5
Ran Traffic Signal	0.3%	0.0%	0.3%	
Swerving/Evasive Action	4.0%	0.7%	4.7%	6.0
Traveling wrong way or on wrong side of road	0.0%	0.3%	0.3%	0.0
Unknown	1.3%	0.3%	1.7%	4.0
Total	**227**	**73**	**300**	**3.1**

Comparing day to night crash ratios for each type of crash with the overall day to night crash ratio provides an understanding of relative frequency. By looking at day to night ratios we observe again that animal crashes are more common during night. Crashes due to driving too fast, following too close, failing to yield at stop sign, and running off the road from left or right are some types of crashes more common during the day.

STATISTICAL ANALYSIS

Summary of Data

Crash Data

Information on crashes by time of day and presence of light is presented in Table 7. As indicated, Phase II crashes cover January 2006 through March 2011.

Table 7. Crash information for Phase II

Type	Lighted	Unlighted
Number of Intersections	101	86
Total Crashes	193	107
Day Crashes	148	79
Night Crashes	45	28
Day Crashes per Intersection	1.47	0.92
Night Crashes per Intersection	0.45	0.33
Night to Day Crash Ratio	0.3	0.35
Night to Total Crash Ratio	0.23	0.26

Table 8 provides similar information from the Phase I project, which used crashes from 2001 through 2005.

Table 8. Crash information for Phase I

Type	Lighted	Unlighted
Number of Intersections	137	86
Total Crashes	191	98
Day Crashes	137	61
Night Crashes	54	37
Day Crashes per Intersection	1	0.71
Night Crashes per Intersection	0.39	0.43
Night to Day Crash Ratio	0.39	0.61
Night to Total Crash Ratio	0.28	0.38

Lighting Data

When modeling quality of lighting levels per intersection, the illuminance method as recommended by IESNA was considered. Initially, whether the intersections had the minimum recommended average illuminance values was checked. Recommended values for the illuminance method change based on the type of pavement.

Among 101 lighted intersections in this study; 23 had concrete pavement and the remaining 78 had asphalt pavement. Based on the type of pavement, the average illuminance values were evaluated (see Table 1for details). The independent variable RecIllum was coded 1 for the intersections for which average illuminance was higher than the recommended minimum. Then, to come up with quality of lighting levels; the intersections were statistically clustered based on quality of lighting data variables (average illuminance, uniformity ratio, and average glare). Details are provided in the next subsection.

Analysis

A cross-sectional statistical study was used to evaluate effect of quality of lighting and other treatments on the safety benefits for the 187 intersections in this study. This section first presents the independent variables that represent intersection characteristics and the dependent variables that are used to represent safety performance at each intersection.

The safety performances of intersections were evaluated by a series of Bayesian Poisson regression models. One independent variable used in the analyses was the lighting level. Lighting levels were assigned based on a statistical K-Means clustering analysis. Finally, a multinomial regression model was applied to the combined crash and intersection data set to see if lighting has any statistically-significant effect on the severity of crashes.

Variables

The independent variables used in the analysis are given below:

- *IsectControl:* A dummy variable that indicates whether the intersection had stop signs on the minor or all-way stops (0: stops for the minor street, 1: all-way stop)
- *OtherControl:* A dummy variable that indicates type of control at an intersection other than stop signs (1: red flags on stop, 2: flashing red beacon, 3: flashing red on stop sign, 4: other, 5: none)
- *NumChannel:* A numeric variable that indicates number of approaches with channelization
- *NumLeft:* A numeric variable that indicates the number of left-turn lanes
- *NumRight:* A numeric variable that indicates the number of right-turn lanes
- *Legs4:* A dummy variable that indicates whether the intersection had three or four approaches
- *IsRumbleSt:* A dummy variable that indicates whether rumble strips were present on any approach

- *LogAADT:* A numeric variable equal to the log of total intersection AADT (total intersection AADT is the sum of AADT for each approach divided by 2)
- *ConcPvmnt:* A dummy variable that indicates whether the pavement at the intersection is concrete or asphalt (0: Asphalt, 1: Concrete)
- *IsLight:* A dummy variable that indicates presence of lighting at the intersection (0: Unlighted, 1: Lighted)
- *NumLights:* A numeric variable that indicates number of lights at the intersection
- *Illum:* A numeric variable for the average illuminance value at the intersection (lux)
- *RecIllum:* A dummy variable that indicates whether the intersection has the minimum recommended illuminance value (0: below, 1: above, preferred) (only six intersections were above the minimum recommended average illuminance value by IESNA**;** see Table 1 for the recommended values)
- *AvgGlare:* A numeric variable that indicates the average glare at the intersection
- *RatioUni:* A numeric value that indicates uniformity ratio at the intersection
- *LightClstr:* A dummy variable that indicates lighting cluster assigned (1: Cluster 1, lower average illuminance and glare, 2: Cluster 2, higher average illuminance and glare, 3: unlighted intersections)

Figure 5 shows the distributions of some independent variables that are given to indicate the frequency of the levels of intersection characteristics. Among study intersections, only eight had all-way stop signs. Twenty intersections were observed to have other types of controls other than stop signs. Thirty-three intersections had at least one approach with channelization and only six intersections had left-turn lanes. Right-turn lanes were more frequent than the left turn lanes and 50 intersections had at least one right-turn lane among the study intersections. Almost 75 percent of the intersections had four approaches and for 68 percent of the intersections, rumble strips were present on any approach. The pavement at 118 intersections was asphalt, whereas, it was concrete for the remaining 69 intersections. Lighted intersections were more common: 101 of 187 intersections were lighted.

The dependent variables used are as follows:

- *IsectNight:* Number of nighttime crashes at the intersection
- *IsectDay:* Number of daytime crashes at the intersection
- *IsectTotal:* Number total crashes at the intersection
- *NightCrshRt:* Nighttime crash rate at the intersection
- *DayCrshRt:* Daytime crash rate at the intersection
- *TotalCrshRt:* Total crash rate at the intersection
- *NighttoTotal:* Ratio of nighttime crashes to total number of crashes
- *NighttoDay:* Ratio of nighttime crashes to daytime crashes
- *CrashSev:* A dummy variable that indicates crash severity (1: Fatal and major injury crashes, 2: minor injury crashes, 3: property damage only crashes)

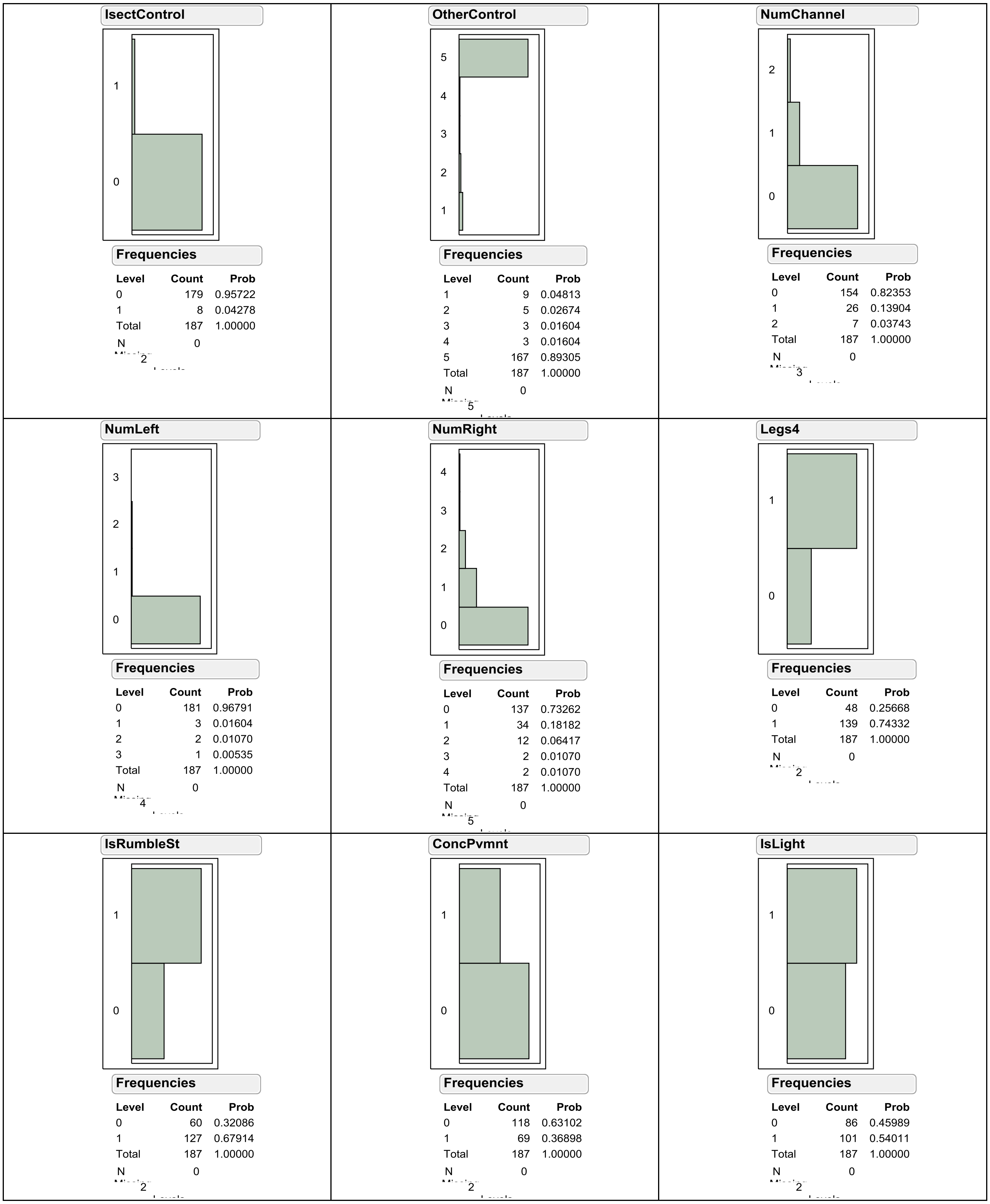

Figure 5. Distribution of independent variables for study intersections

Crash rates defined within the dependent variables were calculated based on Equation 1 (Isebrands et al. 2006).

$$Crash\ rate = \frac{(Number\ of\ Crashes)*10^6}{(DEV_i)*(n\ years)*(365\frac{days}{year})} \quad (1)$$

where:

DEV_i = Daily entering volume for an intersection (assumed to be the sum of AADT for each approach divided by 2).

Clustering Analysis for Lighting

The K-means clustering algorithm classifies a given data set into a certain number of clusters based on the multidimensional space of the independent variables. The algorithm first assigns centroids for each cluster and assigns points to the nearest centroid. Then, new centroids are calculated given the new set of cluster points. The iterative procedure continues until a metric based on the distance between all points and their respective centroids is minimized.

For determining quality of lighting levels in this study the K-means clustering algorithm was applied to the dataset using the SAS 9.2 statistical platform. Different numbers of clusters were considered; however, having two clusters for lighted intersections and one for unlighted intersections was preferred. When a higher number of clusters were considered, some clusters ended up having too few counts to represent a lighting level.

Average illuminance, average glare, and uniformity ratio were the independent variables for this analysis. Table 9 presents the mean values and counts for the final clusters.

Table 9. Lighting cluster analysis

			Cluster Means		
Cluster	**Count**	**Character**	**Avg. Illuminance**	**Avg. Glare**	**Uniformity Ratio**
1	75	Lower illuminance and glare	2.1	9.2	11.2
2	26	Higher illuminance and glare	5.9	11.6	30.3

Cluster 1 represents the intersections with lower average illuminance, glare, and uniformity ratios when compared with Cluster 2 intersections. As indicated, the independent variable LightClstr was coded 1 for Cluster 1, and 2 for Cluster 2, and 3 for unlighted intersections.

Bayesian Poisson Regression Models for Safety Analysis

The general Bayesian Poisson regression model used for the cross-sectional analysis was as follows:

$$y_i \sim Poisson(\mu_i)$$

$$\log(\mu) = \beta_1 + \beta_2 * LogAADT + \beta_3 * I\sec tControl + \beta_4 * OtherControl + \beta_5 * NumChannel$$
$$+ \beta_6 * NumLeft + \beta_7 * NumRight + \beta_8 * Legs4 + \beta_9 * IsRumbleSt + \beta_{10} * LogAADT$$
$$+ \beta_{11} * ConcPvmnt + \beta_{12} * IsLight + \beta_{13} * NumLights + \beta_{14} * Illum + \beta_{15} IllumR$$
$$+ \beta_{16} * \operatorname{Re} cIllum + \beta_{17} * AvgGlare + \beta_{18} * RatioUni + \beta_{19} * LightClstr$$

The final models included below are based on this main model but have a refined number of independent variables. The first criterion considered while selecting these models was to exclude highly-correlated independent variables. When Pearson correlation coefficients were checked for the list of independent variables, a high number of correlated variables were observed. This situation was expected considering these variables represent related intersection characteristics (e.g., NumChannel and NumRight or Illum and IsLight). Multicollinearity among the set of independent variables should be avoided because it causes increased standard errors for estimated model parameters and leads to misleading results. Other criteria considered in the model selection were the convergence of the model and significance of the independent variables.

Model 1: Day Crash Rate

The model presented below looks at the effect of several countermeasures and intersection properties on daytime crash rate.

$$y_i \sim Poisson(\mu)$$

$$\log(\mu) = \beta_1 + \beta_2 * I\sec tControl + \beta_3 * OtherControl1 + \beta_4 * OtherControl2 + \beta_5 * OtherControl3$$
$$+ \beta_6 * OtherControl4 + \beta_7 * NumLeft + \beta_8 * Legs4 + \beta_9 * IsRumbleSt$$

$$\hat{\mu}_i = \exp(\beta_1 + \beta_2 * I\sec tControl + \beta_3 * OtherControl1 + \beta_4 * OtherControl2 + \beta_5 * OtherControl3$$
$$+ \beta_6 * OtherControl4 + \beta_7 * NumLeft + \beta_8 * Legs4 + \beta_9 * IsRumbleSt)$$

Table 10 presents the posterior parameter estimates from the Bayesian Poisson regression model. Similar tables are included for the following models and other output on the models are included in the Appendix.

Table 10. Parameter estimates for day crash rate

	Posterior Summaries(DayCrshRt)						
				Standard	**Percentile**		
	Parameter	**N**	**Mean**	**Deviation**	**25%**	**50%**	**75%**
β_1	Intercept	10000	-0.1659	0.231	-0.3189	-0.159	-0.00672
β_2	IsectControl	10000	-1.0945	1.0092	-1.6933	-0.9801	-0.3794
β_3	OtherControl1*	10000	-0.02	0.7077	-0.439	0.0523	0.4709
β_4	OtherControl2*,**	10000	1.401	0.5517	1.0546	1.4394	1.7802
β_5	OtherControl3*	10000	1.007	0.8931	0.466	1.1103	1.6414
β_6	OtherControl4*	10000	1.2123	0.9681	0.6495	1.322	1.9028
β_7	NumLeft	10000	-1.3901	1.0113	-1.9659	-1.2082	-0.6408
β_8	Legs4**	10000	-0.8649	0.2853	-1.0562	-0.8615	-0.6744
β_9	IsRumbleSt**	10000	-0.8497	0.2691	-1.0271	-0.8482	-0.6718

*Comparison group: OtherControl5
**Significantly different from zero at 95 percent posterior probability interval

In this model, for parameters with significant positive estimates, higher day crash rates were observed while negative estimates suggest lower day crash rates. The estimates with high standard deviation values relative to the mean value are weak estimates.

The percentile values for the estimates give information on the distribution of the estimate. For example, for OtherControl1, β_3 is estimated at -0.02 with a standard deviation of 0.71. The percentile values range from negative to positive values and include zero. Given the range includes zero, the model does not suggest a relationship between OtherControl1 (red flags on stop) and the daytime crash rate.

The weak but negative parameter estimate for IsectControl suggests reduction in day crash rates when stop signs were present on all roads instead of only on minor roads. Positive parameter estimates for OtherControl2-4 suggest that day crash rates are higher at intersections with additional controls such as flashing red beacon (OtherControl2), flashing red on stop sign (OtherControl3), or other controls (OtherControl4) versus intersections with only stop signs for control.

The parameter estimates for Legs4 and IsRumbleSt are stronger estimates and significantly different from zero at the 95 percent confidence level. The estimates suggest a reduction in day crash rate when the intersections have rumble strips on any approach or when they are four-leg intersections (with respect to three-leg intersections).

Model 2: Presence of Light

The effect of presence of lighting on safety performance was evaluated by two models. Table 11 gives the subsequent summaries for the parameters when the dependent variable is night to day crash ratio. Expectedly, model results suggest an increasing night to day crash ratio with increasing volume.

Table 11. Parameter estimates for night to day crash ratio, presence of light

	Posterior Summaries(NighttoDay)						
				Standard	Percentile		
	Parameter	N	Mean	Deviation	25%	50%	75%
β_1	Intercept*	10000	-15.6260	3.1585	-17.6692	-15.4820	-13.4437
β_2	LogAADT*	10000	4.1095	0.9099	3.4808	4.0670	4.7097
β_3	IsLight	10000	-0.4383	0.4104	-0.7146	-0.4466	-0.1704
β_4	IsectControl	10000	-4.1801	3.5895	-6.4283	-3.4124	-1.4433
β_5	OtherControl1	10000	-0.4002	1.3158	-1.1656	-0.1999	0.5482
β_6	OtherControl2	10000	-1.5819	2.0461	-2.7591	-1.2187	-0.0597
β_7	OtherControl3*	10000	-41.8889	24.7853	-63.4215	-41.6007	-20.7552
β_8	OtherControl4	10000	-0.7568	1.3844	-1.5371	-0.5378	0.2433

*Significantly different from zero at 95 percent posterior probability interval

The parameter estimate for presence of light is negative and suggests a reduction in night to day crash ratio at lighted intersections. However, the standard deviation is very close to the mean value and, therefore, this is not a strong estimate. Given this, a likely reduction in the night to day crash ratio with presence of lighting can be suggested but this relationship is weak.

The negative parameter estimate for OtherControl3 suggests that the night to day crash ratio is lower at the intersections with flashing red on stop sign when compared with intersections with only stop signs for control.

The parameter estimates when the dependent variable is the number of nighttime crashes are presented in Table 12. IsectControl has again a negative but weak mean parameter estimate due to the high standard deviation. The only significant parameter estimate at the 95 percent confidence level is volume.

Table 12. Parameter estimates for number of night time crashes, presence of light

	Posterior Summaries(IsectNight)						
				Standard	Percentile		
	Parameter	N	Mean	Deviation	25%	50%	75%
β_1	Intercept*	10000	-9.8705	1.7021	-10.9695	-9.8417	-8.7000
β_2	LogAADT*	10000	2.6695	0.5022	2.3258	2.6608	2.9982
β_3	IsLight	10000	-0.2220	0.2605	-0.3958	-0.2211	-0.0471
β_4	IsectControl	10000	-1.0695	0.8841	-1.6044	-1.0000	-0.4522
β_5	OtherControl1	10000	0.6936	0.5110	0.3692	0.7214	1.0466
β_6	OtherControl2	10000	0.1838	0.7090	-0.2483	0.2342	0.6642
β_7	OtherControl3	10000	-0.5231	1.2381	-1.2185	-0.3429	0.3606
β_8	OtherControl4	10000	0.6033	0.5570	0.2520	0.6483	1.0019

*Significantly different from zero at 95 percent posterior probability interval

Model 3: Quality of lighting

Table 13 and Table 14 present the parameter estimates when the lighting levels found by statistical clustering is included as an independent variable for nighttime crashes.

Table 13. Parameter estimates for night to day crash ratio, lighting level

	Posterior Summaries(NighttoDay)						
				Standard	**Percentile**		
	Parameter	**N**	**Mean**	**Deviation**	**25%**		**75%**
β_1	Intercept**	10000	-15.6613	3.2175	-17.7831	-15.5162	-13.4462
β_2	LogAADT**	10000	4.1179	0.9258	3.4800	4.0853	4.7279
β_3	LightClstr1*	10000	-0.4570	0.4364	-0.7485	-0.4577	-0.1663
β_4	LightClstr2*	10000	-0.4531	0.5856	-0.8368	-0.4261	-0.0478
β_5	IsectControl	10000	-4.2412	3.6249	-6.4693	-3.5122	-1.4681
β_6	OtherControl1	10000	-0.4238	1.3201	-1.1565	-0.2339	0.5153
β_7	OtherControl2	10000	-1.6010	2.0648	-2.7572	-1.2310	-0.0772
β_8	OtherControl3**	10000	-42.1824	24.6127	-63.4284	-42.3078	-21.1683
B_9	OtherControl4	10000	-0.7284	1.3589	-1.4946	-0.5264	0.2644

*Reference group LightClstr3(unlighted)

**Significantly different from zero at 95 percent posterior probability interval

Table 14. Parameter estimates for number of night time crashes, lighting level

	Posterior Summaries(IsectNight)						
				Standard	**Percentile**		
	Parameter	**N**	**Mean**	**Deviation**	**25%**	**50%**	**75%**
β_1	Intercept	10000	-9.6231	1.7147	-10.7741	-9.5725	-8.4237
β_2	LogAADT	10000	2.6531	0.5069	2.3006	2.6396	2.9920
β_3	LightClstr1	10000	-0.3699	0.2873	-0.5586	-0.3703	-0.1789
β_4	LightClstr2	10000	0.0751	0.3388	-0.1456	0.0744	0.3058
β_5	Legs4	10000	-0.2722	0.2743	-0.4568	-0.2761	-0.0939
β_6	IsectControl	10000	-1.1039	0.9055	-1.6434	-1.0356	-0.4712
β_7	OtherControl1	10000	0.5883	0.5180	0.2701	0.6196	0.9470
β_8	OtherControl2	10000	0.1188	0.7232	-0.3293	0.1754	0.6275
B_9	OtherControl3	10000	-0.4219	1.2339	-1.1389	-0.2459	0.4750
β_{10}	OtherControl4	10000	0.7912	0.5543	0.4438	0.8224	1.1810

We do not observe any strong relationship between lighting levels and nighttime crashes. Negative parameter estimates for LightClstr1 and LightClstr2 suggest lower night-to-day crash ratios for both groups of lighted intersections with respect to unlighted intersections. However, this relationship is not significant. The weak parameter estimates for both groups are almost equal and does not indicate any difference between the two lighting levels.

When we look at number of nighttime crashes (Table 14); model results suggest a lower number of nighttime crashes for lower average illuminance intersections (LightClstr1) when compared with unlighted and higher average illuminance intersections (LightClstr2). However, a significant relationship cannot be found due to the high standard deviations of the parameter estimates. The only significant parameter for this model is volume.

Model 4: Crash Severity and Lighting

Crash severity was modeled by a multinomial logistic regression to see if presence of light or lighting level has any statistically-significant effect on the relative probability of crash severities.

Presence of light was not a significant parameter on the crash severity (Table 15). However, nighttime crashes were more severe than daytime crashes at the 95 percent confidence level. In this model, Function 1 compares severity 1 with severity 3 (fatal and major injury crashes versus property damage only) and function 2 compares severity 2 with severity 3. Positive parameter estimates for both functions suggest that the probability of having a major injury crash or a minor injury crash with respect to a property damage only crash increases at nighttime.

Table 15. Maximum likelihood estimates of crash severity model parameters

Analysis of Maximum Likelihood Estimates						
Parameter		**Function Number**	**Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**
Intercept		1	0.3041	2.1794	0.02	0.8890
		2	-2.3888	1.8622	1.65	0.1996
LogAADT		1	-0.9353	0.6351	2.17	0.1408
		2	0.2903	0.5402	0.29	0.5910
IsNight	0	1	1.1151	0.5199	4.60	0.0320
	0	2	0.5063	0.2106	5.78	0.0162
IsLight	0	1	-0.0505	0.2485	0.04	0.8388
	0	2	0.0902	0.1671	0.29	0.5892

Conclusions

This cross-sectional statistical study evaluated the effect of the quality of lighting and other treatments on the safety benefits for 101 lighted rural intersections as compared to 86 unlighted rural intersections. Based on the results of the analysis, the following conclusions can be made:

- As with any study that includes field data and limited resources, there are limitations on the number of available data points, randomness of data, and ranges of data values (number of crashes, light levels, volume, and intersection control).
- For all but nine of the lighted intersections, the measured illuminance levels were below the recommended values and this limits the robustness of the cluster analysis and results in the inability to contrast different illuminance ranges.
- The negative parameter estimates for lower average illuminance and glare (LightClstr1) and higher average illuminance and glare (LightClstr2) suggest lower night-to-day crash ratios for both groups of lighted intersections with respect to unlighted intersections.
- Model results suggest a lower number of nighttime crashes for lower average illuminance intersections (LightClstr1) when compared with unlighted and higher average illuminance intersections (LightClstr2). However, a significant relationship cannot be found due to the high standard deviations of the parameter estimates and there was an imbalance between the data sets with 75 lower illuminance intersections as opposed to only 26 higher illuminance intersections.

Based on the findings from both the Phase I and II studies, lighted intersections experience fewer crashes when compared to unlighted conditions. Quantifying the safety contribution of light quality remains elusive at best. Even with the far majority of intersections falling below standard illumination levels, the presence of lighting still made a significant impact on safety when compared to non-lighted locations.

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APPENDIX

The GENMOD Procedure
Bayesian Analysis

Model Information	
Data Set	WORK.DATA
Burn-In Size	2000
MC Sample Size	10000
Thinning	1
Sampling Algorithm	ARMS
Distribution	Poisson
Link Function	Log
Dependent Variable	DayCrshRt

Number of Observations Read	187
Number of Observations Used	187

Class Level Information		
Class	Levels	Values
OtherControl	5	1 2 3 4 5

Algorithm converged.

Posterior Summaries						
			Standard	Percentiles		
Parameter	N	Mean	Deviation	25%	50%	75%
Intercept	10000	-0.1659	0.2310	-0.3189	-0.1590	-0.00672
IsectControl	10000	-1.0945	1.0092	-1.6933	-0.9801	-0.3794
OtherControl1	10000	-0.0200	0.7077	-0.4390	0.0523	0.4709
OtherControl2	10000	1.4010	0.5517	1.0546	1.4394	1.7802
OtherControl3	10000	1.0070	0.8931	0.4660	1.1103	1.6414
OtherControl4	10000	1.2123	0.9681	0.6495	1.3220	1.9028
NumLeft	10000	-1.3901	1.0113	-1.9659	-1.2082	-0.6408
Legs4	10000	-0.8649	0.2853	-1.0562	-0.8615	-0.6744
IsRumbleSt	10000	-0.8497	0.2691	-1.0271	-0.8482	-0.6718

The GENMOD Procedure
Bayesian Analysis

Model Information	
Data Set	WORK.DATA
Burn-In Size	2000
MC Sample Size	10000
Thinning	1
Sampling Algorithm	ARMS
Distribution	Poisson
Link Function	Log
Dependent Variable	NighttoDay

Number of Observations Read	187
Number of Observations Used	187

Class Level Information		
Class	Levels	Values
OtherControl	5	1 2 3 4 5

Algorithm converged.

Posterior Summaries						
			Standard	Percentiles		
Parameter	N	Mean	Deviation	25%	50%	75%
Intercept	10000	-15.6260	3.1585	-17.6692	-15.4820	-13.4437
LogAADT	10000	4.1095	0.9099	3.4808	4.0670	4.7097
IsLight	10000	-0.4383	0.4104	-0.7146	-0.4466	-0.1704
IsectControl	10000	-4.1801	3.5895	-6.4283	-3.4124	-1.4433
OtherControl1	10000	-0.4002	1.3158	-1.1656	-0.1999	0.5482
OtherControl2	10000	-1.5819	2.0461	-2.7591	-1.2187	-0.0597
OtherControl3	10000	-41.8889	24.7853	-63.4215	-41.6007	-20.7552
OtherControl4	10000	-0.7568	1.3844	-1.5371	-0.5378	0.2433

The GENMOD Procedure
Bayesian Analysis

Model Information	
Data Set	WORK.DATA
Burn-In Size	2000
MC Sample Size	10000
Thinning	1
Sampling Algorithm	ARMS
Distribution	Poisson
Link Function	Log
Dependent Variable	IsectNight

Number of Observations Read	187
Number of Observations Used	187

Class Level Information		
Class	Levels	Values
OtherControl	5	1 2 3 4 5

Algorithm converged.

Posterior Summaries						
			Standard	Percentiles		
Parameter	N	Mean	Deviation	25%	50%	75%
Intercept	10000	-9.8705	1.7021	-10.9695	-9.8417	-8.7000
LogAADT	10000	2.6695	0.5022	2.3258	2.6608	2.9982
IsLight	10000	-0.2220	0.2605	-0.3958	-0.2211	-0.0471
IsectControl	10000	-1.0695	0.8841	-1.6044	-1.0000	-0.4522
OtherControl1	10000	0.6936	0.5110	0.3692	0.7214	1.0466
OtherControl2	10000	0.1838	0.7090	-0.2483	0.2342	0.6642
OtherControl3	10000	-0.5231	1.2381	-1.2185	-0.3429	0.3606
OtherControl4	10000	0.6033	0.5570	0.2520	0.6483	1.0019

The GENMOD Procedure
Bayesian Analysis

Model Information	
Data Set	WORK.DATA
Burn-In Size	2000
MC Sample Size	10000
Thinning	1
Sampling Algorithm	ARMS
Distribution	Poisson
Link Function	Log
Dependent Variable	NighttoDay

Number of Observations Read	187
Number of Observations Used	187

Class Level Information		
Class	Levels	Values
LightClstr	3	1 2 3
OtherControl	5	1 2 3 4 5

Algorithm converged.

Posterior Summaries						
			Standard	Percentiles		
Parameter	N	Mean	Deviation	25%	50%	75%
Intercept	10000	-15.6613	3.2175	-17.7831	-15.5162	-13.4462
LogAADT	10000	4.1179	0.9258	3.4800	4.0853	4.7279
LightClstr1	10000	-0.4570	0.4364	-0.7485	-0.4577	-0.1663
LightClstr2	10000	-0.4531	0.5856	-0.8368	-0.4261	-0.0478
IsectControl	10000	-4.2412	3.6249	-6.4693	-3.5122	-1.4681
OtherControl1	10000	-0.4238	1.3201	-1.1565	-0.2339	0.5153
OtherControl2	10000	-1.6010	2.0648	-2.7572	-1.2310	-0.0772
OtherControl3	10000	-42.1824	24.6127	-63.4284	-42.3078	-21.1683
OtherControl4	10000	-0.7284	1.3589	-1.4946	-0.5264	0.2644

The GENMOD Procedure
Bayesian Analysis

Model Information	
Data Set	WORK.DATA
Burn-In Size	2000
MC Sample Size	10000
Thinning	1
Sampling Algorithm	ARMS
Distribution	Poisson
Link Function	Log
Dependent Variable	IsectNight

Number of Observations Read	187
Number of Observations Used	187

Class Level Information		
Class	Levels	Values
OtherControl	5	1 2 3 4 5
LightClstr	3	1 2 3

Algorithm converged.

Posterior Summaries						
			Standard	Percentiles		
Parameter	N	Mean	Deviation	25%	50%	75%
Intercept	10000	-9.6231	1.7147	-10.7741	-9.5725	-8.4237
LogAADT	10000	2.6531	0.5069	2.3006	2.6396	2.9920
LightClstr1	10000	-0.3699	0.2873	-0.5586	-0.3703	-0.1789
LightClstr2	10000	0.0751	0.3388	-0.1456	0.0744	0.3058
Legs4	10000	-0.2722	0.2743	-0.4568	-0.2761	-0.0939
IsectControl	10000	-1.1039	0.9055	-1.6434	-1.0356	-0.4712
OtherControl1	10000	0.5883	0.5180	0.2701	0.6196	0.9470
OtherControl2	10000	0.1188	0.7232	-0.3293	0.1754	0.6275
OtherControl3	10000	-0.4219	1.2339	-1.1389	-0.2459	0.4750
OtherControl4	10000	0.7912	0.5543	0.4438	0.8224	1.1810

The CATMOD Procedure

Data Summary			
Response	CrashSev	Response Levels	3
Weight Variable	None	Populations	129
Data Set	CSEVERITY	Total Frequency	239
Frequency Missing	0	Observations	239

Response Profiles	
Response	CrashSev
1	1
2	2
3	3

Maximum Likelihood Analysis
Maximum likelihood computations converged.

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
Intercept	2	1.81	0.4037
LogAADT	2	2.91	0.2332
IsNight	2	9.77	0.0075
IsLight	2	0.39	0.8236
Likelihood Ratio	250	229.76	0.8161

Analysis of Maximum Likelihood Estimates						
Parameter		Function Number	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept		1	0.3041	2.1794	0.02	0.8890
		2	-2.3888	1.8622	1.65	0.1996
LogAADT		1	-0.9353	0.6351	2.17	0.1408
		2	0.2903	0.5402	0.29	0.5910
IsNight	0	1	1.1151	0.5199	4.60	0.0320
	0	2	0.5063	0.2106	5.78	0.0162
IsLight	0	1	-0.0505	0.2485	0.04	0.8388
	0	2	0.0902	0.1671	0.29	0.5892

Function # 1 Severity 1 compared to severity 3 (Sev1/Sev3)
Function # 2 Severity 2 compared to severity 3 (Sev2/Sev3)
Crash Severity 3 is the referent group
π_1 = probability of 'Crash Severity=1'
π_2 = probability of 'Crash Severity=2'
π_3 = probability of 'Crash Severity=3'
$\text{logit}(\theta_1) = \log(\pi_1/\pi_3)$,
$\text{logit}(\theta_2) = \log(\pi_2/\pi_3)$.