# Safety Impacts Of Street Lighting at Isolated Rural Intersections

## Part II, Year 1 Report

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# SAFETY IMPACTS OF STREET LIGHTING AT ISOLATED RURAL INTERSECTIONS – PART II

## Year 1 Report

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## EXECUTIVE SUMMARY

Several research efforts, including one initiated by the Minnesota Local Road Research Board (LRRB), have suggested that rural intersection lighting reduces nighttime crashes and is a cost-effective crash mitigation strategy. However, many Minnesota highway agencies do not routinely install or maintain streetlights at rural intersections or retain formal warrants or guidelines for installation. This study was initiated to evaluate the effectiveness of rural street lighting in reducing nighttime crashes at isolated rural intersections so that Minnesota agencies have more information to make lighting evaluations.

Two methods were used to analyze rural intersection crash data for Minnesota. A comparative analysis compared lighted and unlighted intersections from the Minnesota Department of Transportation (Mn/DOT) intersection database. The second method was a before-and-after study of intersection locations that had lighting installed.

**Comparative Analysis**

A comparative analysis was used to evaluate 3,622 rural stop-controlled intersections from the Mn/DOT intersection database (223 were lighted with point, partial, or full lighting and the rest were categorized as unlighted). Intersections selected were located on either US or Minnesota trunk highways. Both daytime and nighttime volumes were determined and a daytime and nighttime crash rate was calculated for each intersection. Overall, the average daytime crash rate was higher at lighted intersections while the average nighttime crash rate was slightly lower at lighted intersections than at unlighted intersections. However, the ratio of nighttime to daytime crash rate was much lower at lighted intersections than at unlighted ones (1.43 versus 2.03). Crash type, crash severity, and intersection geometry were also compared for lighted versus unlighted intersections.

Additionally, a linear regression model was used to compare the ratio of night crashes to total crashes. Results indicated that the ratio of nighttime crashes to total crashes depends on the presence or absence of lighting, daily entering volume, and the number of approach legs for the intersection. The expected night to total crash ratio for unlighted intersections was 7% higher than at lighted intersections and was statistically significant.

A Poisson regression model was used to model the night crash rate for the comparative analysis. When the night crash rate was modeled with lighting, posted speed, and number of approach legs as independent variables, all three variables were statistically significant. The expected night crash rate at unlighted intersections was 11% lower than the night crash rate at lighted intersections, while the day crash rate was 33% lower at unlighted intersections, holding all other variables equal. These findings suggest that locations that already have safety problems were more likely to have lighting installed. Consequently, overall crash statistics are already higher at those locations. The relevant difference appears to be in the ratio of night to total crashes, which was lower at lighted intersections.

The Poisson regression model also indicated that intersections with posted speed limits at 55 mph or higher for all approaches had night crash rates that were 43% higher than approaches with at least one (1) approach with a posted speed limit less than 55 mph. Intersections with 4-approaches had night crash rates 17% higher than 3-approach intersections. This implies that lighting may be more beneficial at intersections with 55 mph posted approach speeds and at 4-approach intersections.

**Before-and-After Analysis**

A before-and-after study was also used to evaluate the impact of lighting on nighttime crashes. Minnesota counties were surveyed to determine locations where lighting had been installed at rural intersections. Site visits were made to the majority of the intersections to collect geometric and surrounding land use data. A total of 90 potential intersections were initially identified. Intersections with significant differences, such as severe skew angle or close proximity to a railroad crossing, were removed from the list. The resulting list included 49 intersections.

Of the 49 selected intersections, 11 had lighting installed in 2003, 2 had lighting installed in 2002, and another 2 had lighting installed late in 2001. Therefore, a significant number of intersections did not have enough data to be included in the first year analysis. These intersections will be included in the analysis when an update to this report is made in 2005 and 2006. The final number of intersections for the first year analysis was 34.

The intent of the research was to conduct an initial analysis in Year 1 and then update the analysis in Years 2 and 3 when new data becomes available for the intersections that had lighting installed near the beginning of the study period. The analysis presented in this report is for Year 1. The before-and-after analysis will be updated and a section added to this report for Years 2 and 3. Year 1 includes data that were available through 2003, Year 2 will include data available through 2004, and Year 3 will include data available through 2005.

Comparing locations before-and-after installation of street lighting indicated that after lighting was installed, 44% of the intersections had a reduction in the number of nighttime crashes, although daytime crashes increased at 47% of the intersections. The nighttime to total and nighttime to daytime crash ratios also decreased by approximately 32% after lighting was installed, representing a consistent decline in the number of crashes after lighting was installed. Both daytime and nighttime crash rates were also calculated. The nighttime crash rate decreased by 35% after installation of lighting while daytime crash rate increased by 30%. The ratio of night crash rate to day crash rate also decreased.

Poisson and linear regression models were used to determine the statistical significance at the 10% significance level. The decrease in the night crash rate and decrease in the ratio of night to total crashes were both statistically significant. The expected night crash rate in the before period was 54% higher than the after period and the expected ratio of night to total crashes was reduced by 15% in the after period. Additionally, the expected day crash rate increased by 24% in the after period. This indicates that lighting had a statistically significant positive safety benefit.

Additionally, the before-and-after analysis also appears to have yielded a more robust analysis that the comparative analysis.

**Report Organization**

This report presents a detailed description of the data collection and analysis for both the comparative and before-and-after analysis methods. Section 1 provides the problem statement and objectives for the project. Section 2 provides background information on existing studies that have evaluated the impact of lighting at rural intersections. Section 3 provides an overview of lighting warrants in Minnesota for rural intersections and provides information from other states as well. The comparative analysis is presented in Section 4 and the before-and-after study is presented in Section 5. Section 6 summarizes report information and provides conclusions and recommendations.

# 1. INTRODUCTION

## 1.1 Problem Statement

The State of Minnesota identified reducing the number of traffic deaths and serious injuries as one of its safety goals in the FY 2003 Highway Safety Plan (State of Minnesota, 2002). Reducing the number of fatal intersection crashes is also one of the safety initiatives included in the Federal Highway Administration's (FHWA) program "Vital Few." FHWA's goal is to reduce intersection fatalities by 10% by FY 2007 (USDOT, 2002).

Nighttime driving can be particularly problematic. The US Department of Transportation (USDOT) and the National Highway Transportation Safety Administration (NHTSA) both report that while only 27% of total crashes occur under dark conditions, 45% of fatalities occur under dark conditions (NHTSA, 2003). Two studies 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).

Roadway lighting has been referred to as an effective strategy to reduce nighttime crashes. Roadway lighting provides visibility, helps drivers obtain enough visual information to complete the driving task, and supplements vehicle headlights when warranted (Hasson and Lutkevich, 2002). The public also sees lighting as a positive safety and security measure and often pressures agencies to install lighting at locations that the public perceives are problematic. As a result, agencies often face pressure to routinely install lighting on new facilities and place lighting at problematic locations on existing facilities. At the same time, state and local agencies are facing shrinking resources and increasing demands. Consequently, states need better information to make decisions about when lighting is justified.

Several research efforts, including one initiated by the Minnesota Local Road Research Board (LRRB), have suggested that rural intersection lighting reduces nighttime crashes and is a cost-effective crash mitigation strategy. However, many Minnesota agencies do not routinely install or maintain streetlights at rural intersections and retain no formal warrants/guidelines for installation. The Minnesota DOT (Mn/DOT) has existing lighting warrants; however, thresholds are so high that less than 10% of rural intersections meet the criteria.

The research presented in this report supplements the earlier findings in the April 1999 Final Report of "Safety Impacts of Street Lighting at Isolated Rural Intersections," completed for the Mn/DOT by Preston and Schoenecker, hereafter referred to as the "original LRRB study." The results of this 12 intersection before-and-after study concluded that street lighting at rural intersections resulted in a 25–40% reduction in nighttime crash frequency, as well as an 8-26% reduction in the nighttime crash severity. Although the results were encouraging, it was speculated the 12 intersections studied did not offer a large enough sample size to provide results with robust statistical significance. One of the main goals of the research presented in this report was to increase the number of locations evaluated and confidence in the results.

### 1.2 Project Scope and Objectives

In order to evaluate the effectiveness of rural intersection lighting in reducing nighttime crashes, both comparative and before-and-after statistical analyses were conducted. The comparative study analyzed rural intersections in Minnesota that were included in the Mn/DOT intersection attribute database. Intersections both with and without street lighting were included. A before-and-after study was conducted for a sample of isolated rural intersections with street lighting. For the purposes of this study, an isolated intersection is defined as an intersection at least one mile from significant development or the nearest signalized intersection. Minnesota counties participated by providing an inventory of lighted intersections within their respective counties through a survey. Poisson and linear regression models were used to evaluate the statistical significance of street lighting on nighttime crashes.

The objectives of the proposed research study included the following:

- Quantify and analyze the effectiveness of rural lighting in reducing nighttime crashes at isolated rural intersections through comparative and before-and-after analyses.
- Analyze the comparative and before and after data for statistical significance.
- Further assess the short- and long-term safety impacts of lighting at isolated rural intersections by investigating, verifying, and/or refining the recommended lighting guidelines from the original LRRB study.

### 1.3 Report Overview

Major sections to this report include the following:

- Background information on other research that evaluated the effectiveness of rural intersection lighting
- Evaluation of the existing lighting warrants for rural highways
- A comparative safety analysis of rural intersections from the Mn/DOT intersection attribute database which compared nighttime to daytime crashes for lighted and unlighted intersections using descriptive statistics
- A before-and-after analysis of 49 intersections (34 intersections in 2004) was also conducted which compared the ratio of nighttime to total crashes and night time crash rate
- Discussion of linear and Poisson regression models used to evaluate the statistical significance of the ratio of night to total crashes and crash rate

### 1.4 Technical Advisory Committee

The research was guided by coordination with the Technical Advisory Committee. Each member contributed valuable expertise. The board consisted of:

- Mr. Roger Gustafson, (Carver County)
- Mr. Dan Warzala (Minnesota DOT)
- Mr. Loren Hill (Minnesota DOT)
- Mr. Dave Robley (Douglas County)

## 2. BACKGROUND

Intersections are a vital component of the roadway system; however, they are "a planned point of conflict" that increase the likelihood for crashes (Bared and Hasson, 2003). In 2003, intersection-related crashes accounted for approximately 28% of all fatal crashes in the United States (U.S.) and approximately 31% of fatal crashes in Minnesota. Roughly 37% of these intersection-related fatal crashes in Minnesota occurred at night, dusk, or dawn. Nationally, only 25–33% of the vehicle miles traveled occur at night, but nighttime crashes account for half of the fatal crashes. Furthermore, Minnesota experienced 70% of its fatal crashes in rural areas, as compared to 58% nationally (FARS, 2004). These statistics infer that rural intersections at night are at higher risk for fatal crashes than other locations in Minnesota.

In 1999, the original LRRB study (Preston and Schoenecker) on safety impacts of street lighting was published by the Mn/DOT. That study found that the installation of street lighting reduced nighttime crash frequency by 25–40%. The study also reported a reduction in crash severity from 8–26% when lighting was installed. Revised guidelines for installing street lights were presented based on roadway volumes, functional classification, and crash frequency. It was suggested that the existing crash-based guideline for installing lighting (3 night crashes in 1 year) be lowered to 3 nighttime crashes in a 3 year period.

Wortman et al. (1972) reported on results of a study in Illinois that evaluated the impacts of illumination on accidents at rural U.S. and state highway intersections. They analyzed a random sample of illuminated and non-illuminated intersections using analysis of variance. The study compared the ratio of night to total accidents at each intersection. The researchers felt that this minimized the influence of variables that could not be included in the study, such as differences in geometry, given that the ratio reflected differences only between daytime and nighttime conditions. The effects of lighting, channelization, and different number of approach legs on the ratio of night to total accidents was tested by evaluating different combinations of those variables. They found that lighting could contribute significantly to the reduction of night accidents but reported that the benefit only occurred when the nighttime accidents were at least 1/3 the number of day accidents. However, no relationship was found between severity and illumination. The researchers report that illumination results in a 45% reduction in the night accident rate and a 22% reduction in the night to total accident ratio (Lipinski and Wortman, 1976).

Walker and Roberts (1976) also reported reductions in nighttime accident frequency for rural at-grade intersections in Iowa after conducting a before-and-after analysis at 47 intersections. They evaluated channelization and number of approaches in their analysis. Overall, they indicated a 49% reduction in frequency of night accidents after lighting was installed. The average night accident rate was also reduced from 1.89 to 0.91 crashes per million entering vehicles, a reduction of 52%. Their results were statistically significant at the 1% level. More specifically, they found no statistical difference in before and after night accident rates after lighting was installed for unchannelized intersections, but there was a highly significant reduction for channelized intersections. No change in accident rate occurred for T or Y intersections when lighting was installed, but significant reductions occurred for 4-leg intersections. The researchers indicated that this may have been due to fewer possible conflicts points for T and Y intersections.

More recently, Green, et al. (2003) completed a before-and-after study in Kentucky that analyzed safety benefits associated with roadway lighting. A high percentage of the nighttime crashes had one or more of the following characteristics: occurred on a weekend, involved one vehicle, took place on a curve, or occurred in snow and ice conditions. As part of the research, a procedure was developed to identify locations in Kentucky that have a high number or rate of nighttime crashes. A significant number of the locations were identified as rural; however, urban sites were also included. The researchers conducted analysis of 9 intersections before and after the installation of lighting and found that nighttime crashes were reduced by 45%. Similar to the original LRRB study, the sample size for this analysis was small and may have affected the statistical significance and influence regression to the mean.

In a related study, reductions in nighttime crashes are reported at non-intersection and urban areas after installation of lighting. Box (1989) evaluated the impact of lighting along a roadway corridor in a suburban area of Chicago by performing a before-and-after analysis using two years of before data and two years of after data. During the analysis period, daytime crashes increased, which was likely due to increased volume, while the percentage of all nighttime crash types decreased. At corridor intersections, property damage only (PDO) crashes were reduced from 30% to 25%, while injury/fatal accidents were reduced from 42% to 28%. The greatest reductions were fixed object accidents at intersections.

Elvik (1995) conducted a meta-analysis of 37 published studies, reported from 1948 to 1989 in 11 different countries, which evaluated the safety effects of lighting. Analysis of the different studies indicates roughly a 65% reduction in nighttime fatal accidents, 30% reduction in injury accidents, and 15% reduction in PDO accidents for both intersections and roadway segments on rural, urban, and freeway facilities when lighting was installed. The effect of installing lighting was greater at intersections than non-intersections and similar results were found for rural, urban, and freeway environments.

In contrast to these and other similar studies, an evaluation of destination lighting was conducted by Carstens and Berns (1984) in Iowa. Destination lighting is intended only to guide a driver to the intersection and may not provide sufficient lighting to increase visibility. This study found no significant differences in crashes between lighted and unlighted intersections on secondary roads. This research only considered destination lighting and low volume roads where the volume ranges were not defined. It was unclear whether other studies included intersections with these characteristics. Currently, the State of Iowa does have specific warrants for both full lighting and destination lighting at rural intersections.

A summary of the statistical methods used in each study discussed in the previous paragraphs, including sample size, analysis period, and study results, is presented in Table 2-1.

## Table 2.1. Summary of lighting studies

| Study location | Author | (R)ural (U)rban | Report year | Sample size | Analysis period (before/after) | Reduction in night crashes | Statistical test used | Research α value[1] | Reduction significant |
|---|---|---|---|---|---|---|---|---|---|
| Kentucky | Green et al. | R/U | 2003 | 9 | 4/3 | 45% | Not stated | Not stated | Not stated |
| Minnesota | Preston, Schoenecker | R | 1999 | 12 | 3/3 | 25-40% | Poisson | Not stated | Y |
| Illinois | Box | U | 1987 | 14 | 2/2 | 21%[a] | t-test | Not stated | Y |
| Iowa | Carstens, Berns | R | 1984 | 91 | Variable[2] | None[3] | t-test | 0.05 | N |
| Iowa | Roberts, Walker | R | 1976 | 47 | 3/3 | 49% | Analysis of variance | Not stated | Y |
| Illinois | Wortman, Lipinski | R | 1972 | [b] | Comparative[4] | 30% | Analysis of variance | 0.10 | Y |

[1] This is not the p-value or level of significance
[2] Number of before and after years vary from 1 to 3 in the before period and 2 to 4 in the after period
[3] No reduction in night crash rate
[4] The sample size is in data years (263 lighted intersection data years and 182 unlighted intersection data years)
[a] Intersections only, excludes mid-block results
[b] The total population of rural lighted intersections for the State of Illinois and a sample of unlighted intersections

## 3. WARRANTS

Warrants for installation of street lighting were discussed in detail in the original LRRB study. From the study, it was concluded that warrants limit Mn/DOT's ability to apply a documented safety strategy at intersections. The existing lighting warrants for all at-grade intersections, as published in the Minnesota Traffic Engineering Manual (2004) and Minnesota Manual of Uniform Traffic Control Devices (MN MUTCD, 2004), are presented in Appendix A and summarized in Table 3.1.

**Table 3.1. Mn/DOT lighting warrants for at-grade intersections**

| | |
|---|---|
| Lighting of at-grade intersections is warranted if either geometric conditions mentioned in the AASHTO Guide or one or more of the following conditions exist: | |
| **Volume** | Traffic signal warrant volumes are satisfied for any single hour during non-daylight conditions excluding the time period between 6:00 am and 6:00 pm |
| **Crashes** | Traffic signal warrants for the following:<br><br>Minimum vehicular volume—Warrant 1, Condition A (see Figure 3-1), Interruption of continuous traffic—Warrant 1, Condition B (see Figure 3-1), or Minimum pedestrian volume—Warrant 4 |
| **Intersecting roadway** | 3 or more crashes per year occurring during conditions other than daylight |
| **Channelization** | Intersecting roadway is lighted |
| **School crossing** | The intersection is channelized and the $85^{th}$ percentile approach speed exceeds 40 mph (a continuous median is not considered channelization for the purpose of this warrant). |
| **Signalization** | Certain events that result in pedestrian volumes ≥ 100 pedestrians/hour during non-daylight hours |
| **Flashing beacons** | Intersection is signalized |

Since the warrants are for both urban and rural at-grade intersections, criteria are stringent enough that rural locations are not likely to meet the warrants. Lighting warrants for "Minimum Vehicle Volume" (Figure 3.1) are based on traffic signal installation warrants and are only met by 5% of the rural intersections in the 2002 Mn/DOT intersection database. Furthermore, the volumes presented for the higher-volume minor street approach represent 30% of the volume for both major street approaches and are met by less than 10% of the rural intersections on the Minnesota trunk highway system. Consequently, even fewer county and town roadways would meet these guidelines. Present crash frequency warrants require 3 or more crashes per year occurring during non-daylight hours (excluding the time period between 6:00 am and 6:00 pm). This warrant exceeds the number of crashes at approximately 98% of the rural intersections in the 2000–2002 Mn/DOT crash database. Rural intersections are also not likely to meet signalization or school zone crossing warrants. As a result, it is often difficult to make the case for lighting a rural intersection.

**Condition A - Minimum Vehicle Volume**

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | Vehicles per hour on higher-volume minor street approach (one direction only) | | |
|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 100%[a] | 80%[b] | 70%[c] |
| 1............... | 1............... | 500 | 400 | 350 | 150 | 120 | 105 |
| 2 or more... | 1............... | 600 | 480 | 420 | 150 | 120 | 105 |
| 2 or more... | 2 or more... | 600 | 480 | 420 | 200 | 160 | 140 |
| 1............... | 2 or more... | 500 | 400 | 350 | 200 | 160 | 140 |

**Condition B - Interruption of Continuous Traffic**

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | Vehicles per hour on higher-volume minor street approach (one direction only) | | |
|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 100%[a] | 80%[b] | 70%[c] |
| 1............... | 1............... | 750 | 600 | 525 | 75 | 60 | 53 |
| 2 or more... | 1............... | 900 | 720 | 630 | 75 | 60 | 53 |
| 2 or more... | 2 or more... | 900 | 720 | 630 | 100 | 80 | 70 |
| 1............... | 2 or more... | 750 | 600 | 525 | 100 | 80 | 70 |

[a] Basic minimum hourly volume.
[b] Used for combination of Conditions A and B after adequate trial of other remedial measures.
[c] May be used when the major street speed exceeds 40 mph or in an isolated community with a population of less than 10,000.

**Figure 3.1. Minimum vehicular volume and interruption of continuous traffic warrants (source: Minnesota MUTCD)**

Preston and Schoenecker (1999) addressed this difficulty in the original LRRB study. They developed a new range of typical rural volumes, shown in Table 3.2. These criteria were developed by Preston and Schoenecker to more accurately address typical rural highway volumes for both the minor and major approaches. The “high priority” category corresponds to approximately 25% of the rural highways. Since the original report was published, two Minnesota counties have adopted these guidelines for lighting installation.

**Table 3.2. Prioritization of street light installation by functional class**

| | **Major street functional classification** | | | |
|---|---|---|---|---|
| | **Principal arterial (TH)** | **Minor arterial (TH or CSAH)** | **Collector (CSAH or CR)** | **Local (CR or TWN Rd)** |
| **Priority** | **Major street volumes in vehicles per day** (% of major street volume that is recommended on the minor street ) | | | |
| Low | 0–2000 (10%) | 0–1000 (10%) | 0–500 (10%) | 0–250 (10%) |
| Moderate | 2,000–5,000 (15%) | 1,000–2,000 (15%) | 500–1000 (15%) | 250–500 (15%) |
| High | > 5,000 (20%) | > 2,000 (20%) | > 1,000 (20%) | > 500 (20%) |

In addition to addressing rural volumes, the original LRRB study recommended lowering the crash warrant threshold to 3 or more nighttime crashes in a 3 year period rather than 3 nighttime crashes per year in order to apply the guidelines to a more representative number of rural intersections. This proposed crash frequency guideline would apply to approximately 8% of the intersections in the 2000–2002 database.

Four Minnesota counties were found to have quantitative warrants. Quantifiable warrants refer to volume and crash criteria with specified values instead of vague statements such as “history of crashes,” “heavy volumes on side streets,” or “complex geometry.” Two counties have adopted the guidelines suggested in the original LRRB study and guidelines for the other two counties are listed below:

1. Intersections with all approach average daily traffic (ADT) greater than 1,000
2. State highway intersections with an ADT greater than 500 and a minor road ADT greater than 150.

Five additional counties use the existing Mn/DOT lighting warrants presented in Table 3.1.

NCHRP 152 (1974) and AASHTO's *Informational Guide for Roadway Lighting* (1984) are also well-known and often-used publications that address warrants for the installation of street lighting. AASHTO provides volume and crash warrants for freeways, but only provides general guidelines for non-freeway facilities. NCHRP 152 provides a rating system for geometric, operational, and environmental factors as well as accidents, and compares the calculated value to a pre-established warranting condition value. NCHRP 152 is the most comprehensive resource available for lighting warrants and includes accident rate as the second-highest weighted factor in the rating. Several of the NCHRP 152 rating tables are included in Appendix B.

Many states have lighting warrants but do not have specific guidelines for rural intersections or identify specific measurements (i.e. volume or crash criteria) for lighting consideration. In an Illinois study, Wortman and Lipinski (1974) suggested consideration for lighting installation at rural intersections where the night crashes are 1/3 the number of day crashes. A 2003 study by Green et al., surveyed all states regarding their lighting warrants. Of those that responded to the survey, 7 states have quantifiable warrants for rural intersection lighting. Illinois, Iowa, Mississippi, New York, North Dakota, and Oklahoma all use volumes and/or crash experience over a specified time period to determine if lighting should be considered at an intersection. Table 3.3 summarizes the rural roadway lighting warrants from this survey.

**Table 3.3. State rural lighting warrants (quantitative only)**

| State | Warrants |
|---|---|
| **Illinois** | ≥ 2.4 accidents/MEV in 3 consecutive years, or<br>≥ 2.0 accidents/MEV/yr and ≥ 4.0 accidents/yr in 3 consecutive years, or<br>≥ 3.0 accidents/MEV/yr and ≥ 7.0 accidents/yr in 2 consecutive years |
| **Iowa** | See Table 6.4 |
| **Mississippi** | NCHRP 152 |
| **New York** | Night to day crash rate ratio ≥ 3.0 and total crash rate is at least 2 times greater that the state average provided 1 nighttime crash per intersection has occurred over a 3 year period |
| **North Dakota** | US/state roads: night-to-day crash rate ratio ≥ 2.0<br>Intersections: 4.0 nighttime accidents in 1 year or ≥ 6.0 in 2 years, or<br>≥ 6.0 total accidents in ≤ 3 years and<br>night-to-day crash rate ratio is ≥ 1.5 |
| **Oklahoma** | ADT ≥ 6,000 for 2 lane highway, or<br>ADT ≥ 12,000 for 4 lane roadway, or<br>ADT ≥ 4,000 for rural intersection mainline, or<br>Night-to-day crash rate ratio ≥ 1.5 |

The Iowa DOT provides detailed lighting warrants for full lighting and destination lighting in their *Traffic and Safety Manual* and the *Iowa Administrative Code* (State of Iowa, 2004). Warrants include applications for new or reconstructed intersections and existing intersections. The warrants are presented in Table 3.4. These warrants provide a wide range of measurements for evaluating the need for lighting at rural intersections by considering volume, intersection characteristics, intersection sight distance (included in the safety adjustment factor), night to day crash rate ratio, and night crashes.

**Table 3.4. Iowa DOT rural intersection lighting warrants**

| | Full lighting[1] | Destination lighting[1] |
|---|---|---|
| **New or reconstructed intersections** | **Primary/primary** | **Primary/primary and primary/minor** |
| | ADT ≥ 3500 entering vehicles, and channelized, or<br>"T" configuration, or<br>Major route changes direction | ADT ≥ 1750 entering vehicles, and channelized, or<br>"T" configuration, or<br>Major route changes direction |
| **Existing intersections** | **Primary/primary** | **Primary/primary and primary/minor** |
| | Meets criteria above, or 1Safety Adjustment Factor (SAF) Calculation > 3000 | Meets criteria above, or<br>Night to day crash rate ratio ≥ 1.0 and minimum of 2 reportable night crashes in 5 year period |
| | **Primary/Secondary** | |
| | Night to day crash rate ratio ≥ 2.0 and minimum of 3 reportable night crashes in 12 month period | |
| | Commercial or business development affecting operations | |
| | Operational problems | |
| | Roadway/Traffic Factor[1] > 3000 | |

[1] Destination lighting is intended only to guide the driver to the intersection and full lighting is designed to increase visibility
[2] See Appendix C

# 4. COMPARATIVE ANALYSIS

The objective of this research was to determine the safety impacts of lighting at rural intersections in terms of reduction in nighttime crashes and to ensure that the results were statistically significant. The first statistical analysis compared crashes at both lighted and unlighted existing rural intersections to determine whether locations with lighting had proportionately less nighttime crash experience (comparative analysis). The comparative analysis evaluated the effectiveness of rural intersection lighting on reducing nighttime crashes. Intersection, crash, and exposure data were obtained from the Mn/DOT. Nighttime and daytime crashes were compared for lighted and unlighted intersections. Data collection, methodology, and results are presented in the following sections.

Data were analyzed by simple comparison of data and is presented in Section 4.2. A statistical model was also developed to test the statistical significance between variables and is presented in Section 4.3.

## 4.1 Data

### *4.1.1 Intersection Data*

The intersection attribute dataset used for the comparative analysis was provided by the Mn/DOT Office of Traffic, Security and Operations. This database includes all intersections with roadways on the trunk highway system (i.e. interstates, U.S. trunk highways, and Minnesota trunk highways). The dataset consists of several relational databases, which consists of A, B, C, and D Card Codes. Each card has different variables that contain various attributes, as shown in Table 4.1.

**Table 4.1. Mn/DOT I/I attribute card codes**

| Attribute | Attribute |
|---|---|
| **A Card Codes** | **C Card Codes** |
| Route System | Road Description |
| Route Number | Lower and Upper Limits from Intersection |
| Reference Point | D Card Codes |
| Intersection Type | Leg Number |
| Intersection Description | Direction from Intersection |
| Traffic Control Device | ADT |
| Lighting | Year |
| General Environment | Posted Speed Limit |
| Specific Environment | Approach Traffic Control |
| **B Card Codes** | Approach Turn Lane |
| Verbal Description | |

The Mn/DOT intersection database was queried to select intersections with the attributes shown in Table 4.2. Rural intersections with stop control on the minor approaches and either point, partial, full lighting or no lighting were selected. Intersections were chosen that were located on either US or Minnesota trunk highways. Four intersection categories were included. Initially, the study intended to focus only on right angle, four-approach ("+") intersections. However, it quickly became apparent that a number of lighted intersections with three-approach configurations existed and the impacts of street lighting on crashes at these intersections should also be investigated. A total of 3,622 rural intersections met the criteria shown in Table 4.2 and were used in the analysis. The minimum and maximum values for daily entering volume, posted approach speed and crashes for the cross sectional analysis is shown in Table 4.3. Figure 4.1 illustrates the percentage of intersections by geometry.

**Table 4.2. Intersection attributes**

| Criteria | Attribute |
|---|---|
| Roadway system | USTH[2], MNTH[3] |
| General environment | Rural |
| Intersection description | T, Y, cross (+), cross with skew (X) |
| Traffic control device | Through/stop |
| Lighting | None, point, partial, full[1] |

[1] point = single light;
partial = lights in two quadrants and diagonally across;
full = lights in all four quadrants;
Note: intersections with 3 lights could be included in either the partial or full category
[2] US trunk highways (non-interstate)
[3] Minnesota trunk highways

**Table 4.3. Range of variables included in cross-sectional analysis**

| Attribute | Minimum | Maximum |
|---|---|---|
| DEV | 68 | 35,705 |
| Posted Speed | 15 | 65 |
| Crashes | 0 | 28 |

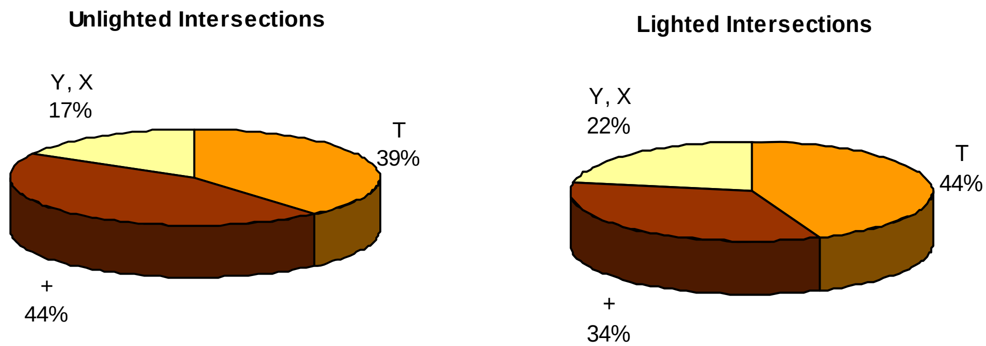


**Figure 4.1. Rural intersections by geometry**

### *4.1.2 Crash Data*

Crash data were provided by Mn/DOT from the Intersection Accident Listing database. Crash data is coded and maintained by the Minnesota Driver Vehicle Services Department database. The crash data are translated into a format suitable for transportation purposes and updated continuously. Crash data are typically accessible within six months. The Intersection Accident Listing contains detailed information about reported crashes as documented on the official accident report. This report contains a reference point field for the location of the crash on the highway system that corresponds with the intersection attribute database.

The Mn/DOT accident database was queried to find crashes during a 3-year analysis period (2000–2002) for both the lighted and unlighted intersections that corresponded to the intersection database. Crash data with incomplete or ambiguous time data, approximately 1% of both lighted and unlighted crashes, were discarded.

### *4.1.3 Exposure Data*

Volume data were allocated to nighttime and daytime periods so that both daytime and nighttime crash rates could be calculated. Average daily traffic (ADT) was available by approach in the intersection attribute database. Approach ADT was used to calculate daily entering volume (DEV), which reflects the number of vehicles entering an intersection, using Equation 4.1. The average DEV for the unlighted and lighted intersections was approximately 4,500 and 7,500, respectively. Lighted intersections had an average DEV that was 1.7 times higher than unlighted intersections. This difference will likely impact the interpretation of some of the crash measurements.

$$DEV = \frac{(ADT_N + ADT_S + ADT_E + ADT_W)}{2} \tag{4.1}$$

where:

*DEV = Daily entering volume for an intersection*

$ADT_N$ = *ADT from north approach*

$ADT_S$ = *ADT from south approach*

$ADT_E$ = *ADT from east approach*

$ADT_W$ = *ADT from west approach*

An estimate of the quantity of nighttime versus daytime average annual daily traffic (AADT) on the Minnesota highways was also necessary to calculate crash rate by time of day. AADT by hour was obtained from the continuous count data reported in the "2002 Mn/DOT Automatic Traffic Recorder (ATR) Report." AADT by time of day was determined for 6 rural county state aid highways (CSAH) and 20 rural trunk highways. The ATR summary is presented in Appendix D. Sunrise, sunset, and civil twilight (dusk and dawn) hours for St. Cloud, MN were obtained from the U.S. Naval Observatory and used to determine when daytime and nighttime hours by month occurred, as shown in Figure 4.2. St. Cloud was chosen because of its location in central Minnesota and appropriately represents the average day and nighttime hours for the state. AADT volumes were assigned day or night status by month and hour of the day according the allocation in Figure 4.2.

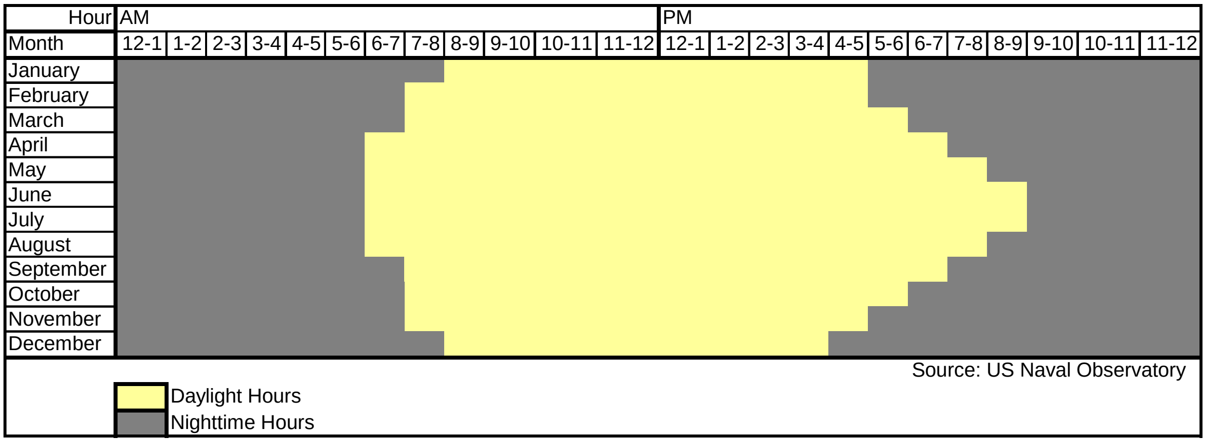


**Figure 4.2. Allocation of daytime and nighttime hours by month for St. Cloud, MN**

The percentage of AADT that occurred by time of day was calculated by dividing the AADT that occurred during nighttime or daytime hours by total AADT for both class of roadway types according to Equations 4.2 and 4.3.

$$\%AADT_{night} = \frac{\sum AADT_{night_i}}{\sum AADT_i} \tag{4.2}$$

where

$\%AADT_{night}$ = Percentage of AADT that occurs during nighttime hours

$AADT_{night_i}$ = Total AADT that occurs during nighttime hours for month $i$

$AADT_i$ = Total AADT for month $i$

$$\%AADT_{day} = \frac{\sum AADT_{day_i}}{\sum AADT_i} \tag{4.3}$$

where:

$\%AADT_{day}$ = Percentage of AADT that occurs during daytime hours

$AADT_{day_i}$ = Total AADT that occurs during daytime hours for month $i$

$AADT_i$ = Total AADT for month $i$

It was determined that an average of 23% of the AADT occurs at night and 77% of AADT occurs during the day. The same percentages were found for both rural CSAHs and trunk highways. Twilight periods were included in the nighttime hours because it was assumed that visibility may be affected during these hours immediately before sunrise and after sunset, and thus are better represented in the nighttime category. This was different than the original LRRB study, in which dusk and dawn crashes were omitted from the study.

## 4.2 Summary Statistics

The comparative analysis was performed using the Mn/DOT intersection attribute database of rural intersections, which were divided into two groups, lighted and unlighted intersections. Day and nighttime crash histories (2000–2002) were evaluated and descriptive statistics were used to summarize the crash experience by the following measurements:

1. Crash frequency
2. Ratio of night to day and total crashes
3. Crash rate

Additionally, crash severity (i.e. resulting degree of injury), type of collision, number of vehicles involved in the crashes and number of crashes by intersection geometry were also quantified.

### *4.2.1 Crash Frequency*

A total of 6,729 crashes were reported at the 3,622 rural intersections over the 3-year analysis period. Crashes were allocated to either the daytime or nighttime category. Nighttime and daytime hours by month were shown in Figure 4.2 above. A total of 63% of the crashes occurred during the daytime and 37% of the crashes occurred at night. Table 4.4 summarizes the crash frequency data.

**Table 4.4. Crash frequency by type of intersection**

| 2000–2002 Crash data | Unlighted intersections | Lighted intersections | Total |
|---|---|---|---|
| Number of intersections | 3,399 | 223 | 3,622 |
| Day crashes | 3,678 | 569 | 4,247 |
| Night crashes | 2,241 | 241 | 2,482 |
| Total crashes | 5,919 | 810 | 6,729 |
| Day crashes/intersection/year | 0.36 | 0.85 | |
| Night crashes/intersection/year | 0.22 | 0.36 | |
| Total crashes/intersection/year | 0.58 | 1.21 | |

From Table 4.4, it can be seen that a total of 0.58 crashes/year occur at unlighted intersections compared to 1.21 crashes/year at lighted intersections. Therefore, lighted intersections have twice as many overall crashes and 1.6 times more nighttime crashes. Crash frequency does not consider exposure and that lighted intersections are more likely to have higher volumes than unlighted intersections. Additionally, locations where lighting is installed may already be high crash locations where lighting was installed as a corrective measure. To account for these considerations, a number of studies use the ratio of night to total crashes or night to day crashes as the metric to evaluate the impact of lighting. The ratio of both the night to total and night to day crash ratios are less at lighted intersections. As shown in Table 4.5, the nighttime to total crash ratio is 0.38 at unlighted intersections compared to 0.30 at lighted intersections, or 37% higher for unlighted intersections. The ratio of night to day crashes is 0.42 at lighted intersections and 0.61 at unlighted intersections.

**Table 4.5. Crash ratios**

| 2000–2002 Crash data | Unlighted intersections | Lighted intersections |
|---|---|---|
| Night/total crash ratio | 0.38 | 0.30 |
| Night/day crash ratio | 0.61 | 0.42 |

### *4.2.2 Crash Rate*

Crash rate accounts for vehicle exposure and was calculated using Equation 4.4. Intersections with no crashes during the three year analysis period had a crash rate of zero. Intersection crash rate was calculated using the following equation with million entering vehicles (MEV) as the measure of exposure:

$$Crash\ Rate = \frac{(Number\ of\ Crashes)x10^6}{(DEV_i)x(n\ years)x\left(365\ {}^{days}/_{year}\right)} \tag{4.4}$$

where

*Crash Rate = Crashes MEV*

*n = analysis time period in years*

$DEV_i$ *= daily entering vehicles for time period i*

DEV is the total of all vehicles entering the intersection. Nighttime crash rates were calculated using a DEV that reflected nighttime volumes while daytime crashes were calculated using a DEV that reflected daytime volumes. Crash rates are presented in Table 4.6. The nighttime crash rates for both lighted and unlighted intersections were higher than the daytime crash rates. For unlighted intersections, the nighttime crash rate was twice the daytime crash rate. Unlighted intersections showed a nighttime crash rate that was about 3% higher than the daytime rate. This suggests that there was not much difference in nighttime crash rates between lighted and unlighted intersections; however, ADT (and therefore DEV) may be strongly correlated to lighting installation and may skew these results, as suggested in the previous section. As discussed, locations where lighting is installed may have already been determined to be a high crash location. Consequently, the ratio of nighttime to daytime crash rate was also compared.

The ratio of nighttime to daytime crash rates for unlighted intersections was 2.03 compared to 1.43 for lighted intersections. This was 42% higher for unlighted intersections. The ratio of night crash rate to total crash rate was also higher at unlighted intersections as compared to lighted intersections (1.64 versus 1.30).

**Table 4.6. Crash rate by time of day by intersection type**

| 2000-2002 Crash data | Unlighted intersections | Lighted intersections |
|---|---|---|
| Day crash rate (crashes/MEV) | 0.29 | 0.40 |
| Night crash rate (crashes/MEV) | 0.59 | 0.57 |
| Ratio of night to day crash rate | 2.03 | 1.43 |
| Total crash rate (crashes/MEV) | 0.36 | 0.44 |
| Ratio of night to total crash rate (crashes/MEV) | 1.64 | 1.30 |

### *4.2.3 Crash Severity*

The severity of crashes for the two groups of intersections was also evaluated. Property damage, personal injury, and fatal crashes were extracted from the data to examine the ratio of personal injury crashes to total crashes for the intersections. Lighted and unlighted intersection crashes reported similar percentages of crashes for each of the three categories, as shown in Table 4.7. Personal injury and fatal crashes accounted for between 35% and 44% of all crashes, regardless of the presence of street lighting or time of day. No significant differences were noted between the severity of daytime and nighttime crashes at unlighted versus lighted intersections.

**Table 4.7. Crash severity by type of intersection**

| 2000–2002 Crash data | Unlighted intersections | | Lighted intersections | |
|---|---|---|---|---|
| | Total crashes | % | Total crashes | % |
| **Night** | | | | |
| Property damage | 1,465 | 65% | 150 | 62% |
| Personal injury[1] | 740 | 33% | 88 | 37% |
| Fatal | 36 | 2% | 3 | 1% |
| Personal injury and fatal crashes/total night crashes | 35% | | 38% | |
| **Day** | | | | |
| Property damage | 2,055 | 56% | 326 | 57% |
| Personal injury[1] | 1,547 | 42% | 230 | 40% |
| Fatal | 76 | 2% | 13 | 2% |
| Personal injury and fatal crashes/total day crashes | 44% | | 43% | |

[1] Includes A – Incapacitating, B – Non-incapacity, C – Possible

### *4.2.4 Crash Types*

Various collision types were reviewed for the intersections and are presented in Table 4.8. The three most frequent collision types for the intersections evaluated were run off the road, right angle, and rear end (excluding unknown, other, and not applicable). These three collision types are also the most common crash types overall in Minnesota (State of Minnesota, 2002). Run off the road crashes occurred at night 38% and 85% more than during the day at both unlighted and lighted intersections, respectively. The percentage of nighttime run off the road crashes at unlighted intersections was 70% higher than at lighted intersections (22% versus 13%). The percentage of right angle crashes was higher at lighted intersections during both the night and day by 70% and 24%, respectively. The higher crash experience for turning and stopping vehicles at lighted intersections may be a result of higher vehicle exposure at the intersections. Rear end crashes occur two times more often during the day than at night and the most frequent type of collision occurring during the day is the right angle crash for both lighted and unlighted intersections.

**Table 4.8. Most frequent collision types**

| 2000 – 2002 Crash data | Unlighted intersections | | Lighted intersections | |
|---|---|---|---|---|
| | Total crashes | % | Total crashes | % |
| **Night** | | | | |
| Run off the road | 500 | 22% | 31 | 13% |
| Right angle | 436 | 19% | 76 | 32% |
| Rear end | 198 | 9% | 28 | 12% |
| **Day** | | | | |
| Run off the road | 586 | 16% | 39 | 7% |
| Right angle | 1,223 | 33% | 235 | 41% |
| Rear end | 718 | 20% | 112 | 20% |

Multiple and single vehicle crashes were also compared, as shown in Table 4.9. Single vehicle crashes were more common at night compared to the day. They occurred 50% more at night and 2 times more during the day for unlighted intersections compared to lighted intersections. The single vehicle crash rates during nighttime hours were also higher for unlighted intersections at 0.37 crashes/MEV. The data shows that the crash rate for multiple vehicle crashes during the day was 3 times higher than single vehicle crashes for unlighted intersections and over 7 times higher at lighted intersections.

**Table 4.9. Single and multiple vehicle crashes**

| 2000–2002 Crash data | Unlighted intersections | | | Lighted intersections | | |
|---|---|---|---|---|---|---|
| | **Total crashes** | **%** | **Crash rate** | **Total crashes** | **%** | **Crash rate** |
| **Night** | | | | | | |
| Single vehicle | 1,400 | 62% | 0.37 | 100 | 41% | 0.24 |
| Multiple vehicle | 841 | 38% | 0.22 | 141 | 59% | 0.33 |
| **Day** | | | | | | |
| Single vehicle | 944 | 26% | 0.07 | 73 | 13% | 0.05 |
| Multiple vehicle | 2,734 | 74% | 0.21 | 496 | 87% | 0.35 |

### *4.2.5 Effect of Intersection Geometry*

Table 4.10 shows the breakdown of crashes and crash rate (per MEV) by intersection geometry. Approximately 60% of all crashes occurred at four-approach intersections. Intersections that cross at right angles (+) have 10% more crashes at unlighted intersections than lighted intersections and crashes at T intersections occur 8% more at night than during the day. Figure 4.3 shows the average DEV by intersection type. T and + lighted intersections have 1.6 and 2.1 times more DEV than their unlighted counterparts, respectively. When comparing all intersection geometries, it was found that right-angle, four-approach, unlighted intersections have the highest crash rate during the daytime and nighttime. Skewed four-approach intersections had the highest crash rate for lighted intersections.

**Table 4.10. Crashes by intersection geometry**

| 2000–2002 Crash data | Unlighted intersections | | | Lighted intersections | | |
|---|---|---|---|---|---|---|
| **Intersection type** | **Total crashes** | **%** | **Crash rate** | **Total crashes** | **%** | **Crash rate** |
| **Night** | | | | | | |
| "T" | 893 | 40% | 0.52 | 100 | 41% | 0.51 |
| "+" | 914 | 41% | 0.67 | 72 | 30% | 0.49 |
| "Y" | 161 | 7% | 0.62 | 7 | 3% | 0.42 |
| "X" | 273 | 12% | 0.57 | 62 | 26% | 0.96 |
| **Day** | | | | | | |
| "T" | 1,186 | 32% | 0.21 | 186 | 33% | 0.28 |
| "+" | 1,753 | 48% | 0.38 | 208 | 36% | 0.42 |
| "Y" | 218 | 6% | 0.25 | 18 | 3% | 0.33 |
| "X" | 521 | 14% | 0.32 | 157 | 28% | 0.73 |

Regardless of geometry, the ratio of night to total crashes and the ratio of night to day crashes were higher for unlighted intersections. These results are presented in Table 4.11. The night to total crash ratios are at least 17% higher for unlighted intersections than lighted intersections. Four-approach unlighted intersections have a lower ratio of night to total crashes than three-approach intersections. This suggests that three-legged intersections have a higher crash experience and may be the reason almost half of the lighted intersections have three-approaches. Lighted T intersections have between 25% and 35% higher night to total crash ratios than the other three intersection configurations.

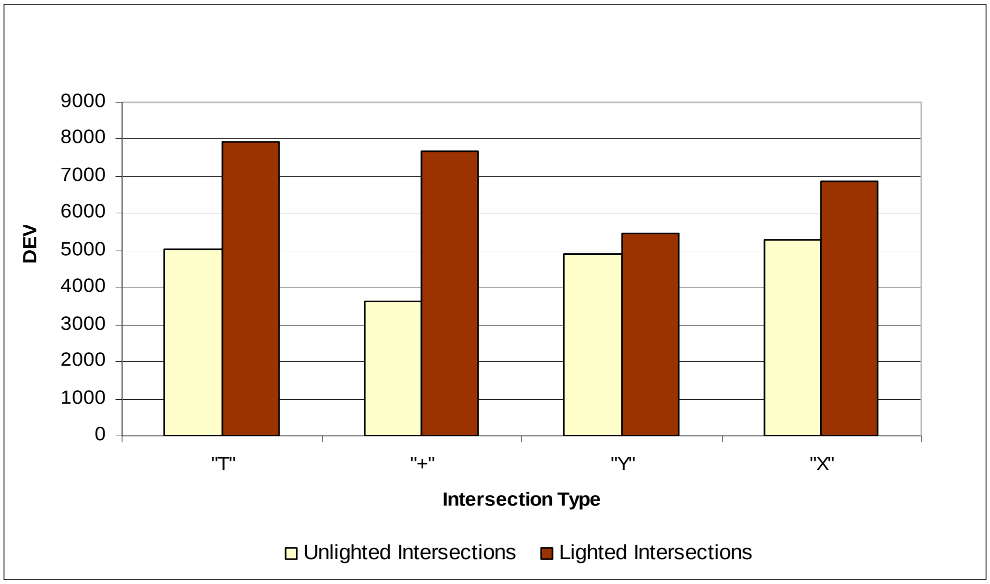


**Figure 4.3. Average DEV by intersection geometry**

**Table 4.11. Crash ratios by intersection geometry**

| 2000–2002 Crash data | Unlighted intersections | Lighted intersections |
|---|---|---|
| **Ratio of night to total crashes** | | |
| "T" | 0.43 | 0.35 |
| "+" | 0.34 | 0.26 |
| "Y" | 0.42 | 0.28 |
| "X" | 0.34 | 0.28 |
| **Ratio of night to day crashes** | | |
| "T" | 0.75 | 0.54 |
| "+" | 0.52 | 0.35 |
| "Y" | 0.74 | 0.39 |
| "X" | 0.52 | 0.39 |

## 4.3 Statistical Analysis

A linear regression model was used to model the ratio of night to total crashes and a Poisson regression model was used to model the night crash rate. A detailed description of the statistical models and their appropriateness in crash modeling is provided in Appendix E. SAS 9.1, a statistical software package, was used to run the statistical analyses.

The linear regression model was used to compare the means for the ratio of night to total crashes and the Poisson regression model was used to compare the mean crash rates. Both statistical models used a 10% level of significance for the analysis. This implies that there was a 90% probability that the differences found in the means were actual differences and there was only a 10% probability that the differences were arbitrary.

### *4.3.1 Variables*

The response variables were crash rate and ratio of night to total crashes for the Poisson regression and the linear regression, respectively. The explanatory variables used to compare the lighted and unlighted intersections include lighting, DEV, number of approach legs, and posted speed limit. Table 4.12 shows these variables and values for the models. Except for DEV, all variables are dummy variables, meaning there are only two possible answers (0 or 1). A “1” indicates the condition existed (i.e. lighted) and a “0” indicates that the condition did not exist.

**Table 4.12. Comparative model parameters tested**

| Variables | Definition | Values |
|---|---|---|
| Response variables | Ratio of night to total Crashes (linear) | Predicted |
| | Crash rate (Poisson) | Predicted |
| Explanatory variables | Lighting | 0–unlighted<br>1–lighted |
| | Daily entering volume | Value |
| | Number of approach legs | 0–Four<br>1–Three |
| | Posted speed limit[1] | 0 - = 55 mph<br>1 - < 55 mph |

[1] The speed limit parameter for = 55 mph implies that all legs are posted at 55 mph and < 55 mph implies that at least one leg has a posted speed limit of less than 55mph.

### *4.3.2 Linear Regression Model*

A linear regression model compared the means for the ratio of night to total crashes. All of the explanatory variables were considered in the linear model. The best fit model showed that lighting, daily entering volume, and number of approach legs were statistically significant at the 10% significance level. However, posted speed limit was not significant. The level of significance is presented in Table 4.13. The expected night to total crash ratio was 7% higher at unlighted intersections than at lighted intersections, when all other variables were constant. Four-approach intersections have a 4% lower night to total crash ratio than three-approach intersections. This implies that three-legged intersections have a higher percentage of night crashes than four-legged intersections at the 10% significance level, when all other variables are equal. The best fit model is presented in Appendix F.

**Table 4.13. Statistical significance of explanatory variables**

| Explanatory variables | Level of significance (p-value) |
|---|---|
| Lighting | 0.005 |
| DEV (night) | < 0.001 |
| Number of approach legs | 0.002 |

#### *4.3.3 Poisson Regression Model*

A Poisson regression model was used to compare the mean crash rates at lighted and unlighted intersections to determine statistical significance. This was not unexpected because the mean night crash rates were very similar (0.59/MEV and 0.57MEV). The best fit model, however, includes all the variables and each was statistically significant at the 10% level of significance. Table 4.14 summarizes the level of significance for each variable. Consequently, the Poisson regression model suggests that night crash rates at unlighted intersections was 11% lower than lighted intersections, when posted speed and number of approach legs are constant. The difference between the night crash rate at lighted and unlighted intersections, however, was quite small to begin with. Intersections with all posted approach speeds equal to 55 mph have crash rates 43% higher than approaches with at least one leg less than 55 mph. Lastly, intersections with four-approaches have crash rates 17% higher than three-approach intersections.

**Table 4.14. Statistical significance of explanatory variables for night crash rate in the comparative model**

| Explanatory variables | Level of significance (p-value) |
|---|---|
| Lighting | 0.094 |
| Posted Speed | < 0.001 |
| Number of approach legs | < 0.001 |

The difference in the day crash rate for lighted and unlighted intersections was statistically significant at the 10% level, as was the total crash rate. Day crash rate was 33% lower at unlighted intersections holding all other variables constant (posted speed and number of approach legs). The levels of significance are presented in Table 4.15. The significant differences for both however, showed a higher crash rate at lighted intersections. Based on the descriptive statistics, these results were anticipated. The day and total crash rate models also showed that posted speed and number of approach legs were significant to the daytime crash rate. The SAS output is shown in Appendix G.

**Table 4.15. Statistical significance of crash rate between lighted and unlighted intersections**

| Dependent variable | Level of significance (p-value) |
|---|---|
| Night crash rate | 0.5678 |
| Day crash rate | < 0.001 |
| Total crash rate | < 0.001 |

### 4.4 Summary of Comparative Analysis

The comparative analysis evaluated 3,622 rural intersections on the Minnesota trunk highway system, which included 3,399 unlighted intersections and 223 lighted intersections. Using ATR data from rural highways and allocation of daytime and nighttime hours, it was determined that approximately 23% of the vehicle miles traveled occur at night. 6,729 crashes were reported at these intersections with 37% occurring during hours of darkness.

Unlighted intersections average about 0.6 crashes per year and 0.2 nighttime crashes per year overall, which was about 40% to 50% less than the average crash per lighted intersection. While lighted intersections experience more crashes per intersection than unlighted intersections, the average DEV at lighted intersections was almost 70% higher. This may suggest that lighted intersections experience more crashes than unlighted intersection because street lighting is being installed as a safety device at high crash intersections with higher volumes.

The assessment of night to total crash ratio for lighted and unlighted intersections shows that the presence of lighting reduces nighttime crashes. Unlighted intersections were reported to have a night to total crash ratio of 0.38 which was 27% higher than lighted intersections. The nighttime crash rate for lighted intersections was 0.57/MEV which was only 3% lower than unlighted intersections and may not be a good measurement because the higher volumes may be highly correlated to the presence of lighting. Unlighted intersections have a nighttime crash rate 2 times the daytime crash rate compared to 1.4 times higher at lighted intersections. Although a large difference in night crash rates was not evident between the lighted and unlighted intersections, the difference between day and night crash rates was substantial.

A linear regression model compared the means for the ratio of night to total crashes. The best fit model showed that lighting, DEV, and number of approach legs were statistically significant at the 10% significance level. The expected night to total crash ratio was 7% higher at unlighted intersections than at lighted intersections holding all other variables constant. Four-approach intersections have a 4% lower night to total crash ratio than three-approach intersections.

A Poisson regression model was used to model night crash rate. When the night crash rate was modeled with lighting, posted speed, and number of approach legs, all three variables were statistically significant. The expected night crash rate at unlighted intersections was 11% lower than lighted intersections. The difference between the night crash rate at lighted versus unlighted intersections, however, was quite small to begin with. Intersections with all posted approach speeds equal to 55 mph have crash rates 43% higher than approaches with at least one leg less than 55 mph. Intersections with four-approaches have crash rates 17% higher than three-approach intersections. This implies that lighting may be more beneficial at intersections with 55 mph posted approach speeds and at four-approach intersections.

The ratio of night to day crashes was determined by the linear regression model to be lower at lighted intersections. This suggests that for the comparative analysis, locations that already had safety problems were more likely to have lighting installed. Consequently, crashes overall are already higher at those locations. The relevant difference appears to be in the ratio of night to total crashes which was lower at lighted intersections. Additionally, it was not known if significant other differences between the much smaller sample set of lighted intersections and unlighted intersections existed.

## 5. BEFORE-AND-AFTER ANALYSIS

A before-and-after study was conducted in addition to the comparative analysis described in the previous section. The comparative analysis evaluated nighttime and daytime crashes at lighted and unlighted rural intersections statewide using the Mn/DOT intersection attribute database of rural intersections. The results provided an overall general trend in the crash data for the state. On a more detailed level, the before-and-after study looked at individual isolated rural intersections to compare the nighttime crash history before and after installation of roadway lighting. A survey of counties provided locations for many of the intersections while the remainder of the data came from site visits and the intersection and crash databases. The data collection, methodology, and results for the before-and-after study are presented in the following sections.

Data were analyzed by simple comparison of data, presented in Section 5.5. A statistical model was also developed to test the statistical significance between variables and is presented in Section 5.6.

### 5.1 Survey

A list of lighted intersections for the before-and-after study was solicited from all 87 Minnesota county engineers through an electronic survey in January 2004. A copy of the survey is provided in Appendix H. County engineers were asked to complete the survey by listing the number of lighted isolated rural intersections maintained within their county and provide details about each of these intersections, as well as other attributes which included:

- Number of lights
- Type of stop control
- Posted Speed limit
- Type of facility
- Lighting installation dates (before or after 1990)
- Other significant improvements made at the intersection
- Pavement structure
- Presence of turn lanes

- Configuration (T, Y, X, ＋)

The survey also requested information regarding the source of funding, warrants, number of lights per intersection, type of luminaries and wattage, and typical cost for installation. Responses are provided in Appendix I.

Of the counties surveyed, 35 (40%) returned the surveys via mail or email. Counties that did not respond by the survey deadline were called for a phone interview, which raised the total number of participating counties to 66 counties (76%). In some cases, counties responded, but did not have lighted intersections to report. The survey resulted in identifying an estimated 80 lighted intersections that could be considered for the before-and-after study. An inventory of the counties and the number of lighted intersections is included in Appendix J.

### 5.2 Initial Study Locations

Site visits were made to the majority of the 80 intersections and additional characteristics were recorded, including adjacent land use, proximity to horizontal and vertical curves, type of light poles and advanced warning devices. The site visits were conducted from March to June 2004. Several other lighted intersections were identified during the site visits and were added to the list of initial locations. Intersections that were not visited in the field were viewed using 1992 aerial photography in ArcView and details were extracted from the Intersection Accident Listing or discussed in more detail with the county engineer if selected for consideration. A list of initial intersection locations is provided in Appendix K. The survey and additional locations identified during the site visits resulted in a total of 90 intersections located in 25 counties throughout Minnesota that could potentially be used for the before-and-after analysis.

### 5.3 Selection of Final Study Intersections

Originally, the study team and advisory committee decided that intersections that were as similar as possible should be selected for the before-and-after study. One of the preliminary criteria was to include only intersections with four approaches at right angles (＋). However, after reviewing the initial list of 90 possible intersections, it became evident that three-approach intersections (T or Y) made up a large percentage of the lighted intersections. Consequently, it was determined that the study should be representative of the common types of intersections that were lighted in

Minnesota, and both three and four-approach intersections were included. The 90 intersections were evaluated and intersections with significant differences, which would possibly skew the study, were removed from the list for the before-and-after analysis. Intersections determined to be atypical were removed if any of the following conditions existed:

- Flashing warning lights
- Gas station or other land uses in the immediate vicinity of the intersection that would attract vehicle trips
- Intersection not included in the attribute files
- Severe skew angle
- Railroad crossing within 20 feet of intersection
- Street light not installed at time of field visit

Using these criteria, the number of intersections was narrowed down to 65 intersections in 22 counties. These intersections were determined to be quality candidates for the before-and-after study. At this point, all of the counties were contacted again to clarify any information that may have been omitted from the original survey and establish the installation dates of the street lighting at each intersection. The knowledge of the installation dates varied widely from county to county. In several cases, the study team had to contact the townships and local utility companies to obtain this information. From this correspondence, 16 more intersections were eliminated for the following reasons:

- Located on a new alignment
- Installation dates were not known and could not be determined
- Lighting was installed prior to 1986, when reliable crash data was not available
- Other significant improvements to the intersection had been made in addition to lighting

The final list was reduced to 49 intersections in 18 counties and was comprised of lighted intersections that have installation dates ranging from 1985 to 2003. A map of the counties included in the study is shown in Figure 5.1. Over half of the lighting installation dates recorded included the month and year, which provided for a more accurate method of excluding crash data in the period immediately after the installation. This process will be discussed in more detail in

Section 5.4.2.1. Table 5.1 shows the breakdown of the intersections by installation date. A majority of the lights were installed between 1990 and 1994 and more recently, in 2003.

**Table 5.1. Number of intersections by year of street light installation**

| Year | Number |
|---|---|
| 2003 | 11 |
| 2002 | 2 |
| 2001 | 2 |
| 2000 | 2 |
| 1995–1999 | 7 |
| 1990–1994 | 19 |
| 1986–1989 | 3 |
| 1985 | 3 |

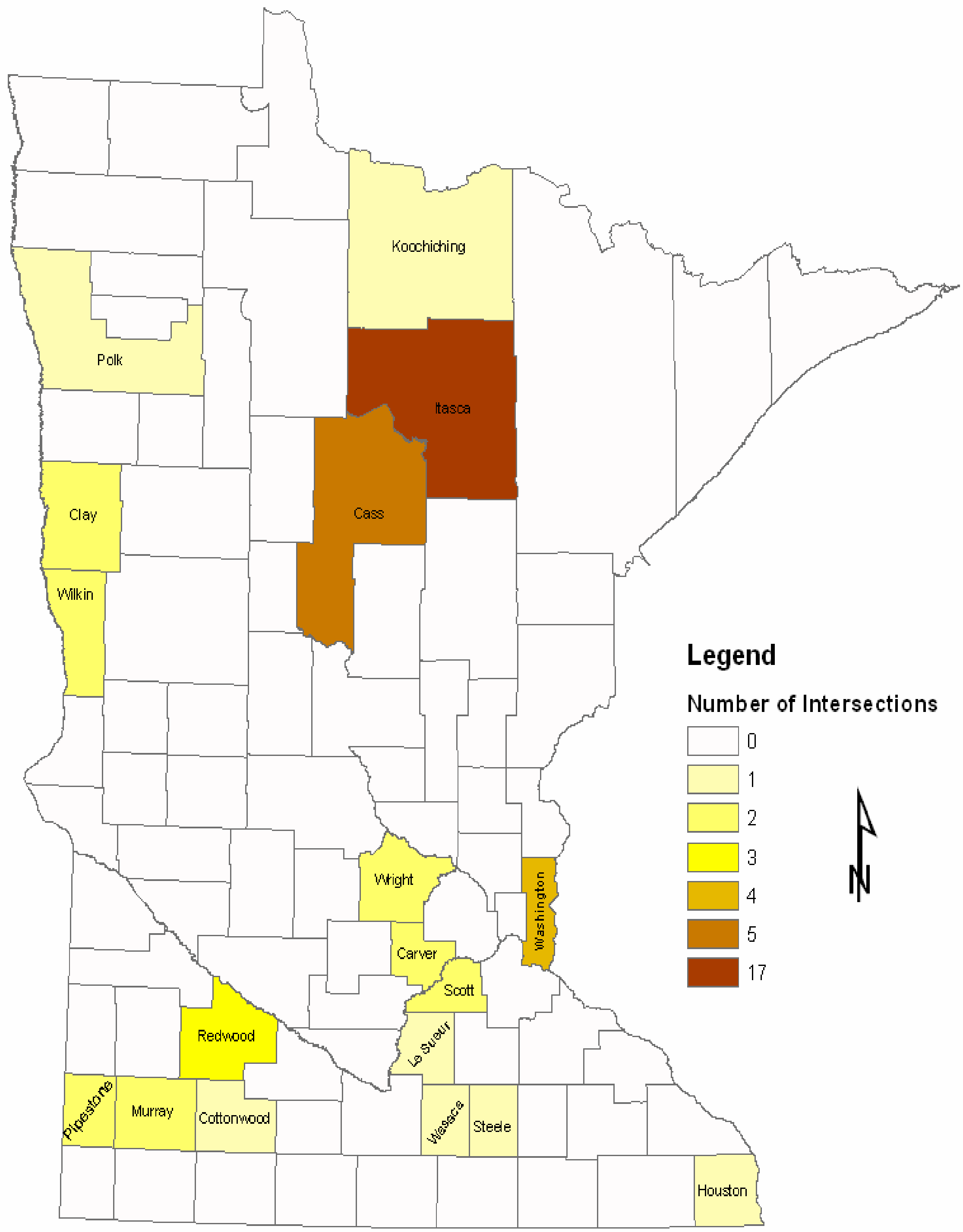


**Figure 5.1. Counties with intersections included in before-and-after study**

## 5.4 Data

### *5.4.1 Intersection Attributes*

The intersection attribute database for the county highway system is not as comprehensive as the state highway intersection database that was used in the comparative analysis. Therefore, attribute data for the before-and-after study was obtained from four sources; county surveys, site visits, the Mn/DOT Intersection Attribute File, and a county intersection attribute file obtained from Mn/DOT specifically for the counties included in this study.

The final 49 intersections have major routes that are split fairly even between the county and state highway system. A total of 26 intersections have the county highway system as the major route and 23 have the state trunk highway system as the major route. Approximately 45% of the intersections had 3 approaches, either a T or Y configuration. Table 5.2 summarizes the intersections described above and a detailed list of the final intersections, including images of some locations, is provided in Appendix L. The minimum and maximum values for daily entering volume, posted approach speed, and crashes for the before-and-after analysis are shown in Table 5.3.

**Table 5.2. Summary of final intersections by approach legs**

| Intersection | Number | Site visit | County intersections | State intersections |
|---|---|---|---|---|
| 4 legs | 27 | 26 | 16 | 11 |
| 3 legs | 22 | 18 | 10 | 12 |
| Total | 49 | 44 | 26 | 23 |

**Table 5.3. Range of variables included in before-and-after analysis**

| Attribute | Minimum | Maximum |
|---|---|---|
| DEV | 846 | 13,900 |
| Posted Speed | 30 | 55 |
| Crashes | 0 | 11 |

### *5.4.2 Crash Data*

The Minnesota crash database has comprehensive records for both state and county intersections dating back to the early 1980s. An inventory of crashes from 1984 to 2003 (updates will occur in 2004 and 2005) was obtained from the Mn/DOT for each of the 49 intersections. Crash data prior to 1984 were not available. Mn/DOT felt that crash data prior to 1984 was not reliable. These records were queried to include only those crashes that occurred within 300 feet of the intersection, which were assumed to be intersection related for this analysis.

Three intersections were installed in 1985 and consequently, only 2 years of before data for these intersections were available. For the rest of the intersections, three years of before data were available. State highway crash records included 2003 data, while the county crash data included crashes through 2002. This allows for 3 years of after data for the final list, where lighting had been installed prior to 2000 for the county intersections and 2001 for the state intersections. Consequently, a total of 15 intersections will have an after period less than 3 years. Updates to the Mn/DOT report will occur using 2003, 2004, and 2005 crash data and will extend the analysis period to 3 years after installation of lighting for 34 intersections. The remaining 15 intersections can be updated in the following years, if desired. A list of intersections and number of crashes in the before-and-after periods for the 2004 analysis is in Appendix M.

### *5.4.3 Analysis Periods*

In order to increase the intersection sample size, crash data for the before period consisted of both 2- and 3-year periods prior to installation of the lighting, as discussed in the previous section. To account for this variation, the analysis equations were weighted. An adjustment period was also allowed for the first year after installation and therefore it was not included in the analysis. The year omitted may differ from the installation year depending on the month the lighting was installed. For example, if a light was installed in December of 2000, the year omitted from the study would be 2001.

Table 5.4 shows the number of intersections that will be analyzed in each of the three analysis years included in this study and Table 5.5 shows the number of intersections by installation year and analysis installation year. The analysis installation year is the year excluded from the study.

**Table 5.4. Intersections for before-and-after by analysis year**

| Analysis | 2004 | 2005 | 2006 |
|---|---|---|---|
| 3 years before/3 years after | 29 | 31 | 34 |
| 3 years before/2 years after | 2 | 3 | 11 |
| 2 years before/3 years after | 3 | 3 | 3 |
| 3 years before/1 year after | 0 | 11 | 1 |

**Table 5.5. Street light installation years for analysis**

| Year of installation | Number | Analysis year of installation | Number |
|---|---|---|---|
| 2004 | 0 | 2004 | 1 |
| 2003 | 11 | 2003 | 11 |
| 2002 | 2 | 2002 | 3 |
| 2001 | 2 | 2001 | 0 |
| 2000 | 2 | 2000 | 3 |
| 1995–1999 | 7 | 1995–1999 | 9 |
| 1990–1994 | 19 | 1990–1994 | 16 |
| 1986–1989 | 3 | 1987–1989 | 3 |
| 1985 | 3 | 1986 | 3 |

### *5.4.3 Historic AADT Counts*

The Mn/DOT records traffic volumes for state roadways on a two year cycle and county roads on a four year cycle. An inventory of historic counts is maintained by the Mn/DOT Office of State Aid. Historic ADT counts for the final list of intersections were obtained from the Mn/DOT Office of State Aid for the appropriate before-and-after analysis periods. In most cases, four traffic counts over a 16-year period were documented. Not all roads have recorded ADTs. Typically, these represent low volume county and local roadways where the volumes are low and are likely not fluctuating significantly. Volume estimates for the low volume road approaches were assigned values of 100 to 200 ADT unless field observations suggested otherwise.

In order to estimate traffic volume in the analysis year, historic ADT volumes were plotted to create a trend line and the analysis year ADT was interpolated from the trend line and a growth factor was applied for the before and after periods. The method used to interpolate ADT is provided in Appendix N. Once all approaches were assigned an average volume for the before and after periods, the DEV was calculated using the Equation 4.1, which was described in Section 4. Nighttime DEV was also determined for each intersection using the same method described in Section 4.1.3 to calculate nighttime ADT and subsequently nighttime DEV for the comparative analysis.

Table 5.6 summarizes the vehicle exposure for the final intersections. The average intersection vehicle exposure increased for both county and state roadways between the before-and-after periods by approximately 2–3% per year. The increase between periods was 23% for the county intersections, 9% the state intersections, and 15% for all intersections. Hereafter, “all intersections” refers to both county and state intersections combined. One county intersection had an increase in volume of almost 60% between the before and after period which increased the total county intersection volume by 8%. Furthermore, three-approach intersections have an average of 10% less DEV than four-approach intersections. The average DEVs are approximately 3,700 and 4,100 for three-approach and four-approach intersections, respectively.

**Table 5.6. Average exposure data (DEV)**

| Before-and-after crash data | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| Number of intersections | 15 | | 19 | | 34 | |
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Day exposure | 36,386 | 44,762 | 61,907 | 67,930 | 95,198 | 109,295 |
| Night exposure | 10,869 | 13,371 | 18,492 | 20,291 | 28,436 | 32,647 |
| Total exposure | 47,255 | 58,133 | 80,399 | 88,221 | 123,634 | 141,942 |
| Day exposure/intersection | 2,426 | 2,984 | 3,258 | 3,575 | 2,800 | 3,215 |
| Night exposure/intersection | 725 | 891 | 973 | 1,068 | 836 | 960 |
| Total exposure/intersection | 3,151 | 3,875 | 4,231 | 4,643 | 3,636 | 4,175 |

## 5.5 Descriptive Statistics

Descriptive statistics were used to summarize the crashes in the before and after periods for the study intersections. Similar to the comparative analysis, the following measurements were used to evaluate both nighttime and daytime crashes before and after the installation of street lighting:

1. Crash frequency
2. Ratio of night to day and total crashes
3. Crash rate

Other measures of effectiveness include crash severity, crash types (i.e. collision type and number of vehicles), and type of intersection configuration.

### *5.5.1 Crash Frequency*

The trend for both the county and state highway intersections showed a decrease in the total number of night crashes after street lighting was installed. Figure 5.2 and Table 5.7 show a summary of the crash frequency by roadway and time of day. Reductions in night crash frequency for the county and state intersections were 20% and 30%, respectively, with an overall decrease of 27%. The reduction in crashes was consistent with the original LRRB study that concluded a 25–40% reduction for 12 rural intersections; however, the sample size for this study was almost 3 times larger, which increases confidence in the results. Box plots of the crashes by period are shown in Appendix O.

**Table 5.7. Crash frequency by roadway type**

| **Before-and-after crash data** | **County intersections** | | **State intersections** | | **All intersections** | |
|---|---|---|---|---|---|---|
| Number of intersections | 15 | | 19 | | 34 | |
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Day crashes | 14 | 21 | 16 | 24 | 30 | 45 |
| Night crashes | 10 | 8 | 24 | 17 | 34 | 25 |
| Total crashes | 24 | 29 | 40 | 41 | 64 | 70 |
| % Day crashes | 58% | 72% | 40% | 58% | 47% | 64% |
| Day crashes/intersection/year | 0.33 | 0.47 | 0.28 | 0.42 | 0.30 | 0.44 |
| Night crashes/intersection/year | 0.24 | 0.19 | 0.42 | 0.30 | 0.34 | 0.25 |
| Total crashes/intersection/year | 0.58 | 0.66 | 0.70 | 0.72 | 0.65 | 0.69 |

[1] It should be noted that one county intersection accounted for 9 daytime crashes in the after period, an increase of 7 crashes from the before period.

During the same period, the number of daytime crashes increased by 50%. If an assumption was made that the number of nighttime crashes increased at the same rate as daytime crashes, without the installation of lighting, the expected number of nighttime crashes was calculated using Equation 5.1.

$$Expected\ \ Night\ \ Crashes_{after} = \frac{Day\ Crashes_{after}}{Day\ Crashes_{before}} x\ Night\ \ Crashes_{before} \qquad (5\text{-}1)$$

where:

$Expected\ Night\ Crashes_{after}$ = Total number of nighttime crashes that would have occurred in the after period assuming nighttime crashes increased at the same rate as daytime crashes

$$Day\ Crashes_{after} = Total\ number\ of\ daytime\ crashes\ in\ after\ period$$

$$Day\ Crashes_{before} = Total\ number\ of\ daytime\ crashes\ in\ before\ period$$

$$Night\ Crashes_{before} = Total\ number\ of\ nighttime\ crashes\ in\ before\ period$$

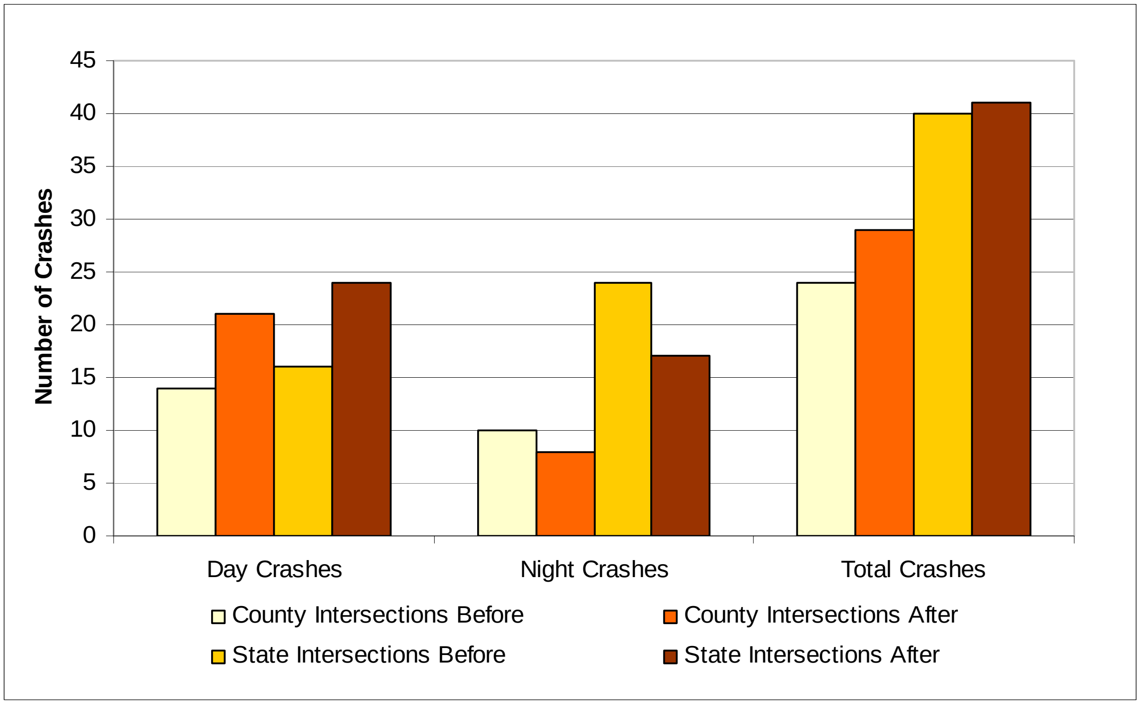


**Figure 5.2. Crash frequency**

Using this equation, the expected crash frequency during the nighttime period was calculated and is provided in Table 5.8 and shown Figure 5.3. As shown, at county highway intersections, the expected number of crashes in the after period, assuming no treatment had been applied, was 15. A total of 8 nighttime crashes were observed after the installation of lighting. For state highway intersections, the expected number of nighttime crashes would have been 36 and a total of 17 nighttime crashes were observed with street lighting present. Therefore, the observed decrease in crash frequencies at night, after lighting was installed, may be more significant because of the increase in the daytime crashes and expected nighttime crashes based on this increase.

**Table 5.8. Increase in nighttime crashes assuming same trend as day crashes if lighting had not been installed**

| Type of intersection | Crash frequency | | |
|---|---|---|---|
| | Before | After (observed) | After (expected) |
| County | 10 | 8 | 15 |
| State | 24 | 17 | 36 |
| All | 34 | 25 | 51 |

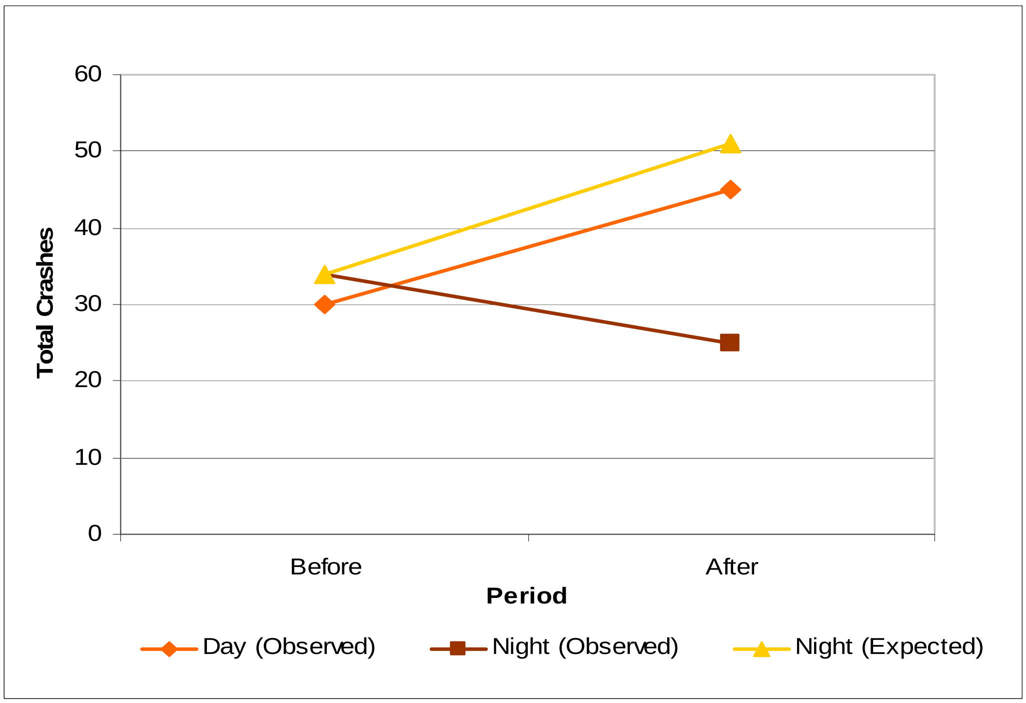


**Figure 5.3. Crashes observed and nighttime crashes expected based on day crash trend**

Considering intersections on an individual basis, 44% of the intersections had a reduction in the number of nighttime crashes and 32% showed no change. Conversely, daytime crashes increased at 47% of the intersections and remained unchanged at 20%. Although the night crashes decreased in the after period, the total crashes increased slightly. This suggests that there may still be a safety problem at some of the intersections or it may be a spike in the crash trend and a longer before and after period could be considered.

The night to total and night to day crash ratios also decreased by approximately 32%, again representing a consistent decline in the number of crashes after lighting was installed. Table 5.9 summarizes the ratios for both roadway types.

**Table 5.9. Crash ratios**

| Before-and-after crash data | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Night/total crashes | 0.42 | 0.28 | 0.60 | 0.42 | 0.53 | 0.36 |
| Night/day crashes | 0.71 | 0.38 | 0.45 | 0.23 | 1.13 | 0.56 |

### *5.5.2 Crash Rate*

The crash rate takes into account the DEV of the intersections, the crash frequency, as well as the analysis period. For the before-and-after study, the analysis period varies for some of the intersections and consequently, the crash rate equation (Equation 4.4) was weighted to account for this variation, as shown in Equation 5.2. The analysis periods include 2 or 3 years in the before condition and 1, 2, or 3 years in the after condition.

$$Crash\ Rate = \frac{\left(\#\ of\ Crashes_i + \#\ of\ Crashes_j + \#\ Crashes_k\right) x * 10^6}{((DEV_{ave} \times n_i\ years) + (DEV_{ave} \times n_j\ years) + (DEV_{ave} \times n_k\ years))\ x\ 365\ \frac{days}{year}} \qquad (5.2)$$

where

$n_{i, j, k}$ = *analysis time period* $_{i, j, k}$

$DEV_{ave}$ = *average daily entering volume for time period* $_{i, j, k}$

Crash rates at night decreased by 35% in the after period for all intersections. Results are presented in Table 5.10. Day crash rates increased in the after period by 30% and the total crash rate decreased by approximately 4%. The ratio of night crash rate to day crash rate decreased by 50% after lighting was installed.

**Table 5.10. Crash rate (crashes/MEV)**

| Before-and-after crash data | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Day crash rate | 0.38 | 0.46 | 0.24 | 0.32 | 0.30 | 0.39 |
| Night crash rate | 0.90 | 0.58 | 1.19 | 0.77 | 1.12 | 0.73 |
| Total crash rate | 0.50 | 0.50 | 0.45 | 0.42 | 0.49 | 0.47 |
| Ratio of night to day crash rate | 2.36 | 1.26 | 4.96 | 2.41 | 3.73 | 1.87 |

### *5.5.3 Crash Severity*

Severity of intersection crashes was also compared for the before-and-after periods. The number of nighttime crashes occurring at county intersections showed a 60% decrease for personal injury and fatal crashes compared to a 33% decline for the state intersections. This was a 41% reduction in personal injury and fatal crashes at night for all intersections. Table 5.11 and Figure 5.4 show these results. The ratio of nighttime personal injury and fatal crashes to total crashes, including property damage, decreased by 20% overall. Property damage crashes occurring at night were reduced by 12%. Personal injury crashes occurring during the day increased in the after period, however the fatal crashes were reduced to zero. Fatal crashes are rare and random events, so results should be used with caution. During daytime hours, all intersections showed an increase of 36% and 62% for property damage only and personal injury crashes, respectively, while the ratio of daytime personal injury and fatal crashes to total crashes, including property damage, also increased slightly from 0.53 to 0.58.

**Table 5.11. Crash severity**

| Before-and-after crash data | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| **Night** | | | | | | |
| Property damage | 5 | 6 | 12 | 9 | 17 | 15 |
| Personal injury[1] | 4 | 2 | 12 | 8 | 16 | 10 |
| Fatal | 1 | 0 | 0 | 0 | 1 | 0 |
| Ratio of personal injury and fatal crashes/total crashes | 0.50 | 0.25 | 0.50 | 0.47 | 0.50 | 0.40 |
| **Day** | | | | | | |
| Property damage | 5 | 8 | 9 | 11 | 14 | 19 |
| Personal injury[1] | 8 | 13 | 6 | 13 | 14 | 26 |
| Fatal | 1 | 0 | 1 | 0 | 2 | 0 |
| Ratio of personal injury and fatal crashes/total crashes | 0.64 | 0.62 | 0.43 | 0.54 | 0.53 | 0.58 |

[1] Includes a – incapacitating, b – non-incapacity, c – possible

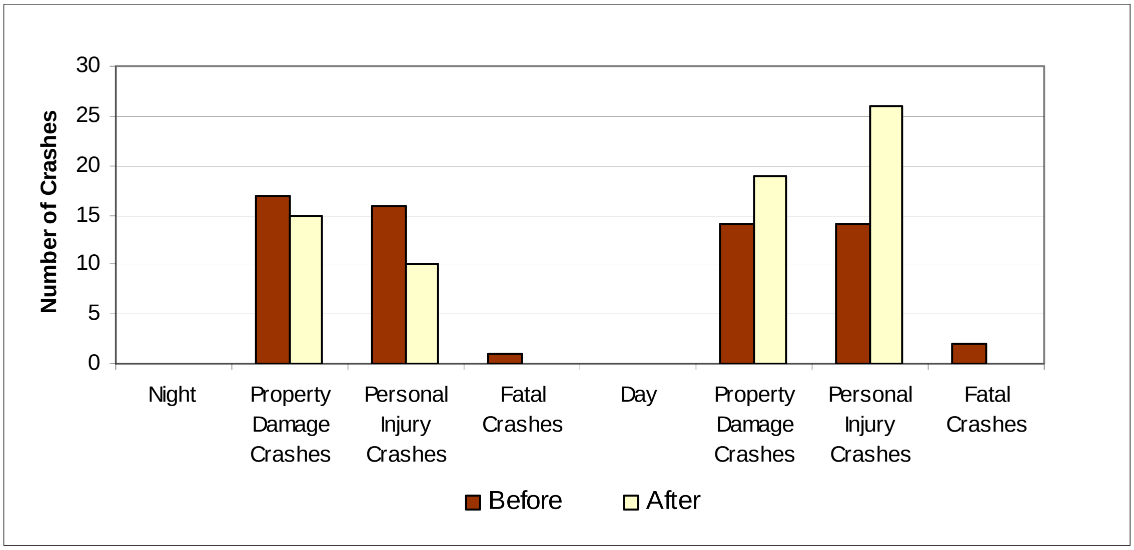


**Figure 5.4. Crash severity for all intersections**

### *5.5.4 Crash Types*

Mn/DOT categorizes crashes into 12 different collision types, as shown in Appendix P. The most frequent crash types for the before-and-after intersections were rear end, right angle, and run off the road. These are the same categories reported for the comparative analysis. Figure 5.5 illustrates the number of night crashes in the five most frequent crash types, excluding other, unknown, and not-applicable. Right angle crashes increased considerably in the after period for both day and night, although most occurred at one county intersection. This was similar to the increase shown in the comparative analysis.

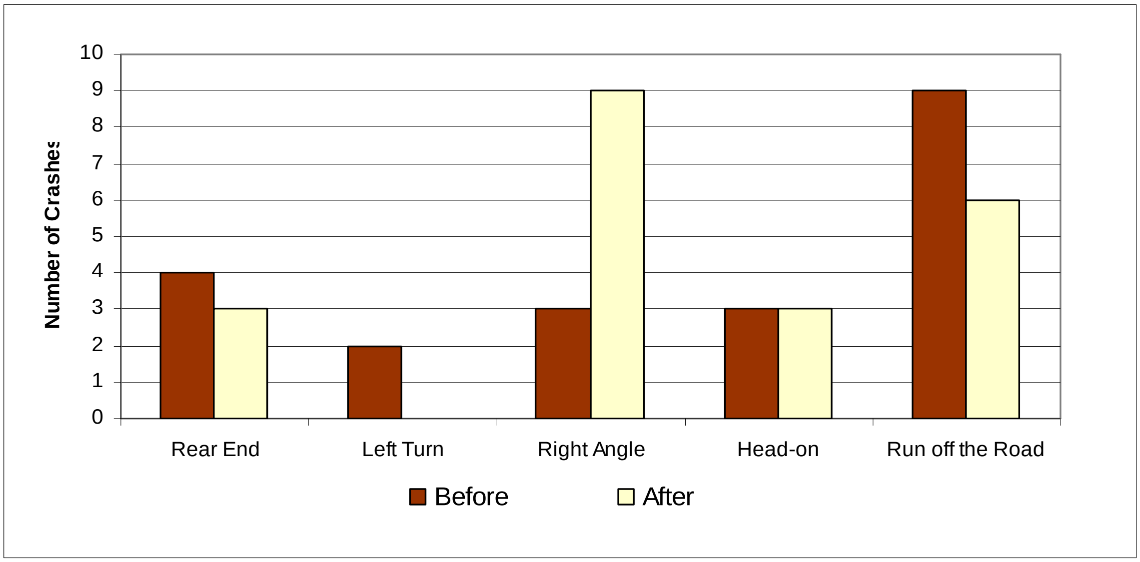


**Figure 5.5. Nighttime collision types for all intersections**

Single vehicle crashes occurring at night were reduced by 44% and multiple vehicle crashes by 11%. The results are presented in Table 5.12. Multiple vehicle crashes accounted for slightly more crashes at night than single vehicle crashes, while almost 80% of the crashes during the day involved multiple vehicles. The single and multiple vehicle crash rates were reduced by 51% and 20%, respectively, and day crash rates for both crash types increased.

**Table 5.12. Single and multiple vehicle crashes**

| Before-and-after crash data | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| **Night** | | | | | | |
| Single vehicle crashes | 4 | 3 | 12 | 6 | 16 | 9 |
| Single vehicle crash rate | 0.36 | 0.22 | 0.59 | 0.27 | 0.53 | 0.26 |
| Multiple vehicle crashes | 6 | 5 | 12 | 11 | 18 | 16 |
| Multiple vehicle crash rate | 0.54 | 0.37 | 0.59 | 0.50 | 0.59 | 0.47 |
| **Day** | | | | | | |
| Single vehicle crashes | 1 | 4 | 2 | 6 | 3 | 10 |
| Single vehicle crash rate | 0.03 | 0.09 | 0.03 | 0.08 | 0.03 | 0.09 |
| Multiple vehicle crashes | 13 | 17 | 14 | 18 | 27 | 35 |
| Multiple vehicle crash rate | 0.35 | 0.37 | 0.21 | 0.24 | 0.27 | 0.30 |

### *5.5.5 Crashes by Intersection Geometry*

For the 2004 analysis, 3-approach T intersections account for 58% and 27% of the total state and county intersections, respectively. Figure 5.6 shows the distribution of all the intersections by geometry. Both T and + intersections show a reduction (37% and 44%) in night crashes after lighting was installed while day crashes increased. Overall, 3-approach intersections (37%) show a greater decrease in the number of night crashes than 4-approach intersections (17%). A higher number of crashes were reported at T intersections at night than during the day in the before period. Table 5.13 reports these results.

**Table 5.13. Before and after crashes by intersection configuration**

| Intersection configuration | County intersections | | State intersections | | All intersections | |
|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After |
| **Night** | | | | | | |
| "T" | 4 | 0 | 12 | 10 | 16 | 10 |
| "+" | 6 | 4 | 12 | 6 | 18 | 10 |
| "Y" | 0 | 0 | 0 | 0 | 0 | 0 |
| "X" | 0 | 4 | 0 | 1 | 0 | 5 |
| **Day** | | | | | | |
| "T" | 2 | 2 | 8 | 16 | 10 | 18 |
| "+" | 10 | 14 | 8 | 7 | 18 | 21 |
| "Y" | 0 | 0 | 0 | 0 | 0 | 0 |
| "X" | 2 | 5 | 0 | 1 | 2 | 6 |

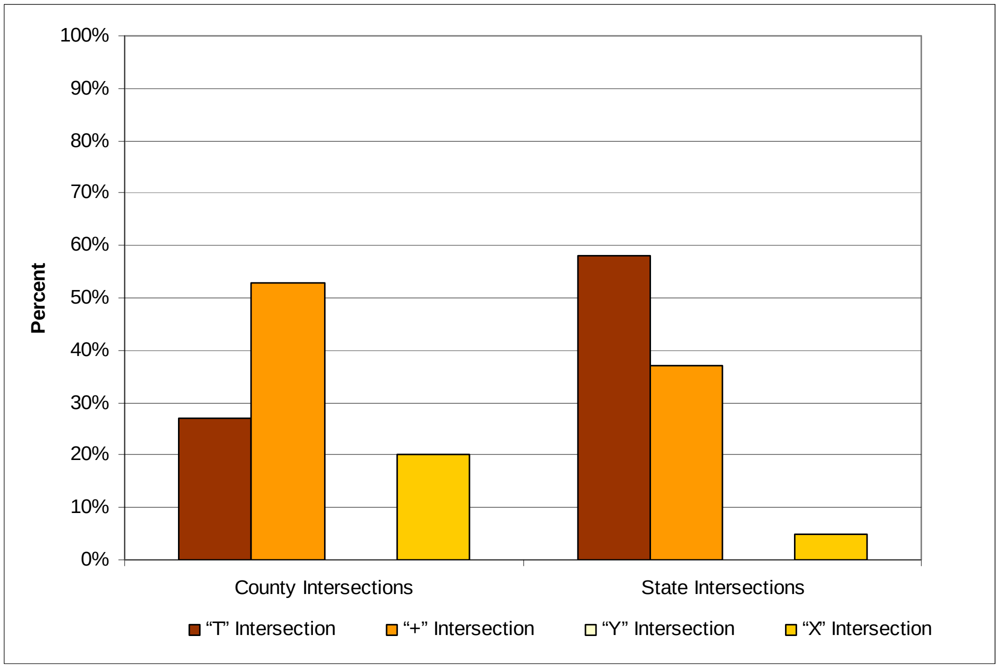


**Figure 5.6. Percentage of intersections by geometry**

## 5.6 Statistical Analysis

Two types of statistical models were used to analyze the crashes to determine statistical significance. A Poisson regression model was used to compare the mean crash rates and a linear regression model was used to model the ratio of night to total crashes. A detailed description of the statistical models and their appropriateness in crash modeling is provided in Appendix E.

### *5.6.1 Methodology*

Differences in mean crash rates and reduction in the night to total crash rate before and after installation of lighting were modeled. Daytime crashes were used as a comparison group. Comparison accidents are used in before-and-after studies to predict what would have occurred had the treatment (in this case lighting) not been applied (Hauer, 1997). An example of this would be as follows: assume a treatment is applied that is expected to reduce crashes and a 7% reduction in crashes is found in the after period. At the same time, the general trend in crash rate goes down by 5% between the before and after period regardless of roadway treatments due to better vehicles, better driver education, etc. It could then be argued that crashes at the treated facility would have gone down by 5% whether or not the treatment had been applied. As a result, the effectiveness of the treatment was actually 2% (7% minus 5%). A comparison group is therefore used to account for the effect of outside phenomenon which cannot be captured in the model.

For this study, daytime crashes for the same intersections were used as the comparison group. Carstens (1984), Wortman (1974), and Green (2003) all used similar comparisons for their data analysis. It was assumed that installation of lighting would not affect daytime crashes and any changes or outside influences at the intersection, beyond the lighting, would be similar for both daytime and nighttime experiences. As a result, if the only safety treatment applied was lighting, daytime crashes should not change significantly from the before period to the after period unless some other factor that was not accounted for was influencing crashes or regression to the mean had occurred. The daytime crash rate was used to evaluate the trend in accidents that may have occurred had lighting not been installed.

A Poisson regression model was used to compare the mean crash rates during the two periods. Linear regression was used to compare the means for the ratio of night to total crashes. Both statistical models used a 10% level of significance for the analysis.

### *5.6.2 Variables*

Similar to the comparative model, the response variables were crash rate and ratio of night to total crashes for the Poisson regression and the linear regression, respectively. The explanatory variables used in the before-and-after model include crashes, DEV, period, number of approach legs, posted speed limit, intersection control, presence of turn lanes, presence of a horizontal or vertical curve and years in period. Table 5.14 shows these variables and values for the models. Except for crashes and DEV, all other variables are dummy variables. Another variable introduced into the equations was the random ID variable which accounts for the fact that each intersection is sampled twice.

**Table 5.14. Before and after model parameters tested**

| Variables | Definition | Values |
|---|---|---|
| **Response variables** | Crash rate (Poisson) | Predicted |
| | Ratio of night to total crashes (mixed linear) | Predicted |
| **Explanatory variables** | Period | 0 – before<br>1 – after |
| | Crashes | Value (0, 1, . . . , n) |
| | Daily entering volume (DEV) | Value |
| | Number of approach legs | 0 – Four<br>1 – Three |
| | Posted Speed limit[1] | 0 - = 55 mph<br>1 - < 55 mph |
| | Intersection control[2] | 0–AWSC<br>1–OWSC/TWSC |
| | Presence of turn lanes | 0–no<br>1–yes |
| | Presence of a curve | 0– no<br>1–yes |
| | Number of years in the period | 1, 2, 3 |
| | Variable to account for the fact that intersections are sampled twice (once in before and once in after period) | 1, 2, . . , n |

[1]The speed limit parameter for = 55 mph implies that all legs are posted at 55 mph and < 55 mph implies that at least one leg has a posted speed limit of less than 55 mph.
[2] AWSC – All Way Stop Control; OWSC – One-way Stop Control; TWSC – Two Way Stop Control

### *5.6.3 Linear Regression Model*

A mixed linear regression model compared the means for the ratio of night to total crashes. The mixed linear model was used rather than a conventional linear model because of the repeated measurements in the before-and-after analysis. In this model, the number of years in the period was weighted to account for the variance associated with periods with unequal years. All of the explanatory variables were considered in the linear model. The best fit model only included period and nighttime DEV, which were both statistically significant at the 10% significance level. The results are presented in Table 5.15 and the SAS output is presented in Appendix Q. The expected ratio of night to total crashes was reduced by 15% in the after period. As shown, the results indicated that the reduction in the ratio of night to total crashes from the before period to the after period is statistically significant.

**Table 5.15. Statistical significance of explanatory variables for ratio of night to total crashes**

| Explanatory Variables | Level of Significance (p-value) |
| --- | --- |
| Period | 0.081 |
| DEV | 0.007 |

### *5.6.4 Poisson Regression Model*

The Poisson regression model compared the mean crash rates during the before-and-after periods to determine statistical significance. The dispersion parameter resulting from the goodness-to-fit test for this model was equal to one, indicating a fit to the Poisson distribution. All of the explanatory variables were considered in the model; however, it was determined that the best fit model included only the variable for period and was statistically significant at the 10% level of significance. This indicated that the only variable that was significant was the difference between the before and after periods. The expected night crash rate in the before period was 54% higher than the after period. Table 5.16 shows the analysis results for night, day, and total crash rates. The reduction in the night crash rate from the before to after period was statistically significant. The expected day crash rate increased by 24% from the before to after period, however, was not statistically significant. The best fit model is shown in the SAS output in Appendix R.

**Table 5.16. Statistical significance of crash rate between periods**

| Dependent variable | Level of significance (p-value) |
|---|---|
| Night crash rate | 0.093 |
| Day crash rate | 0.336 |
| Total crash rate | 0.862 |

### 5.7 Summary of Before-and-After Analysis

The before-and-after analysis evaluated the effects of street lighting on crashes at 34 rural intersections before and after the installation of lighting. All of the descriptive statistic measurements for the before-and-after analysis show a reduction in night crash experience after lighting was installed, while day crash measurements consistently show an increase in the crash experience in the after period at the same intersections.

The frequency of night crashes and number of night crashes per intersection both decreased by 27% after lighting was installed. The same measurements for day crashes showed an increase by 50% in the after period. A 32% reduction was also found for the night to total crash ratio and a 50% reduction for the day to night crash ratio. The night crash rate was reduced by 35% and the ratio of night to day crash rate was reduced by 50% in the after period. Again, the day crash rate increased by 30% from the before to after period. The differences between the night and day crash measurements may suggest that the net effect of lighting at night was greater than the reductions presented. Crash severity decreased at night by 20% in the after period and day crash severity increased by 10%. Single vehicle night crashes and crash rates were reduced by 40% and 11%, respectively and multiple vehicle night crashes and crash rates were reduced by 51% and 20%, respectively.

Two statistical models were also used to test the statistical significance between the before and after periods. Linear regression was used to evaluate the reduction in the ratio of night to total crashes. A number of variables were considered. According to the model, the only variables that were statistically significant were period and nighttime DEV. As indicated, the results show that the reduction in the ratio of night to total crashes from the before period to the after period is statistically significant. The expected ratio of night to total crashes was reduced by 15% in the after period.

Poisson regression was also used to compare mean crash rates during the before-and-after periods to determine statistical significance. Only the variable for period was statistically significant. The model demonstrated that the reduction in the night crash rate before and after installation of lighting was statistically significant. The expected night crash rate in the before period was 54% higher than the after period and the expected day crash rate increased by 24% in the after period.

The before-and-after analysis also appears to have yielded a more robust analysis than the comparative analysis.

# 6.0 RECOMMENDATIONS AND CONCLUSIONS

This research evaluated the effectiveness of rural street lighting in reducing nighttime crashes at isolated rural intersections. Two methods were used to analyze the intersections crash data for Minnesota. A comparative analysis was completed for over 3,600 rural intersections and a before-and-after study evaluated crash data for 34 lighted intersections. Crash data for most of the intersections in the study were analyzed for 3 years before and 3 years after the installation of lighting.

## 6.1 Summary of Findings

### *6.1.1 Comparative Analysis*

A comparative analysis was used to compare night and day crashes at lighted and unlighted intersections. Unlighted intersections had a ratio of night to total crashes 27% higher than lighted intersections. The difference in the mean ratio of night to total crashes for unlighted intersections was statistically different than lighted intersections when considering night DEV and number of approach legs. These findings suggest that lighting does have an impact on intersection crashes at rural intersections.

Day and night crash rates were calculated using DEVs corresponding to the day and nighttime periods. Crash rate is given in million entering vehicles (MEV)

The actual night crash rate was 3% lower at lighted intersections; however, analysis results show that the mean night crash rate at lighted intersections was not statistically significant from lighted intersections. The day crash rate, however, was 22% higher at lighted intersections than unlighted intersections and was statistically significant at the 10% significance level.

Furthermore, the night crash rate was twice as high as the day crash rate at unlighted intersections and only 1.43 times higher at lighted intersections. Considering the ratio of night to day or night to total crashes is important since lighting may have been targeted to locations that were already problematic. As a result, higher crash rates may exist even if treatments were effective.

A linear regression model was used to compare the ratio of night to total crashes. Results indicated that the ratio of nighttime to total crashes depends on the presence or absence of lighting, DEV, and the number of approach legs for the intersection. The expected night to total crash ratio for unlighted intersections was 7% higher than at lighted intersections and was statistically significant.

A Poisson regression model was used to model the night crash rate for the comparative analysis. When the night crash rate was modeled with lighting, posted speed, and number of approach legs as independent variables, all three variables were statistically significant at the 10% level. The expected night crash rate at unlighted intersections was 11% lower than lighted intersections and the day crash rate was 33% lower than lighted intersections with the same variables held constant.

Intersections with all posted approach speeds equal to 55 mph had night crash rates that were 43% higher than approaches with at least one leg less than 55 mph. Intersections with four-approaches had night crash rates 17% higher than 3 approach intersections. This implies that lighting may be more beneficial at intersections with 55 mph posted approach speeds and at four-approach intersections.

The ratio of night to day crashes was, however, lower at lighted intersections, as determined by the linear regression model. This suggests that for the comparative analysis, locations that already had safety problems were more likely to have lighting installed. Consequently, crashes overall are already higher at those locations. The relevant difference appears to be in the ratio of night to total crashes which was lower at lighted intersections. Additionally, it was not known if significant other differences between the much smaller sample set of lighted intersections and unlighted intersections existed.

### *6.1.2 Before-and-After Analysis*

An observational before-and-after analysis compared the reduction of night crashes after the installation of street lighting at 34 rural intersections. The before-and-after analysis showed a 27% reduction in night crash frequency, a 32% reduction for the ratio of night to total crashes and a 35% reduction in the night crash rate. Day crash frequency and rate (from 0.30 to 0.39) increased from the before to after periods. The frequency of night crashes and number of night crashes per intersection both decreased by 27% after lighting was installed. Crash severity decreased at night by 20% in the after period and day crash severity increased by 10%.

A linear regression model was used to evaluate the reduction in the ratio of night to total crashes. The model indicated that the reduction in the ratio between the before and after analysis periods was statistically significant when considering DEV. A Poisson regression model was used to evaluate reduction in night crash rates between the before and after periods was also statistically significant. The expected night crash rate in the before period was 54% higher than the after period. Lastly, the 30% increase in the day crash rate between the periods and the 24% increase in the expected day crash rate in the after period were not statistically significant.

### 6.2 Recommendations and Conclusions

A consistently high percentage of rural intersection crashes occur at night in Minnesota and across the United States. The literature suggests that installing lighting at unlighted intersections is an effective safety countermeasure. Research presented in this report was intended to supplement the earlier findings of the original LRRB study that reported a 25–40% reduction in crash frequency for 12 intersections in the before-and-after study. As presented above, this research found a statistically significant reduction in the ratio of night to total crashes and the nighttime crash rate in the before-and-after analysis of 34 intersections that was consistent with the earlier findings. This suggests that the installation of street lighting does reduce night to total crash ratio and nighttime crash rates. These results reinforce the findings of the original LRRB study and provide Mn/DOT the confidence that lighting is another safety countermeasure tool to reduce the number crashes at rural Minnesota intersections.

The existing Mn/DOT lighting warrants limit the ability of agencies to implement street lighting at rural intersections. Traffic signal volume warrants capture less than 5% and the crash frequency warrant less than 2% of the rural intersections in Minnesota. In order to utilize this confirmed safety tool, the current lighting warrants should be considered for modification. Modified volume warrants should apply to a higher percentage of the rural intersections and provide quantifiable volume and crash measurements, as well as consider roadway functional classification. The guidelines suggested in the original LRRB study would apply to approximately 25% of the rural intersections by volume and functional classification. The percentage of intersections that would meet an increased crash threshold of 3 nighttime crashes in 3 years would vary from year to year. The 2000–2002 crash data suggests that approximately 8% of intersections would meet this warrant.

Modified lighting warrants would allow Minnesota agencies to implement lighting as a safety measure as either a proactive or reactive approach. Agencies may chose to install lighting due to high crash experiences or install lighting at an intersection based on functional classification and volumes on both the major and minor approaches.

As demonstrated in this LRRB research, street lighting has safety benefits for reducing crash experience at isolated rural intersections. In order to effectively implement street lighting as a safety tool at rural intersections for all Minnesota agencies, it is recommended that Mn/DOT modify the current lighting warrants in the Traffic Engineering Manual and any subsequent documents with reference to installation of lighting on Minnesota's roadways. These changes would give Mn/DOT and other agencies the authority to implement street lighting as a safety measure based on revised warrants and guidelines.

The site visits showed that at least 75% of the rural intersection street lighting was mounted on utility poles. Agencies have the option of making an agreement with local utility companies to pay for the electricity either as a flat monthly fee or have a meter installed. Most of these lights would be considered destination lighting as they are not designed to specifically illuminate the intersection. This alternative does not require special installation of a light pole. This provides for a more cost-effective approach for the local agencies, but does not necessarily provide adequate illumination of the intersection.

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# APPENDIX A: MN/DOT LIGHTING WARRANTS



*10-3.01.02 Warrants*

The primary purpose of warrants is to assist administrators and designers in evaluating locations for lighting needs and selecting locations for installing lighting. Warrants give conditions which should be satisfied to justify the installation of lighting. Meeting these warrants does not obligate the state to provide lighting. Conversely, local information in addition to that reflected by the warrants, such as roadway geometry, ambient lighting, sight distance, signing, crash rates, or frequent occurrences of fog, ice, or snow, may influence the decision to install lighting. The warrants are applicable to all lighting projects for which the state participates in the cost, whether the contract is administered by the state or by a local governmental agency.

Warrants for freeway lighting are contained in the AASHTO Guide, with the modifications and additions indicated below:

**Continuous Freeway Lighting**

**Case CFL-1** - Continuous freeway lighting is considered to be warranted on those sections in and near cities where the current ADT is 40,000 or more.

**Case CFL-2** - Continuous freeway lighting is considered to be warranted on those sections where three or more successive interchanges are located with an average spacing of 2.4 km (**1-1/2 miles**) or less, and adjacent areas outside the right-of-way are substantially urban in character.

**Case CFL-3** - Continuous freeway lighting is considered to be warranted where for a length of 3.2 km (**2 miles**) or more, the freeway passes through a substantially developed suburban or urban area in which one or more of the following conditions exist:

a. local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway;

b. the freeway passes through a series of developments such as residential, commercial, industrial and civic areas, colleges, perks, terminals, etc., which includes roads, streets and parking areas, yards, etc., that are lighted;

c. separate cross streets, both with and without connecting ramps, occur with an average spacing of 0.8 km (**one-half mile**) or less, some of which are lighted as part of the local street system; and

d. the freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country.

**Case CFL-4** - Continuous freeway lighting is considered to be warranted on those sections where the ratio of night to day crash rate is at least 2.0 or higher than the state wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

Continuous lighting should be considered for all median barriers on roadway facilities in urban areas. In rural areas each location must be individually evaluated as to its need for illumination.

**Complete Interchange Lighting**

Complete interchange lighting generally is warranted only if the mainline freeway has continuous lighting.

**Partial Interchange Lighting**

**Case PIL-1** - Partial interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 5000 for urban conditions, 5000 for suburban conditions, or 2500 for rural conditions.

**Case PIL-2** - Partial interchange lighting is considered to be warranted where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

**Case PIL-3** - Partial interchange lighting is considered to be warranted where the ratio of night to day crash rate within the interchange area is at least 1.25 or higher than the state wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

The AASHTO Guide also contains guidelines on special considerations for roadway lighting.

The AASHTO Guide gives no specific warrants for continuous lighting of roadways other than freeways (roads with fully controlled access, no at-grade intersections), but does suggest some general criteria that may apply when considering the installation of lighting.

Lighting of at-grade intersections is warranted if the geometric conditions mentioned in the AASHTO Guide exist or if one or more of the following conditions exists:

1. **Volume** - The traffic signal warrant volumes for the minimum vehicular volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian volume warrant are satisfied for any single hour during conditions other than daylight, excluding the time period between

6:00 a.m. and 6:00 p.m. See the "Traffic Signals" chapter of this manual and the "Signals" chapter of the "Minnesota Manual on Uniform Traffic Control Devices" (MN MUTCD) for further information about traffic signal warrants.

2. **Crashes** - There are three or more crashes per year occurring during conditions other than daylight.
3. **Intersecting Roadway** - The intersecting roadway is lighted.
4. **Ambient Light** - Illumination in areas adjacent to the intersection adversely affects the drivers' vision.
5. **Channelization** - The intersection is channelized and the 85th percentile approach speed exceeds 40 miles per hour. A continuous median is not considered as channelization for the purpose of this warrant.
6. **School Crossing** - Scheduled events occurring at least once per week during the school year make it necessary for 100 or more pedestrians to cross at the school crossing during any single hour in conditions other than daylight, or a traffic engineering study indicates a need for lighting.
7. **Signalization** - The intersection is signalized.
8. **Flashing Beacons** - The intersection has a flashing beacon.

Warrants covering lighting for tunnels, underpasses, rest areas, and signs are contained in the AASHTO Guide.

### 10-3.02 Programming

The Transportation District/Division Engineer is responsible for requesting Planning and Programming to encumber funds for lighting installations.

### 10-3.03 Negotiations

In most instances, lighting installations involve negotiations and agreements with local authorities and power companies. The responsibility for negotiating with municipalities, counties, railroads, and power companies rests with the district/division. The district/division should then notify the Lighting Unit of the terms to be included in the agreement. The Utility Agreements Unit of the Office of Technical Support, the Office of Railroads and Waterways, the Lighting Unit, and the Agreements Technician in the Office of Traffic Engineering may all be available to assist the districtdivision in such negotiations.

### 10-3.04 Work Authorities

Work authorities are required before design or construction is started. A function 1 work authority is for preliminary design, function 2 is for detail design, and function 3 is for construction. For projects involving only lighting, the Lighting Engineer should implement the function 2 work authority and send a copy to the district/division traffic engineer. Where the lighting design is part of the road plans, the engineer in charge of the road design should implement the work authority, including the lighting design work, and a separate work authority for the lighting portion of the plan is unnecessary.

### 10-3.05 Preparation of Plans

The Lighting Unit in OTE-ITS or the District/Division Traffic Office designs the lighting system and drafts the plans for lighting systems that will be installed under a state contract.

The lighting plans should include a title sheet showing the project location and description, the state and federal project number(s), the area and job number(s), appropriate signature lines, roadway design values, legends and symbols, a list of scales, and a plan index. Appropriate symbols are contained in the Mn/DOT road design "Technical Manual."

When a municipality is participating in the cost for installing or maintaining the lighting system, the title sheet should include a signature line for the appropriate authority from the municipality. The district/division traffic engineer should submit a final copy of the plan to the municipality for review and approval before the project is let.

Also included in the lighting plans should be a statement of estimated quantities. Normally, the lighting system pay items are itemized showing items for conduit, cable, light standards, etc. Any notes pertaining to any of the items in the estimated quantities should be included on the estimated quantities sheet. Paying for the lighting system as a lump sum item may be more convenient than itemizing in certain situations. To simplify estimating and bidding when a lump sum pay item is used, the plans should include a tabulation of the individual items that are part of the lump sum.

It is sometimes desirable to include provisions for conduit, pull boxes, and junction boxes as part of the roadway project and to have the rest of the lighting plan as a separate project.

Detail sheets should show pole details for each type of pole used in the project, details for mounting the service cabinets and photoelectric controls, any special anchorage details, conduit attachment to bridges for underpass lighting, and any other necessary details.

Each layout sheet should include a layout of the roadway and locations of light standards, cable, service cabinets, conduit, junction boxes, and handholes. All of these items should be properly labeled and identified. A tabulation should list stations, locations, and types of lighting units.

# PART 4. HIGHWAY TRAFFIC SIGNALS

## Chapter 4C. Traffic Control Signal Needs Studies

### 4C.1 Studies and Factors for Justifying Traffic Control Signals

**STANDARD:**

An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.

The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the following traffic signal warrants and other factors related to existing operation and safety at the study location:

Warrant 1, Eight-Hour Vehicular Volume.
Warrant 2, Four-Hour Vehicular Volume.
Warrant 3, Peak Hour.
Warrant 4, Pedestrian Volume.
Warrant 5, School Crossing.
Warrant 6, Coordinated Signal System.
Warrant 7, Crash Experience.
Warrant 8, Roadway Network.

The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal.

**SUPPORT:**

Sections 8D.7 and 10D.5 contain information regarding the use of traffic control signals instead of gates and/or flashing light signals at highway-railroad grade crossings and highway-light rail transit grade crossings, respectively.

**GUIDANCE:**

A traffic control signal should not be installed unless one or more of the factors described in this section are met.

A traffic control signal should not be installed unless an engineering study indicates that installing a traffic control signal will improve the overall safety and/or operation of the intersection.

A traffic control signal should not be installed if it will seriously disrupt progressive traffic flow.

The study should consider the effects of the right-turn vehicles from the minor-street approaches. Engineering judgment should be used to determine what, if any, portion of the right-turn traffic is subtracted from the minor-street traffic count when evaluating the count against the above signal warrants.

Engineering judgment should also be used in applying various traffic signal warrants to cases where approaches consist of one lane plus one left-turn or right-turn lane. The site-specific traffic characteristics dictate whether an approach should be considered as one lane or two lanes. For example, for an approach with one lane for through and right-turning traffic plus a left-turn lane, engineering judgment could indicate that it should be considered a one-lane approach if the traffic using the left-turn lane is minor. In such a case, the total traffic volume approaching the intersection should be applied against the signal warrants as a one-lane approach. The approach should be considered two lanes if approximately half of the traffic on the approach turns left and the left-turn lane is of sufficient length to accommodate all left-turn vehicles.

Similar engineering judgment and rationale should be applied to a street approach with one lane plus a right-turn lane. In this case, the degree of conflict of minor-street right-turn traffic with traffic on the major street should be considered. Thus, right-turn traffic should not be included in the minor-street volume if the movement enters the major street with minimal conflict. The approach should be evaluated as a one-lane approach with only the traffic volume in the through/left-turn lane considered.

At a location that is under development or construction and where it is not possible to obtain a traffic count that would represent future traffic conditions, hourly volumes should be estimated as part of an engineering study for comparison with traffic signal warrants.

For signal warrant analysis, a location with a wide median should be considered as one intersection.

**OPTION:**

Engineering study data may include the following:

A. The number of vehicles entering the intersection in each hour from each approach during 12 hours of an average day. It is desirable that the hours selected contain the greatest percentage of the 24-hour traffic volume.
B. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, public-transit vehicles, and, in some locations, bicycles), during each 15-minute period of the 2 hours in the morning and 2 hours in the afternoon during which total traffic entering the intersection is greatest.

C. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in Paragraph B above and during hours of highest pedestrian volume. Where young, elderly, and/or persons with physical or visual disabilities need special consideration, the pedestrians and their crossing times may be classified by general observation.

D. Information about nearby facilities and activity centers that serve the young, elderly, and/or persons with disabilities, including requests from persons with disabilities for accessible crossing improvements at the location under study. These persons might not be adequately reflected in the pedestrian volume count if the absence of a signal restrains their mobility.

E. The posted or statutory speed limit or the 85th-percentile speed on the uncontrolled approaches to the location.

F. A condition diagram showing details of the physical layout, including such features as intersection geometrics, channelization, grades, sight-distance restrictions, transit stops and routes, parking conditions, pavement markings, roadway lighting, driveways, nearby railroad crossings, distance to nearest traffic control signals, utility poles and fixtures, and adjacent land use.

G. A collision diagram showing crash experience by type, location, direction of movement, severity, weather, time of day, date, and day of week for at least 1 year.

The following data, which are desirable for a more precise understanding of the operation of the intersection, may be obtained during the periods specified in Paragraph B above:

A. Vehicle-hours of stopped time delay determined separately for each approach to be consistent with the Peak Hour Warrant.

B. The number and distribution of acceptable gaps in vehicular traffic on the major street for entrance from the minor street.

C. The posted or statutory speed limit or the 85th-percentile speed on controlled approaches at a point near to the intersection but unaffected by the control.

D. Pedestrian delay time for at least two 30-minute peak pedestrian delay periods of an average weekday or like periods of a Saturday or Sunday.

E. Queue length on stop-controlled approaches.

## 4C.2 Warrant 1, Eight-Hour Vehicular Volume

**SUPPORT:**

The Minimum Vehicular Volume, Condition A, is intended for application where a large volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

The Interruption of Continuous Traffic, Condition B, is intended for application where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or conflict in entering or crossing the major street.

**STANDARD:**

The need for a traffic control signal shall be considered if an engineering study finds that one of the following conditions exist for each of any 8 hours of an average day:

A. The vehicles per hour given in both of the 100 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; or

B. The vehicles per hour given in both of the 100 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

In applying each condition the major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of these 8 hours.

**OPTION:**

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 70 percent columns in Table 4C-1 may be used in place of the 100 percent columns.

**STANDARD:**

The need for a traffic control signal shall be considered if an engineering study finds that both of the following conditions exist for each of any 8 hours of an average day:

A. The vehicles per hour given in both of the 80 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; and

B. The vehicles per hour given in both of the 80 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

| Condition A - Minimum Vehicle Volume | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | Vehicles per hour on higher-volume minor street approach (one direction only) | | |
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 100%[a] | 80%[b] | 70%[c] |
| 1............... | 1............... | 500 | 400 | 350 | 150 | 120 | 105 |
| 2 or more... | 1............... | 600 | 480 | 420 | 150 | 120 | 105 |
| 2 or more... | 2 or more... | 600 | 480 | 420 | 200 | 160 | 140 |
| 1............... | 2 or more... | 500 | 400 | 350 | 200 | 160 | 140 |

| Condition B - Interruption of Continuous Traffic | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | Vehicles per hour on higher-volume minor street approach (one direction only) | | |
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 100%[a] | 80%[b] | 70%[c] |
| 1............... | 1............... | 750 | 600 | 525 | 75 | 60 | 53 |
| 2 or more... | 1............... | 900 | 720 | 630 | 75 | 60 | 53 |
| 2 or more... | 2 or more... | 900 | 720 | 630 | 100 | 80 | 70 |
| 1............... | 2 or more... | 750 | 600 | 525 | 100 | 80 | 70 |

[a] Basic minimum hourly volume.

[b] Used for combination of Conditions A and B after adequate trial of other remedial measures.

[c] May be used when the major street speed exceeds 40 mph or in an isolated community with a population of less than 10,000.

*Table 4C-1. Warrant 1, Eight-Hour Vehicular Volume*

These major street and minor-street volumes shall be for the same 8 hours for each condition; however, the 8 hours satisfied in Condition A shall not be required to be the same 8 hours satisfied in Condition B. On the minor street the higher volume shall not be required to be on the same approach during each of the 8 hours.

**GUIDANCE:**

The combination of Conditions A and B should be applied only after an adequate trial of other alternatives that could cause less delay and inconvenience to traffic has failed to solve the traffic problems.

## 4C.3 Warrant 2, Four-Hour Vehicular Volume

**SUPPORT:**

The Four-Hour Vehicular Volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

**STANDARD:**

The need for a traffic control signal shall be considered if an engineering study finds that, for each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) all fall above the applicable curve in Figure 4C-1 for the existing combination

# APPENDIX B: NCHRP 152 WARRANTING CONDITION TABLES

**Classification for Noncontrolled Access Facility Lighting**

| Classification Factor | Rating 1 | 2 | 3 | 4 | 5 | Unlit Weight (A) | Lighted Weight (B) | Diff (A-B) | Score Rating x(A-B) |
|---|---|---|---|---|---|---|---|---|---|
| **Geometric Factors** | | | | | | | | | |
| No. of Lanes | 4 or less | - | 6 | - | 8 or more | 1.0 | 0.8 | 0.2 | |
| Lane Width | >12' | 12' | 11' | 10' | <10' | 3.0 | 2.5 | 0.5 | |
| Median openings per mile | < 4.0 or one way operation | 4.0-8.0 | 8.1-12.0 | 12.0-15.0 | >15.0 or no access control | 5.0 | 3.0 | 2.0 | |
| Curb Cuts | <10% | 10-20% | 20-30% | 30-40% | >40% | 5.0 | 3.0 | 2.0 | |
| Curves | <3.0° | 3.1-6.0° | 6.1-8.0° | 8.1-10.0° | >10.0° | 13.0 | 5.0 | 8.0 | |
| Grades | <3% | 3.0-3.9% | 4.0-4.9% | 5.0-6.9% | 7%or more | 3.2 | 2.8 | 0.4 | |
| Sight Distance | >700' | 500-700' | 300-500' | 200-300' | <200' | 2.0 | 1.8 | 0.2 | |
| Parking | prohibited both sides | loading zones | off-peak only | permitted one side | permitted both sides | 0.2 | 0.1 | 0.1 | |
| | | | | | | Geometric Total | | | ______ |
| **Operational Factors** | | | | | | | | | |
| Signals | all major intersections signalized | substantial majority of intersections signalized | most major intersections signalized | about half the intersection signalized | frequent non-signalized intersctions | 3.0 | 2.8 | 0.2 | |
| Left turn lane | all major intersections or one way operation | substantial majority of intersections | most major intersections | about half the major intersections | infrequent turn bays or undivided streets | 5.0 | 4.0 | 1.0 | |
| Median Width | 30' | 20-30' | 10-20' | 4-10' | 0-4' | 1.0 | 0.5 | 0.5 | |
| Operating Speed | 25 or less | 30 | 35 | 40 | 45 or greater | 1.0 | 0.2 | 0.8 | |
| Pedestrian traffic at night (peds/mi) | very few or none | 0-50 | 50-100 | 100-200 | >200 | 1.5 | 0.5 | 1.0 | |
| | | | | | | Operational Total | | | ______ |
| **Environmental Factors** | | | | | | | | | |
| % Development | 0 | 0-30% | 30-60% | 60-90% | 100.00% | 0.5 | 0.3 | 0.2 | |
| Predominant Type Development | undeveloped or bakup design | residential | half-residential and/or commercial | industrial or commercial | strip industrial or commercial | 0.5 | 0.3 | 0.2 | |
| Setback Distance | >200' | 150-200' | 100-150' | 50-100' | <50' | 0.5 | 0.3 | 0.2 | |
| Advertising or Area Lighting | none | 0-40% | 40-60% | 60-80% | essentially continuous | 3.0 | 1.0 | 2.0 | |
| Raised Curb Median | none | continuous | at all intersections | at signalized intersections | a few locations | 1.0 | 0.5 | 0.5 | |
| Crime Rate | extremely low | lower than city aver. | city aver. | higher than city aver. | extremely high | 1.0 | 0.5 | 0.5 | |
| | | | | | | Environmental Total | | | ______ |
| **Accidents** | | | | | | | | | |
| Ratio of night to day accident rates | <1.0 | 1.0-1.2 | 1.2-1.5 | 1.5-2.0 | 2 | 10.0 | 2.0 | 8.0 | |
| | | | | | | Accident Total | | | ______ |

*Continuous lighting warranted

| | | |
|---|---|---|
| Geometric Total | ______ | |
| Operational Total | ______ | |
| Environmental Total | ______ | |
| Accident Total | ______ | |
| Sum | ______ | Points |
| Warranting Condition | 85 points | |

# APPENDIX C: IOWA DOT INTERSECTION LIGHTING WARRANTS

**Classification for Intersection Lighting**

| Classification Factor | Rating 1 | Rating 2 | Rating 3 | Rating 4 | Rating 5 | Unit Weight (A) | Lighted Weight (B) | Diff (A-B) | Score Rating x(A-B) |
|---|---|---|---|---|---|---|---|---|---|
| **Geometric Factors** | | | | | | | | | |
| Number of legs | - | 3 | 4 | 5 | 6 or more (including traffic circles) | 3.0 | 2.5 | 0.5 | ______ |
| Approach lane width | >12' | 12' | 11' | 10' | <10' | 3.0 | 2.5 | 0.5 | ______ |
| Channelization | no turn lanes | left turn lanes on major legs | left turn lanes on all legs, right turn lanes on major | left and right turn lanes on major legs | left and right turn lanes on all legs | 2.0 | 1.0 | 1.0 | ______ |
| Approach Sight Distance | >700' | 500-700' | 300-500' | 200-300' | <200' | 2.0 | 1.8 | 0.2 | ______ |
| Grades on Approach Streets | <3% | 3.0-3.9% | 4.0-4.9% | 5.0-6.9% | 7% or more | 3.2 | 2.8 | 0.4 | ______ |
| Curvature on Approach Legs | <3.0° | 3.0-6.0° | 6.1-8.0° | 8.1-10.0° | >10° | 13.0 | 5.0 | 8.0 | ______ |
| Parking in Vicinity | prohibited both sides | loading zones only | off-peak only | permitted one-side only | permitted both sides | 0.2 | 0.1 | 0.1 | ______ |
| | | | | | | Geometric Total | | | ______ |
| **Operational Factors** | | | | | | | | | |
| Operating Speed on Approach Legs | 25 mph or less | 30 mph | 35 mph | 40 mph | 45 mph or greater | 1.0 | 0.2 | 0.8 | ______ |
| Type of Control | all phases signalized (incl. Turn lane) | left turn lane signal control | through traffic signal control only | 4-way stop control | stop control to minor legs or no control | 3.0 | 2.7 | 0.3 | ______ |
| Channelization | left and right signal control | left and right turn lane signal control on major legs | left turn lane signal control on all legs | left turn lane signal control on major legs | no turn lane control | 3.0 | 2.0 | 1.0 | ______ |
| Level of Service (Load Factor) | A(0.0) | B(0-0.1) | C(0.1-0.3) | D(0.3-0.7) | E(0.7-1.0) | 1.0 | 0.2 | 0.8 | ______ |
| Pedestrian Vol. (ped/hr crossing) | very few or none | 0-50 | 50-100 | 100-200 | >200 | 1.5 | 0.5 | 1.0 | ______ |
| | | | | | | Operational Total | | | ______ |
| **Environmental Factors** | | | | | | | | | |
| Percent Adjacent Development | 0 | 0-30% | 30-60% | 60-90% | 100% | 0.5 | 0.3 | 0.2 | ______ |
| Predominant Development near Intersection | undeveloped | residential | 50% residential - 50% industrial or commercial | industrial or commercial | strip industrial or commercial (no circuity) | 0.5 | 0.3 | 0.2 | ______ |
| Lighting in immediate vicinity | none | 0-40% | 40-60% | 60-80% | essentially continuous | 3.0 | 1.5 | 1.5 | ______ |
| Crime Rate | extremely low | lower than city aver. | city aver. | higher than city aver. | extremely high | 1.0 | 0.5 | 0.5 | ______ |
| | | | | | | Environmental Total | | | ______ |
| **Accidents** | | | | | | | | | |
| Ratio of night to day accident rates | 1 | 1.0-1.2 | 1.2-1.5 | 1.5-2.0 | 2.0* | 10.0 | 2.0 | 8.0 | ______ |
| | | | | | | Accident Total | | | ______ |

*Intersection lighting warranted

Geometric Total ____________
Operational Total ____________
Environmental Total ____________
Accident Total ____________
Sum ____________ Points

Warranting Condition = 75 points

# TRAFFIC AND SAFETY MANUAL



# Intersection Lighting Warrants

Originally Issued: 12-17-01, Last Revised: 12-17-01

## Intersection Lighting

The following criteria (warrants) shall be used to determine if a rural primary/primary, rural primary/secondary, or other rural primary/minor road intersection is a candidate for lighting.

The programming of lighting projects is the responsibility of the Transportation Commission and is determined in relation to the needs of the entire highway system and not on the warrants established above. Meeting the warrants, therefore, does not obligate the Department to provide lighting. For funding responsibilities see Section 6A-2 of the Traffic and Safety Manual.

## Full Lighting

### New or Reconstructed Intersections (Primary to Primary)

An intersection is a candidate for lighting if the current average daily traffic (ADT) is 3500 entering vehicles for the intersection AND:

- The intersection is channelized, or
- The intersection is a "T", or
- A change in the direction of the major route occurs.

### Existing intersection (Primary to Primary)

An intersection is a candidate for intersection lighting if:

- It meets the criteria above for lighting of new or reconstructed intersections.
- If after making the calculations as defined in Appendix A the value of ‘c’ exceeds 3000.

### Primary to Secondary

Refer to Transportation Section 761 Chapter 136 of the Administrative Rules.

## Destination Lighting

### New or Reconstructed Intersections (Primary to Primary and Primary to Minor Road)

An intersection is a candidate for destination lighting if the current average daily traffic (ADT) is 1750 entering vehicles for the intersection AND:

- The intersection is channelized, or

- The intersection is a "T", or
- A change in the direction of the major route occurs.

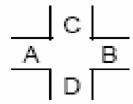
Regardless of volume, an intersection is also a candidate for destination lighting if the District has documentation of motorists experiencing operational problems which might be expected to be reduced by a destination light.

### Existing Intersections (Primary to Primary and Primary to Minor Road)

An intersection is a candidate for destination lighting if one of the following is met:

- The night-to-day crash rate ratio is 1.0 or greater with a minimum of 2 reportable nighttime crashes in a 5-year period.
- The warrants for destination lighting of new or reconstructed intersections are met.

# Appendix A
# Intersection Lighting Warrants




Major traffic flow: A to B & B to A

Minor traffic flow: C to D & D to C

Possible left turns: A to C, B to D, C to B, & D to A

| | Sight Distance | Speed Limit | Approaching Traffic |
|---|---|---|---|
| Actual A: | ______________ | ___________ | _________________ |
| Actual B: | ______________ | ___________ | _________________ |
| Standard: | 2000 FT. | 55 MPH | |
| | 1800 FT. | 50 MPH | |
| | 1700 FT. | 45 MPH | |
| | 1500 FT. | 40 MPH | |

SAF = Safety Adjustment Factor

$$SAF = \frac{\text{Standard sight distance}}{\text{Actual sight distance}} \times \frac{\text{Actual approaching traffic}}{1000}$$

"A" SAF = _________ x $\frac{\_\_\_\_\_\_\_\_\_}{1000}$ = _________

"B" SAF = _________ x $\frac{\_\_\_\_\_\_\_\_\_}{1000}$ = _________

GSAF = Greater Safety Adjustment Factor

GSAF = greater "A" SAF or "B" SAF

GSAF x Traffic from C to D =
GSAF x Traffic from D to C =
GSAF x Traffic from C to B x 1.5 =
GSAF x Traffic from D to A x 1.5 =
"A" SAF x Traffic from B to D x 1.5 =
"B" SAF x Traffic from A to C x 1.5 = ___________
"c" =

**Document Revision History: 12-17-01**

# APPENDIX D: MN/DOT ATR VOLUMES BY TIME OF DAY

| 2002 | County State Aid Highway (CSAH) | | | | | |
|---|---|---|---|---|---|---|
| | CSAH 40 Hubbard Co | CSAH 14 Polk Co | CSAH 1 Dodge Co | CSAH 1 Crow Wing Co | CSAH 5 CottonWood Co | CSAH 5 St Louis Co |
| | 051 E-W | 053 N-S | 054 N-S | 055 E-W | 056 N-S | 057 N-S |
| Average Nighttime AADT | 42 | 50 | 47 | 85 | 47 | 201 |
| Average Daytime AADT | 209 | 152 | 126 | 377 | 147 | 612 |
| | | | | | | |
| Total Average AADT | 251 | 202 | 173 | 462 | 194 | 812 |
| | | | | | | |
| % Nighttime AADT | 17% | 25% | 27% | 18% | 24% | 25% |
| % Daytime AADT | 83% | 75% | 73% | 82% | 76% | 75% |

| 2002 | Rural Trunk Highway | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TH 53 St Louis Co | TH 2 Clearwater Co | TH 10 Clay Co | TH 59 Lyon Co | TH 10 Benton Co | TH 52 Olmsted Co | TH 23 Renville Co | TH 60 Watonman Co | TH 212 Renville Co | TH 75 Pipestone Co | TH 169 Mille Lacs Co | TH 61 Lake Co | TH 1 Lake Co | TH 29 Chippewa Co | TH 2 Itasca Co | TH 71 Hubbard Co | TH 34 Hubbard Co | TH 65 Aitkin Co | TH 371 Cass Co | TH 210 Otter Tail Co |
| | 164 N-S | 170 E-W | 172 E-W | 179 N-S | 187 N-S | 188 N-S | 195 N-S | 197 E-W | 198 E-W | 199 N-S | 204 N-S | 213 N-S | 214 N-S | 218 N-S | 219 E-W | 220 N-S | 221 N-S | 222 N-S | 223 N-S | 225 E-W |
| Average Nighttime AADT | 1089 | 441 | 1737 | 267 | 2350 | 3797 | 282 | 626 | 281 | 180 | 1240 | 786 | 47 | 96 | 425 | 201 | 336 | 185 | 471 | 311 |
| Average Daytime AADT | 3510 | 1428 | 5306 | 804 | 7386 | 10205 | 848 | 1659 | 830 | 647 | 4018 | 2641 | 190 | 327 | 1398 | 809 | 1202 | 738 | 1722 | 1115 |
| | | | | | | | | | | | | | | | | | | | | |
| Total Average AADT | 4599 | 1868 | 7043 | 1071 | 9737 | 14002 | 1129 | 2285 | 1111 | 827 | 5258 | 3427 | 236 | 422 | 1824 | 1011 | 1538 | 923 | 2194 | 1426 |
| | | | | | | | | | | | | | | | | | | | | |
| % Nighttime AADT | 24% | 24% | 25% | 25% | 24% | 27% | 25% | 27% | 25% | 22% | 24% | 23% | 20% | 23% | 23% | 20% | 22% | 20% | 21% | 22% |
| % Daytime AADT | 76% | 76% | 75% | 75% | 76% | 73% | 75% | 73% | 75% | 78% | 76% | 77% | 80% | 77% | 77% | 80% | 78% | 80% | 79% | 78% |

| 2002 | Average | | |
|---|---|---|---|
| | CSAH | TH | Total |
| Average Nighttime AADT | 79 | 757 | 601 |
| Average Daytime AADT | 271 | 2339 | 1862 |
| | | | |
| Total Average AADT | 349 | 3097 | 2463 |
| | | | |
| % Nighttime AADT | 23% | 23% | 23% |
| % Daytime AADT | 77% | 77% | 77% |

## APPENDIX E: DESCRIPTION OF STATISTICAL MODELS

**Models**

Two statistical models were used to analyze the crashes and determine statistical significance. A linear regression model compared the ratio of night to total crashes. A linear regression model is appropriate for comparing the means of ratios and accounting for variation when a model has both classification variables (i.e. day or night, before or after) and continuous variables (i.e. number of crashes, DEV). Assumptions for this model include that the errors are normally distributed, independent and have the same variance.

A Poisson regression model was used to compare the mean crash rates. According to Ott and Longnecker (2001), the Poisson distribution is commonly used for estimating the probability of occurrences of an event that takes place randomly over a specified time period, as long as the assumptions are not unreasonably violated. Given that a crash occurring during one period does not change the probability of another crash occurring in another period and that crashes typically occur one at a time, a Poisson regression model is appropriate method for this analysis. This assumption is consistent with Maiou and Lum (1993) assessment when they concluded that the Poisson regression model is able to effectively explain statistical properties of crashes because of its ability to process discrete random variables compared to conventional linear regression models.

SAS 9.1, a statistical software package, was used for statistical analyses. Both statistical models are presented below in Equations E-1 and E-2.

Linear regression model:

$$y_{ij} = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \gamma_i + \varepsilon_i \qquad \text{(E-1)}$$

where:

$i = 1, 2, \ldots, k \text{ and } j = 0, 1$

$y_{ij}$ = Response variable (Ratio of night to total crashes)

$x_{i1}, x_{i2}, \ldots, x_{ik}$ = Known explantory variable (see Tables 6 - 1 and 6 - 4)

$\beta_0$ = Unknown intercept

$\beta_1, \beta_2, \ldots, \beta_k$ = Unknown effect paramter

$\gamma$ = Random error due to repeated measuremen t (if needed)

$\varepsilon$ = Unknown error

Poisson regression model:

$$\log(\mu) = \log(x) + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \gamma + \varepsilon \qquad \text{(E-2)}$$

$$\mu = \exp\{\log(x) + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \gamma + \varepsilon\} \qquad \text{(a)}$$

$$\mu_{ij} = e^{\log x_j} e^{\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_n x_{ik} + \gamma_i + \varepsilon_i} \qquad \text{(b)}$$

$$\mu_{ij} = x_j * e^{\beta_0 + \beta_1 x_{1i} + \beta_2 x_{i2} + ... + \beta_k x_{ik} + \gamma_i + \varepsilon_i} \quad \text{(c)}$$

$$Crash\ \ Rate = \frac{\mu_{ij}}{x_j} = e^{\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik} + \gamma_i + \varepsilon_i} \quad \text{(d)}$$

where:

$i = 1, 2, ..., k$ and $j = 0, 1$

$\mu_{ij}$ = Response variable (Expected number of crashes)

$$x_j = \frac{\left( DEV * n\ years * 365(\,^{days}\!/_{year}) \right)}{1{,}000{,}000}$$

$x_{i1}, x_{i2}, ..., x_{ik}$ = Known explanatory variables (see Tables 6 - 1 and 6 - 4)

$\beta_0$ = Intercept

$\beta_1, \beta_2, ..., \beta_k$ = Unknown effect parameter

$\gamma_i$ = Random error due to repeated measurement (if needed)

$\varepsilon_i$ = Error

## Comparative Analysis

### *Methodology*

The test hypothesis for both models was that the mean for the lighted intersections was equal to the mean of the unlighted intersections, written as $H_0$: $\mu_{\cdot} = \mu$. The Poisson regression model was used to compare the mean crash rates between lighted and unlighted intersection over a 3 year period (2000–2002) and the linear regression model was used to compare the means for the ratio of night to total crashes in that same period. Both statistical models used a 10% level of significance for the analysis. This implies that there was a 90% probability that the differences found in the means were actual differences and there was only a 10% probability that the differences were arbitrary. If the differences in the means are statistically significant, the test hypothesis is rejected.

### *Variables*

The response variables were crash rate and ratio of night to total crashes for the Poisson regression and the linear regression, respectively. The explanatory variables used to compare the lighted and unlighted intersections include lighting, DEV, number of approach legs and posted speed limit. Table E.1 shows these variables and values for the models. Except for DEV, all other variables are dummy variables, which means there are only two possible answers (0 or 1).

**Table E.1. Comparative model parameters tested**

| Variables | Definition | Parameters | Values |
|---|---|---|---|
| **Response variables** | Crash rate (Poisson) | CR*[1], DEV[2] | Predicted |
| | Ratio of night to total crashes (linear) | RATNTOT | Predicted |
| **Explanatory variables** | Lighting | LIT | 0–unlighted<br>1–lighted |
| | Daily entering volume | DEV*[3] | Value |
| | Number of approach legs | APPR | 0–4<br>1–3 |
| | Posted Speed limit[4] | SPD | 0 - = 55 mph<br>1 - < 55 mph |

[1] The night (cr_n), day (crt_d) and total (cr_tot) crash rates were analyzed.
[2] The Poisson model requires an "offset" term for this model to estimate rate.
[3] The night (dev_n), day (dev_d) and total (dev_tot) daily entering volumes were analyzed. The Poisson model requires an "offset" term for this model.
[4] The speed limit parameter for = 55 mph implies that all legs are posted at 55 mph and < 55 mph implies that at least one leg has a posted speed limit of less than 55 mph.

### *Linear Regression Model*

A linear regression model compared the means for the ratio of night to total crashes. All of the explanatory variables were considered in the linear model. The best fit model showed that lighting, DEV and number of approach legs were statistically significant at the 10% significance level. However, posted speed was not significant. The level of significance is presented in Table E.2. The expected night to total crash ratio was 7% higher at unlighted intersections than at lighted intersections, when all other variables were constant. It was found that 4-approach intersections have a 4% lower night to total crash ratio than 3-approach intersections. This implies that 3-legged intersections have a higher percentage of night crashes than 4-legged intersections at the 10% significance level, when all other variables are equal. The best fit model is presented in Appendix F.

**Table E.2. Statistical significance of explanatory variables for ratio of night to total crashes in cross sectional model**

| Explanatory variables | Level of significance (p-value) |
|---|---|
| Lighting | 0.005 |
| DEV (night) | < 0.001 |
| Number of approach legs | 0.002 |

The prediction equation for the best fit model for ratio of night to total crashes is shown in Equation E.3.

$$Expected\ Ratio\ of\ \ Night\ to\ Total\ Crashes = \beta_0 + \beta_1 Period(0,1) + \beta_2(DEV) + \beta_3 APPR\_LEG(0,1)$$

$$= 0.1447 + (0.0691,0) + 0.000047(DEV) - (0.03591,0) \qquad \text{(E-3)}$$

***Poisson Regression Model***

The Poisson regression model was used to compare the mean crash rates at lighted and unlighted intersections to determine statistical significance. Using a goodness-to-fit test, the model was determined to have dispersion parameters approximately equal to one, which indicates an adequate fit to the Poisson distribution.

Having lighting as the only variable in the model did not result in a statistically significant difference in the means between lighted and unlighted intersections. This was not unexpected because the mean night crash rates were very similar (0.59/MEV and 0.57MEV). The best fit model, however, includes all the variables, and each was statistically significant at the 10% level of significance. Table E.3 summarizes the level of significance for each variable. Consequently, the Poisson regression model suggests that night crash rates at unlighted intersections was 11% lower than lighted intersections, when posted speed and number of approach legs are constant. Intersections with all posted approach speeds equal to 55 mph have crash rates 43% higher than approaches with at least one (1) leg less than 55 mph. Lastly, intersections with 4 approaches have crash rates 17% higher than 3-approach intersections.

**Table E.3. Statistical significance of explanatory variables for night crash rate in the comparative model**

| Explanatory variables | Level of significance (p-value) |
|---|---|
| Lighting | 0.094 |
| Posted Speed | < 0.001 |
| Number of approach legs | < 0.001 |

The prediction equation for the best fit model for night crash rate is shown in Equation E.4.

$$Night\ Crash\ \ Rate = e^{\beta_0 + \beta_1 LIT(0,1) + \beta_2 SPD(0,1) + \beta_3 APPR(0,1)}$$
$$= e^{-0.7394 - (0.1183,0) + (0.3610,0) + 0.1594,0)} \qquad \text{(E-4)}$$

The difference in the day crash rate for lighted and unlighted intersections was statistically significant at the 10% level with only lighting in the model, as was the total crash rate. Day crash rate was 33% lower at unlighted intersections holding all other variables constant (posted speed and number of approach legs). The levels of significance are presented in Table E.4. The significant differences for both, however, showed a higher crash rate at lighted intersections. These results are anticipated based on the descriptive statistics. The day and total crash rate models also showed that posted speed and number of approach legs were significant to the daytime crash rate. The SAS output is shown in Appendix G.

**Table E.4. Statistical significance of crash rate between lighted and unlighted intersections**

| Dependent Variable | Level of Significance (p-value) |
|---|---|
| Night crash rate | 0.5678 |
| Day crash rate | < 0.001 |
| Total crash rate | < 0.001 |

The prediction equation for night crash rate only considering lighting is shown in Equation E.5.

$$Night\ Crash\ \ Rate = e^{\beta_0 + \beta_1 LIT(0,1)} = e^{-0.5635 + (0.387,0)} \qquad \text{(E-5)}$$

## Before-and-After Analysis
### *Methodology*

An observational before-and-after study provides knowledge about the effects of highway and traffic engineering measures on safety (Hauer, 1997). For the purposes of this study, the installation of street lighting at intersections was the safety measure that was added. Intersections that were identified as having significant physical improvements during the study period were removed, as described in previous sections.

As indicated in Chapter 4, daytime crashes at the same intersections were used as the control group. For the before-and-after analysis, both models had to be adjusted to account for the repeated measurement for each intersection that represented the before and after periods. This is necessary since each intersection is sampled twice (once in the before period and once in the after period) and in effect, correlated to itself. In repeated measurement analyses, there are within subject and between subject effects. For example, a within intersection effect would be a change in period (i.e. before or after) and a between intersection effect would be whether the intersection was a three-approach or four-approach configuration. Repeated measurements are correlated and require an additional parameter in the model to explain the covariance structure, as shown in the model equations. A linear mixed model was used to perform the analysis with the repeated measurements.

The hypothesis tested was that the mean in the before period is equal to the mean in the after period, written as $H_0$: $\mu=\mu$. A Poisson regression model was used to compare the mean crash rates during the two periods. Linear regression was used to compare the means for the ratio of night to total crashes. Both statistical models used a 10% level of significance for the analysis. If the means are statistically significant, the test hypothesis is rejected.

### *Variables*

Similar to the comparative model, the response variables were crash rate and ratio of night to total crashes for the Poisson regression and the linear regression, respectively. The explanatory variables used in the before-and-after model include crashes, DEV, period, number of approach legs, posted speed limit, intersection control, presence of turn lanes, presence of a horizontal or vertical curve and years in period. Table E.5 shows these variables and values for the models. Except for crashes and DEV, all other variables are dummy variables. Another variable introduced into the equations was the random ID variable which accounts for repeated measurements, as discussed above.

### *Linear Regression Model*

A mixed linear regression model compared the means for the ratio of night to total crashes. In this model, the number of years in the period was weighted to account for the different variances associated with periods with unequal years. All of the explanatory variables were considered in the linear model. The best fit model only included period and nighttime daily entering volume. Both were statistically significant at the 10% significance level. The results are presented in Table E.6 and the SAS output are presented in Appendix Q.  The expected ratio of night to total crashes was reduced by 15% in the after period.

**Table E.5. Before and after model parameters tested**

| Variables | Definition | Parameters | Values |
|---|---|---|---|
| Response Variables | Crash rate (Poisson) | CRTOT*[1], DEV[2] | Predicted |
| | Ratio of night to total crashes (mixed linear) | RATNTOT | Predicted |
| Explanatory Variables | Period | Period | 0 – Before<br>1 – After |
| | Crashes | CRTOTN, CRTOTD, CRTOT | Value (0, 1,…,n) |
| | Daily entering volume | DEVNAVE, DEVDAVE | Value |
| | Number of approach legs | APPR | 0 – 4<br>1– 3 |
| | Posted speed limit[3] | SPD | 0 - = 55 mph<br>1 - < 55 mph |
| | Intersection control | INTCNTRL | 0 – AWSC<br>1 – OWSC/TWSC |
| | Presence of turn lanes | TURN | 0 – No<br>1 – Yes |
| | Presence of a curve | CURVE | 0 – No<br>1 – Yes |
| | Number of years in the period | YEARS | 1, 2, 3 |
| | Repeated variable | ID | 1, 2,. . ., n |

[1] The night (CRTOTN), day (CRTOTD) and total (CRTOT) crash rates were analyzed.
[2] The Poisson model requires an "offset" term for this model to estimate rate.
[3] The speed limit parameter for = 55 mph implies that all legs are posted at 55 mph and < 55 mph implies that at least one leg has a posted speed limit of less than 55mph.
[4] AWSC – All Way Stop Control; OWSC – One-way Stop Control; TWSC – Two Way Stop Control

**Table E.6. Statistical Significance of Explanatory Variables for Ratio of Night to Total Crashes**

| Explanatory Variables | Level of Significance (p-value) |
|---|---|
| Period | 0.081 |
| DEV | 0.007 |

The prediction equation for the best fit model for ratio of night to total crashes is shown in Equation E.6.

$$Expected\ Ratio\ of\ Night\ to\ Total\ Crashes = \beta_0 + \beta_1(Period) + \beta_2(DEV)$$

$$= 0.03958 + 0.1545 + 0.000239(DEV) \qquad \text{(E-6)}$$

***Poisson Regression Model***

The Poisson regression model compared the mean crash rates during the before-and-after periods to determine statistical significance. The dispersion parameter resulting from the goodness-to-fit test for this model was equal to one, again indicating a fit to the Poisson distribution. All of the explanatory variables were considered in the model; however, it was determined that the best fit model included only the period was statistically significant at the 10% level of significance. Table E.7 shows the analysis results for night, day, and total crash rates. The expected night crash rate in the before period was 54% higher than the after period. The reduction in the night crash rate between the two periods was statistically significant, unlike the day crash rate, which increased. The expected day crash rate increased by 24% from the before to after period, however, was not statistically significant. The best fit model are shown in the SAS output is in Appendix R.

**Table E.7. Statistical significance of crash rate between periods**

| Dependent variable | Level of significance (p-value) |
|---|---|
| Night Crash Rate | 0.093 |
| Day Crash Rate | 0.336 |
| Total Crash Rate | 0.862 |

The prediction equation for the best fit model for night crash rate is shown in Equation E-7.

$$Night\ Crash\ \ Rate = e^{\beta_0 + \beta_1 Period(0,1)} = e^{-0.7569 + (0.0394, 0)} \qquad \text{(E-7)}$$

# APPENDIX F: SAS OUTPUT FOR LINEAR REGRESSION (COMPARATIVE)

Ratio of Night to Total Crashes

Y = LIT APPR_NUM DEV_N

The Mixed Procedure

Solution for Fixed Effects

| Effect | LIT | APPR_NUM | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|---|---|
| Intercept | | | 0.1447 | 0.02595 | 3630 | 5.58 | <.0001 |
| LIT | 0 | | 0.06909 | 0.02440 | 3630 | 2.83 | 0.0047 |
| LIT | 1 | | 0 | . | . | . | . |
| APPR_NUM | | 0 | -0.03591 | 0.01168 | 3630 | -3.07 | 0.0021 |
| APPR_NUM | | 1 | 0 | . | . | . | . |
| DEV_N | | | 0.000047 | 5.211E-6 | 3630 | 8.95 | <.0001 |

Type 3 Tests of Fixed Effects

| Effect | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| LIT | 1 | 3630 | 8.02 | 0.0047 |
| APPR_NUM | 1 | 3630 | 9.45 | 0.0021 |
| DEV_N | 1 | 3630 | 80.19 | <.0001 |

## APPENDIX G: SAS OUTPUT FOR POISSON REGRESSION (COMPARATIVE)

NIGHT CRASH RATE

The GENMOD Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| LIT | 2 | 0 1 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3632 | 4455.2855 | 1.2267 |
| Scaled Deviance | 3632 | 4455.2855 | 1.2267 |
| Pearson Chi-Square | 3632 | 5934.1692 | 1.6339 |
| Scaled Pearson X2 | 3632 | 5934.1692 | 1.6339 |
| Log Likelihood | | -2770.4132 | |

Analysis Of Parameter Estimates

| Parameter | | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|---|
| Intercept | | 1 | -0.5635 | 0.0644 | -0.6898 | -0.4373 | 76.53 | <.0001 |
| LIT | 0 | 1 | 0.0387 | 0.0678 | -0.0941 | 0.1716 | 0.33 | 0.5678 |
| LIT | 1 | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |
| Scale | | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

NOTE: The scale parameter was held fixed.

NIGHT CRASH RATE

The GENMOD Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| LIT | 2 | 0 1 |
| SPD | 2 | 0 1 |
| APPR_NUM | 2 | 0 1 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3630 | 4366.9572 | 1.2030 |
| Scaled Deviance | 3630 | 4366.9572 | 1.2030 |
| Pearson Chi-Square | 3630 | 5702.1799 | 1.5708 |
| Scaled Pearson X2 | 3630 | 5702.1799 | 1.5708 |
| Log Likelihood | | -2726.2490 | |

Analysis Of Parameter Estimates

| Parameter | | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|---|
| Intercept | | 1 | -0.7394 | 0.0690 | -0.8745 | -0.6042 | 114.93 | <.0001 |
| LIT | 0 | 1 | -0.1183 | 0.0707 | -0.2569 | 0.0203 | 2.80 | 0.0944 |
| LIT | 1 | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |
| SPD | 0 | 1 | 0.3610 | 0.0455 | 0.2717 | 0.4502 | 62.85 | <.0001 |
| SPD | 1 | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |
| APPR_NUM | 0 | 1 | 0.1594 | 0.0403 | 0.0804 | 0.2385 | 15.62 | <.0001 |
| APPR_NUM | 1 | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |
| Scale | | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

NOTE: The scale parameter was held fixed.

# APPENDIX H: COUNTY SURVEY LETTER OF TRANSMITTAL AND SURVEY

January 14, 2004

Dear Minnesota County Engineers:

The Mn/DOT Office of Research Services recently approved research for Safety Impacts of Street Lighting at Isolated Rural Intersections – Part II. The research will be conducted by the Center for Transportation Research and Education at Iowa State University in conjunction with the consulting firm Ch2MHILL. The objectives of the study are to evaluate the effectiveness of lighting in preventing nighttime crashes at isolated rural intersections, provide recommendations for installing lighting, and further assess the short and long term safety impacts of lighting at these locations. For the purposes of this study, isolated intersections are defined as an intersection at least one (1) mile from significant development, incorporated areas or nearest the signalized intersection.

A previous Mn/DOT study (http://www.lrrb.gen.mn.us/PDF/199917.pdf) evaluated several rural isolated intersections before and after lighting was installed. The results indicated that the addition of lighting at these sites reduced nighttime crash frequency. This new research will supplement the initial report by increasing the number of intersections studied and extending the analysis period. Results of the research will provide the counties and local officials, including those who provide information, with recommendations for selection, monitoring, and analysis of new lighting installation at isolated rural intersections.

In order to complete the research, we are updating the inventory of isolated rural intersections with lighting in Minnesota counties and are particularly interested in identifying locations where lighting was installed but no other significant improvements were made (i.e. addition of turn lanes, sight triangles cleared, horizontal or vertical grade adjustments). Consequently, we are asking counties to assist us in updating this inventory of isolated rural intersections with lighting. Please complete the attached survey by *February 12, 2004* and return it to Shauna Hallmark (shallmar@iastate.edu), Center for Transportation Research and Education, 2901 South Loop Drive, Suite 3100, Ames, IA 50010-8632.

Thank you in advance for your assistance with this survey. Your participation should be considered entirely voluntary. Your name and contact information will be removed from any information that appears in the project report or other public documents. If you have any questions or would like to discuss the research further, please contact me at 515-294-5249 or Hillary Isebrands at 515-294-7188.

Sincerely,
Dr. Shauna Hallmark, Principal Investigator
Enclosure

| | |
|---|---|
| **County**: | **Date**: |
| **Name**: | **Title:** |
| **Phone Number**: | **E-mail Address**: |
| **Address**: | |
| | |
| **1. Approximately how many isolated rural unsignalized intersections does the county currently maintain?** For the purposes of this study, isolated intersections are defined as an intersection at least one (1) mile from developed or incorporated areas, or the nearest signalized intersection. Include only intersections between public roads (not driveways or commercial entrances). | |
| | |
| **2. How many of these intersections are lighted?** | |
| | |
| **3. If you have installed lighting since 1990, how was installation funded?** | |
| | |
| **4. What warrants were used for the lighting installation (i.e. AASHTO, MnDOT, NCHRP Report 152, Other, None)?** Please attach copies of any other warrants used. | |

**Please circle the response to the following questions:**

**5. How many lights do you typically install at isolated rural intersections?**

**a.) One b.) Two c.) Other________________________**

**6. What type of luminaries and wattage do you typically use for these installations?**

**a.) High Pressure Sodium, 200 W b.) High Pressure Sodium, 250 W c.) Other ______________**

**7. What are your typical installation and maintenance costs for lighting at isolated rural intersections?**

**Installation $______/light Maintenance $_______/year Other $ ______/year**

**8. For each lighted isolated rural intersection, please list or circle the site characteristics (include additional pages as needed).**

| | |
|---|---|
| **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** _________<br><br>**Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor):**<br>**a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete **d)** gravel (one or more approaches)<br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes | **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** _________<br><br>**Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor):**<br>**a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete **d)** gravel (one or more approaches)<br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes |

| | |
|---|---|
| **c.)** none<br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>___________________________________ | **c.)** none<br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>___________________________________ |
| **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** _________<br><br>**Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor):**<br>**a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete<br><br>**d)** gravel (one or more approaches)<br><br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br><br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br><br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes<br>**c.)** none<br><br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>___________________________________ | **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** _________<br><br>**Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor):**<br>**a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete<br><br>**d)** gravel (one or more approaches)<br><br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br><br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br><br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes<br>**c.)** none<br><br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>___________________________________ |
| **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** | **Major Rd**.___________ **Speed Limit:** _________<br><br>**Minor Rd**.___________ **Speed Limit:** |

| | |
|---|---|
| ________ **Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor): a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete<br><br>**d)** gravel (one or more approaches)<br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes<br>**c.)** none<br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>______________________________ | ________ **Lighting Added: a.)** Up to 1990 **b.)** After 1990<br><br>**Pavement structure (major/minor): a.)** asphalt/concrete<br>**b.)** asphalt/asphalt **c.)** concrete/concrete<br><br>**d)** gravel (one or more approaches)<br>**Configuration: a.)** 4 legs - skew or 90°<br>**b.)** 3 legs - T or Y<br>**Control: a.)** two way stop **b.)** all way stop<br>**c.)** yield **d.)** none<br>**Facility: a.)** divided (one or more approaches)<br>**b.)** undivided (all approaches)<br>**Channelization:**<br>**left a.)** turn lanes **b.)** none<br><br>**right a.)** turn lanes **b.)** bypass lanes<br>**c.)** none<br>**Other Significant Improvements within 3 years before or 3 years after installation of lighting:**<br>**a.)** addition of turn lanes<br>**b.)** sight triangles cleared<br>**c.)** horizontal or vertical grade adjustments<br>**d.)** other<br>______________________________ |

**9. Comments:**

**Thank you for your assistance.**

**Please return the survey by *February 12, 2004* to Shauna Hallmark via e-mail or US Mail at the address below. By returning this survey, you acknowledge that it is voluntary and consent to your responses being a part of this research effort. If you have any questions please contact:**



| | | |
|---|---|---|
| Mr. Dan Warzala<br>Mn/DOT – Transportation Department<br>395 John Ireland Boulevard<br>St. Paul, Minnesota 55155-1899<br>Phone: 651-282-2691<br>Fax: 651-297-2354e-mail:<br>dan.warzala@state.mn.us | Mr. Roger Gustafson<br>Carver County Engineer<br>11360 Hwy 2121 West<br>PO Box 300<br>Cologne, MN 55322<br><br>Phone: 952-466-5200<br>Fax: 952-466-5223<br>e-mail:<br>rgustafs@co.carver.mn.us | Dr. Shauna Hallmark<br>Iowa State University, Center for Transportation Research and Education<br>2901 South Loop Drive, Suite 3100<br>Ames, IA 50010-8632<br>Phone: 515-294-5249<br>Fax: 515-294-0467<br>e-mail:<br>shallmar@iastate.edu |

## APPENDIX I: SUMMARY OF SUPPLEMENTAL SURVEY QUESTIONS

**How was the installation of street lighting funded?**[1]

| Source | Number of responses |
|---|---|
| County Funds | 6 |
| Local Funds | 2 |
| County/Local | 1 |
| County/MnDOT | 3 |

**What warrants were used for the lighting installation?**

| Warrant | Number of responses |
|---|---|
| AASHTO | 0 |
| NCHRP Report 152 | 0 |
| Mn/DOT | 5 |
| None | 4 |
| Other | Engineering judgment;<br>ADT > 1000 vpd on all approaches;<br>Local request;<br>LRRB 1999-17;<br>LRRB 1999-17, ambient light and channelization warrants from Mn/DOT;<br>TH ADT (major) > 500 ADT and CSAH, CR, TWN RD (minor) > 150 ADT |

**How many lights do you typically install at isolated rural intersections?**

| Number | Number of responses |
|---|---|
| One | 9 |
| Two | 2 |

**What type of luminaries and wattage do you typically use for these installations?**

| Luminaire and wattage | Number of responses |
|---|---|
| High pressure sodium, 200 W | 3 |
| High pressure sodium, 250 W | 6 |

**What are your typical installation and maintenance costs (per light) for lighting at isolated rural intersections?**

| Installation costs | Number of responses | Maintenance/other costs | Number of responses |
|---|---|---|---|
| < $500 | 1 | $100 to $200 | 4 |
| $500 to $1,000 | 0 | $200 to $300 | 3 |
| $1,000 to $1,500 | 4 | | |
| Variable | 1 | | |
| Other | Donation | | |

## Comments

- We have also had some of these entities install lighting within densely populated areas along main routes which also provides some residual light on adjacent intersections.
- Have six or seven intersections with higher crash rates and would like to evaluate rural intersection lighting as a tool. Also would like to know if Mn/DOT has a done any lighting where state highway intersects a county state aid highway, and if so, what was the cost share agreement?
- Only lights are major highways crossing railroad tracks.
- I have suggested to Mn/DOT several times they should consider lighting a couple of rural intersections but it always falls on deaf ears, or answer is no money, but we will do in it if you want to pay for it. We only have one intersection that has one light at the intersections in the entire county, but I feel Mn/DOT should maybe do some.
- There are some state highway crossings of county roads. These may be lighted by a city or the state, most likely the city with a farm yard light? County has, in the past, felt lights were unaffordable. I am interested in starting a program on intersections of paved county roads with state highways and some crash prone county roads.
- Do not light intersections due to cost for installation and utilities.
- New streetlight installation warrants were approved recently, which will result in installation of lighting at approximately 18 more of these 62 intersections this year. A total of 42 new streetlights were approved, the rest are within 1 mile of municipal limits, though still rural in character. Lighting has sometimes been installed at new development street accesses onto the county road system, with installation funded by the developer and operation funded by the homeowner's association. However, these installations are not tracked and the county assumes no responsibility for their operation or maintenance. "Developed" is probably a better criterion to differentiate urban from rural, however "developed" would need to be defined. For example, some incorporated areas have very low development density despite their potential for future development. Conversely, some unincorporated township areas allow residential subdivisions as dense as 1 lot per 2.5 acres, making those areas seem more developed than some incorporated areas. Neither example currently has water or sewer service. Some platted areas have very low densities, some small un-platted areas have relatively high densities. For the purposes of the survey, I used the criteria of one mile from the nearest corporate limits or the nearest traffic signal, despite the fact that this excluded some areas which are rural in character.
- I know I have more lighted intersections. Many of them were initially lighted when they were "rural" but development has worked its way near or around them. Many other lights were installed by others (i.e. city, township, residents) and I have no record of them.
- Wright County established a "Rural Intersection Street Lighting" Policy on January 8, 2002. The policy is mostly based on the concept of using an existing power pole at an intersection. Wright Hennepin electric will install a street light (Mast arm & luminaire) at such situations, at no or little cost to the County, in exchange for a flat monthly power fee.

## APPENDIX J: INVENTORY OF LIGHTED INTERSECTIONS BY COUNTY

| Minnesota County | County No. | Lighted Intersections |
|---|---|---|
| Aitkin County | 1 | 0 |
| Becker County | 3 | 0 |
| Blue Earth County | 7 | 6 |
| Brown County | 8 | 0 |
| Carver County | 10 | 3 |
| Cass County | 11 | 6 |
| Chippewa County | 12 | 0 |
| Chisago County | 13 | 0 |
| Clay County | 14 | 3 |
| Cook County | 16 | 0 |
| Cottonwood County | 17 | 1 |
| Crow Wing County | 18 | 0 |
| Dakota County | 19 | 0 |
| Dodge County | 20 | 0 |
| Faribault County | 22 | 1 |
| Fillmore County | 23 | 0 |
| Freeborn County | 24 | 0 |
| Goodhue County | 25 | 0 |
| Grant County | 26 | 0 |
| Houston County | 28 | 3 |
| Hubbard County | 29 | 1 |
| Itasca County | 31 | 20 |
| Jackson County | 32 | 1 |
| Kanabec County | 33 | 0 |
| Kandiyohi County | 34 | 0 |
| Kittson County | 35 | 0 |
| Koochiching County | 36 | 1 |
| Lac Qui Parle County | 37 | 0 |
| Lake County | 38 | 6 |
| Lake of the Woods County | 39 | 0 |
| Le Sueur County | 40 | 1 |
| Lincoln County | 41 | 1 |
| Lyon County | 42 | 0 |
| McLeod County | 43 | 1 |
| Marshall County | 45 | 0 |
| Meeker County | 47 | 0 |
| Mille Lacs County | 48 | 0 |
| Mower County | 50 | 0 |
| Murray County | 51 | 2 |
| Nicollet County | 52 | 0 |
| Nobles County | 53 | 0 |
| Otter Tail County | 56 | 0 |
| Pennington County | 57 | 0 |
| Pine County | 58 | 0 |
| Pipestone County | 59 | 3 |
| Polk County | 60 | 1 |
| Redwood County | 64 | 5 |
| Renville County | 65 | 0 |
| Rice County | 66 | 0 |
| Rock County | 67 | 0 |
| Scott County | 70 | 2 |
| Sherburne County | 71 | 0 |
| Sibley County | 72 | 0 |
| Stearns County | 73 | 0 |
| Steele County | 74 | 0 |
| Stevens County | 75 | 0 |
| Swift County | 76 | 0 |
| Traverse County | 78 | 0 |
| Wabasha County | 79 | 0 |
| Wadena County | 80 | 0 |
| Waseca County | 81 | 2 |
| Washington County | 82 | 2 |
| Watonwan County | 83 | 0 |
| Wilkin County | 84 | 2 |
| Wright County | 86 | 6 |
| Yellow Medicine County | 87 | 0 |
| | **SUM** | **80** |

# APPENDIX K: INITIAL INTERSECTION LOCATIONS

| County (#) | Intersection | |
|---|---|---|
| Blue Earth County (7) | | |
| | CSAH 90 | TH 22 |
| | CSAH 90 | TH 66 |
| | CSAH 90 | CSAH 8 |
| | CSAH 90 | CSAH 16 |
| | CSAH 90 | CSAH 33 |
| | CSAH 90 | CSAH 69 |
| Carver County (10) | | |
| | CSAH 10 | CSAH 43 S (east int) |
| | CSAH 10 | CSAH 43 N (west int) |
| Cass County (11) | | |
| | CSAH 77 | CSAH 70 |
| | CSAH 77 | CSAH 18 S |
| | TH 64 | CSAH 33 |
| | TH 200 | CSAH 13 |
| | CSAH 77 | CSAH 18 N |
| | TH 200/371 | CSAH 38 |
| Clay County (14) | | |
| | CSAH 22[1] | CSAH 3 |
| | CSAH 52 | CSAH 11 |
| | CSAH 22[1] | CSAH 1 |
| Cottonwood County (17) | | |
| | CSAH 5 | CSAH 10 |
| Fairbault County (22) | | |
| | CSAH 13 | 170th Street |
| Houston County (28) | | |
| | TH 16 | TH 26 |
| | TH 44 | TH 76 |
| | TH 44 | Green Acres Rd |
| Hubbard County (29) | | |
| | TH 34 | CSAH 4 |
| Itasca County (31) | | |
| | US 169 | Mishawaka Road |
| | US 169 | CSAH 64 (Harris Town Road) |
| | US 169 | Lakeview Road |
| | US 169 | Harbor Heights Road |
| | US 169 | CR 437 (Crystal Springs Road) |
| | CSAH 64 (Harris Town Road) | Sunny Beach Road |
| | US 169 | Gary Drive |
| | US 169 | Southwood Road |
| | US 169 | CSAH 66 ( Laplant Rd)/CR 437 (Shadywood Rd) |
| | US 169 | Bear Creek Road/ CR 222 - 8 Mile Road |
| | US 169 | CSAH 67 (9 Mile Corner) |
| | CSAH 3 | CSAH 64 (Harris Town Road) |
| | CSAH 64 (Harris Town Road) | Wendigo Park Road |
| | CSAH 3 | CSAH 67 (Wendigo Road) |
| | CSAH 3 | Wendigo Park Road |
| | US 169 | CSAH 69 |
| | CSAH 69 | Twin Lakes Drive |
| | TH 65 | West Bay Drive |
| | TH 65 | Badavinac Road |
| | TH 65 | Lakeview Street/CR 560 (West Shore Dr.) |
| | CSAH 83 | CR 529 (Simpson Blvd.) |
| | US 169 | TH 65 |
| | US 169 | Ethel Street |
| | US 2 | CSAH 25 |
| | US 2 | Shallow Lake Road |
| Koochiching County (36) | | |
| | US 53[1] | TH 332 |

| | | |
|---|---|---|
| Lake County (38) | | |
| | TH 61 | CSAH 61 |
| | CSAH 2 | 200 S |
| | CSAH 2 | 200 N |
| | 200 E | 200 S |
| | 200 E | 200 N |
| | 200 S | 200 W |
| Le Sueur County (40) | | |
| | TH 13 | TH 99 |
| | TH 60 | CSAH 62 (CSAH 3 Waseca) |
| Lincoln County (41) | | |
| | CSAH 8 | CSAH 11 |
| McLeod County (43) | | |
| | US 212 | TH 15 |
| Murray County (51) | | |
| | US 59 | CSAH 13/CSAH 48 |
| | CSAH 13 | CR 104 |
| Pipestone County (59) | | |
| | TH 23[1] | CSAH 15 |
| | TH 30[1] | CSAH 18 |
| | TH 23[1] | CSAH 18 |
| Polk County (60) | | |
| | US 75 | CSAH 9 |
| Redwood County (64) | | |
| | CSAH 2 | CSAH 13 |
| | CSAH 2 | Lower Sioux Comm Ent |
| | TH 19 | CSAH 19 |
| | CSAH 7 | CSAH 9 |
| | CSAH 101 | CSAH 25 |
| Scott County (70) | | |
| | CSAH 21 | CSAH 91 |
| | CSAH 59 | CR 66 |
| Sibley County (72) | | |
| | TH 19 | TH 15 |
| Steele County (74) | | |
| | CSAH 12 | CSAH 1 |
| | TH 30[1] | CSAH 45 |
| | TH 30[1] | CSAH 3 |
| | CSAH 19 | CR 59 |
| Waseca County (81) | | |
| | US 14 | CR 27 |
| Washington County (82) | | |
| | CSAH 19 | CSAH 20 |
| | CSAH 18 | CSAH 19 |
| | CSAH 20 | CSAH 13 |
| | CSAH 20 | Woodlane Drive |
| Wilkin County (84) | | |
| | US 75[1] | CSAH 22 |
| | TH 210[1] | CSAH 19 |
| Wright County (86) | | |
| | TH 55 | CSAH 6 |
| | TH 55 | CSAH 7 & CSAH 37 |
| | TH 55 | CR 115 |
| | CSAH 37 | CSAH 18 |
| | CSAH 35 | CR 134 |
| | CSAH 34 | CR 134 |
| | CSAH | County State Aid Highway |
| | CR | County Road |
| | TH | Minnesota Trunk Highway |

# APPENDIX L: FINAL INTERSECTION LOCATIONS AND SELECT PHOTOS

| County | Intersection Location | | Approach Legs |
| --- | --- | --- | --- |
| | Major | Minor | |
| Carver County (10) | | | |
| | CSAH 10 | CSAH 43 S (east int) | 3 |
| | CSAH 10 | CSAH 43 N (west int) | 3 |
| Cass County (11) | | | |
| | CSAH 77 | CSAH 70 | 4 |
| | CSAH 77 | CSAH 18 S | 3 |
| | TH 64 | CSAH 33 | 3 |
| | CSAH 77 | CSAH 18 N | 4 |
| | TH 200/371 | CSAH 38 | 4 |
| Clay County (14) | | | |
| | CSAH 22[1] | CSAH 3 | 4 |
| | CSAH 22[1] | CSAH 1 | 4 |
| Cottonwood County (17) | | | |
| | CSAH 5 | CSAH 10 | 3 |
| Houston County (28) | | | |
| | TH 44 | TH 76 | 4 |
| Itasca County (31) | | | |
| | TH 169 | Mishawaka Road | 3 |
| | TH 169 | CSAH 64 (Harris Town Road) | 3 |
| | TH 169 | Lakeview Road | 3 |
| | TH 169 | Harbor Heights Road | 4 |
| | TH 169 | CR 437 (Crystal Springs Road) | 3 |
| | CSAH 64 (Harris Town Road) | Sunny Beach Road | 3 |
| | TH 169 | Gary Drive | 3 |
| | TH 169 | CSAH 66 ( Laplant Rd)/CR 437 (Shadywood Rd) | 4 |
| | TH 169 | Bear Creek Road/ CR 222 - 8 Mile Road | 4 |
| | CSAH 3 | CSAH 64 (Harris Town Road) | 4 |
| | CSAH 64 (Harris Town Road) | Wendigo Park Road | 4 |
| | CSAH 3 | CSAH 67 (Wendigo Road) | 3 |
| | CSAH 3 | Wendigo Park Road | 3 |
| | TH 65 | West Bay Drive | 3 |
| | TH 65 | Badavinac Road | 4 |
| | TH 169 | TH 65 | 3 |
| | TH 169 | Ethel Street | 3 |
| Koochiching County (36) | | | |
| | US 53[1] | TH 332 | 4 |
| Le Sueur County (40) | | | |
| | TH 60 | CSAH 62 (CSAH 3 Waseca) | 3 |
| Murray County (51) | | | |
| | US 59 | CSAH 13/CSAH 48 | 4 |
| | CSAH 13 | CR 104 | 3 |
| Pipestone County (59) | | | |
| | TH 30[1] | CSAH 18 | 4 |
| | TH 23[1] | CSAH 18 | 3 |
| Polk County (60) | | | |
| OK | US 75 | CSAH 9 | 4 |
| Redwood County (64) | | | |
| | CSAH 2 | CSAH 13 | 3 |
| | CSAH 7 | CSAH 9 | 4 |
| | CSAH 101 | CSAH 25 | 3 |
| Scott County (70) | | | |
| | CSAH 21 | CSAH 91 | 4 |
| | CSAH 59 | CR 66 | 4 |
| Steele County (74) | | | |
| | CSAH 19 | CR 59 | 4 |
| Waseca County (81) | | | |
| | US 14 | CR 27 | 4 |
| Washington County (82) | | | |
| | CSAH 19 | CSAH 20 | 4 |
| | CSAH 18 | CSAH 19 | 4 |
| | CSAH 20 | CSAH 13 | 4 |
| | CSAH 20 | Woodlane Drive | 4 |
| Wilkin County (84) | | | |
| | US 75[1] | CSAH 22 | 3 |
| | TH 210[1] | CSAH 19 | 3 |
| Wright County (86) | | | |
| | CSAH 35 | CR 134 | 4 |
| | CSAH 34 | CR 134 | 4 |

**Carver County: CSAH 10 and CSAH 43 North (looking south)**

**Cass County: TH 64 and CSAH 33 (looking south)**

**Cass County: TH 371/200 and CSAH 38 (looking north)**

**Itasca County: TH 65 and West Bay Drive (looking north)**


**Washington County: CSAH 20 and CSAH 13 N (looking east)**


**Murray County: US59 and CSAH 13/CSAH 48 (looking south)**

## APPENDIX M: 2004 BEFORE-AND-AFTER INTERSECTIONS WITH CRASH TOTALS

| # | Intersection location | | Total crashes before | Total crashes after |
|---|---|---|---|---|
| 1 | CSAH 22[1] | CSAH 3 | 1 | 0 |
| 2 | CSAH 22[1] | CSAH 1 | 2 | 2 |
| 3 | CSAH 3 | CSAH 64 (Harris Town Road) | 1 | 2 |
| 4 | CSAH 3 | Wendigo Park Road | 1 | 0 |
| 5 | CSAH 64 (Harris Town Road) | Wendigo Park Road | 0 | 0 |
| 6 | CSAH 64 (Harris Town Road) | Sunny Beach Road | 2 | 2 |
| 7 | CSAH 2 | CSAH 13 | 1 | 0 |
| 8 | CSAH 7 | CSAH 9 | 1 | 0 |
| 9 | CSAH 101 | CSAH 25 | 2 | 0 |
| 10 | CSAH 21 | CSAH 91 | 8 | 1 |
| 11 | CSAH 19 | CR 59 | 1 | 1 |
| 12 | CSAH 19 | CSAH 20 | 0 | 7 |
| 13 | CSAH 18 | CSAH 19 | 3 | 11 |
| 14 | CSAH 20 | CSAH 13 | 1 | 2 |
| 15 | CSAH 20 | Woodlane Drive | 0 | 1 |
| 16 | TH 44 | TH 76/Ewald Road | 4 | 1 |
| 17 | US 169 | Mishawaka Road | 2 | 2 |
| 18 | US 169 | CSAH 64 (Harris Town Road) | 3 | 5 |
| 19 | US 169 | Harbor Heights Road | 3 | 6 |
| 20 | US 169 | Lakeview Road | 5 | 2 |
| 21 | US 169 | CR 437 (Crystal Springs Road) | 3 | 6 |
| 22 | US 169 | Gary Drive | 2 | 4 |
| 23 | US 169 | CSAH 66 ( Laplant Rd)/CR 437 (Shadywood Rd) | 2 | 1 |
| 24 | US 169 | Ethel Street | 3 | 1 |
| 25 | TH 65 | Badavinac Road | 1 | 0 |
| 26 | TH 65 | West Bay Drive | 0 | 0 |
| 27 | US 53[1] | TH 332 | 0 | 2 |
| 28 | TH 60 | CSAH 62 (CSAH 3 Waseca) | 1 | 3 |
| 29 | US 59 | CSAH 13/CSAH 48 | 1 | 0 |
| 30 | TH 23[1] | CSAH 18 | 0 | 0 |
| 31 | TH 30[1] | CSAH 18 | 1 | 2 |
| 32 | US 14 | CR 27 | 8 | 3 |
| 33 | US 75[1] | CSAH 22 | 0 | 2 |
| 34 | TH 210[1] | CSAH 19 | 1 | 1 |
| Totals | | | 64 | 70 |

# APPENDIX N: EXAMPLE CALCULATIONS FOR HISTORIC ADT

**Known Data**

| Use | Year | ADT | % Growth Per Year |
|---|---|---|---|
| y | 1988 | 2,450 | |
| y | 1992 | 3,000 | 5.19 |
| y | 1996 | 3,900 | 6.78 |
| y | 2000 | 5,600 | 9.47 |

Ave. Annual % Growth = 7.15

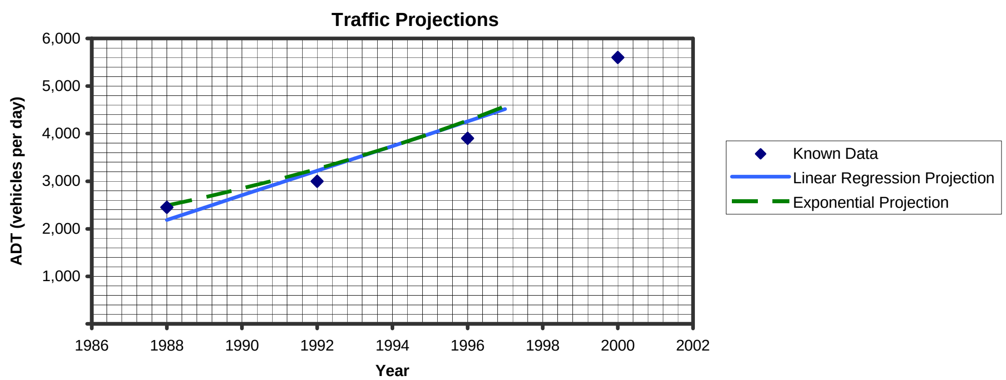
**Projected Data**

| | Linear Regression Projection | | Exponential Projection | |
|---|---|---|---|---|
| Year | ADT | % Growth Per Year | ADT | % Growth Per Year |
| 1988 | 2,185 | | 2,486 | |
| 1989 | 2,444 | 11.84 | 2,661 | |
| 1990 | 2,703 | 10.59 | 2,847 | |
| 1991 | 2,961 | 9.57 | 3,046 | |
| 1992 | 3,220 | 8.74 | 3,259 | |
| 1993 | 3,479 | 8.04 | 3,487 | |
| 1994 | 3,738 | 7.44 | 3,732 | |
| 1995 | 3,996 | 6.92 | 3,993 | |
| 1996 | 4,255 | 6.47 | 4,272 | |
| 1997 | 4,514 | 6.08 | 4,571 | |

Projected % Growth Per Year = 7.00

**Known Data Used for Linear Regression**

| Year | ADT |
|---|---|
| 1988 | 2450 |
| 1992 | 3000 |
| 1996 | 3900 |
| 2000 | 5600 |




Recommendation: ________________________________

**NOTES**

(1) Growth percentages based on formula: $ADT_B = ADT_A * (1+i)^{ADT_B - ADT_A}$

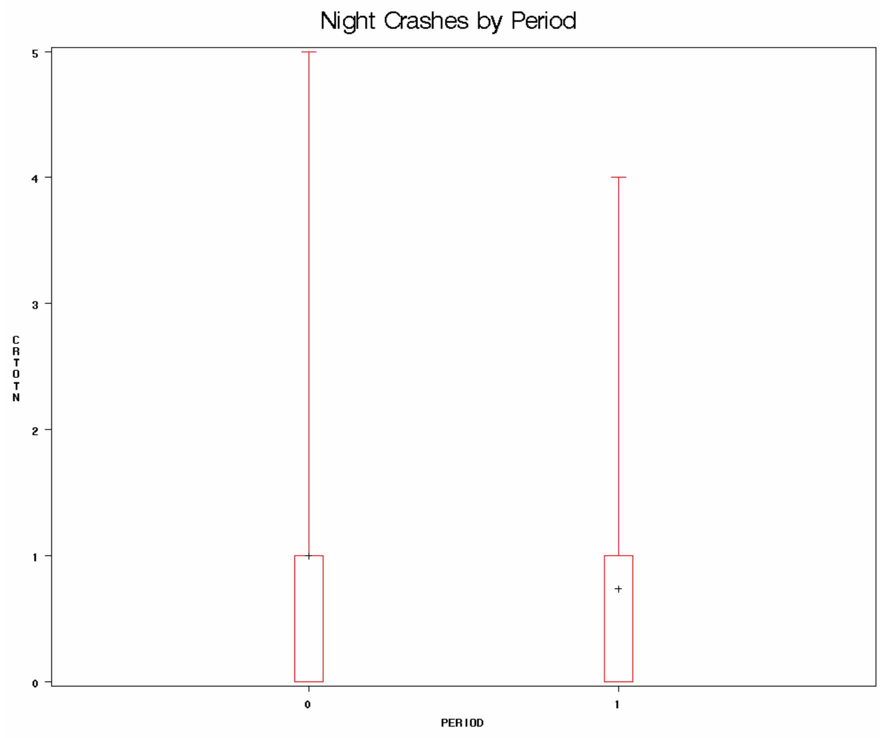
(2) The projected ADT formula is "forecasted" using linear regression

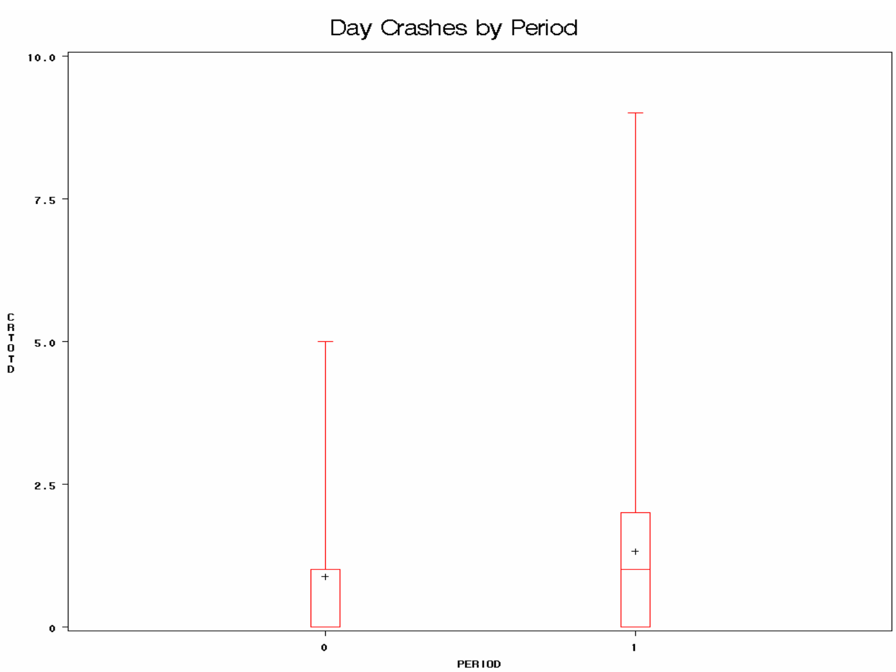
(3) The equation for FORECAST is a+bx, where:

$$a = \overline{Y} - b\overline{X} \quad \text{and:} \quad b = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2}$$

Source: Owen Ayres & Associates

# APPENDIX O: BOX PLOTS OF CRASHES BY PERIOD




Period 0 = Before, Period 1 = After

# APPENDIX P: SEVERITY OF CRASHES BY COLLISION TYPE

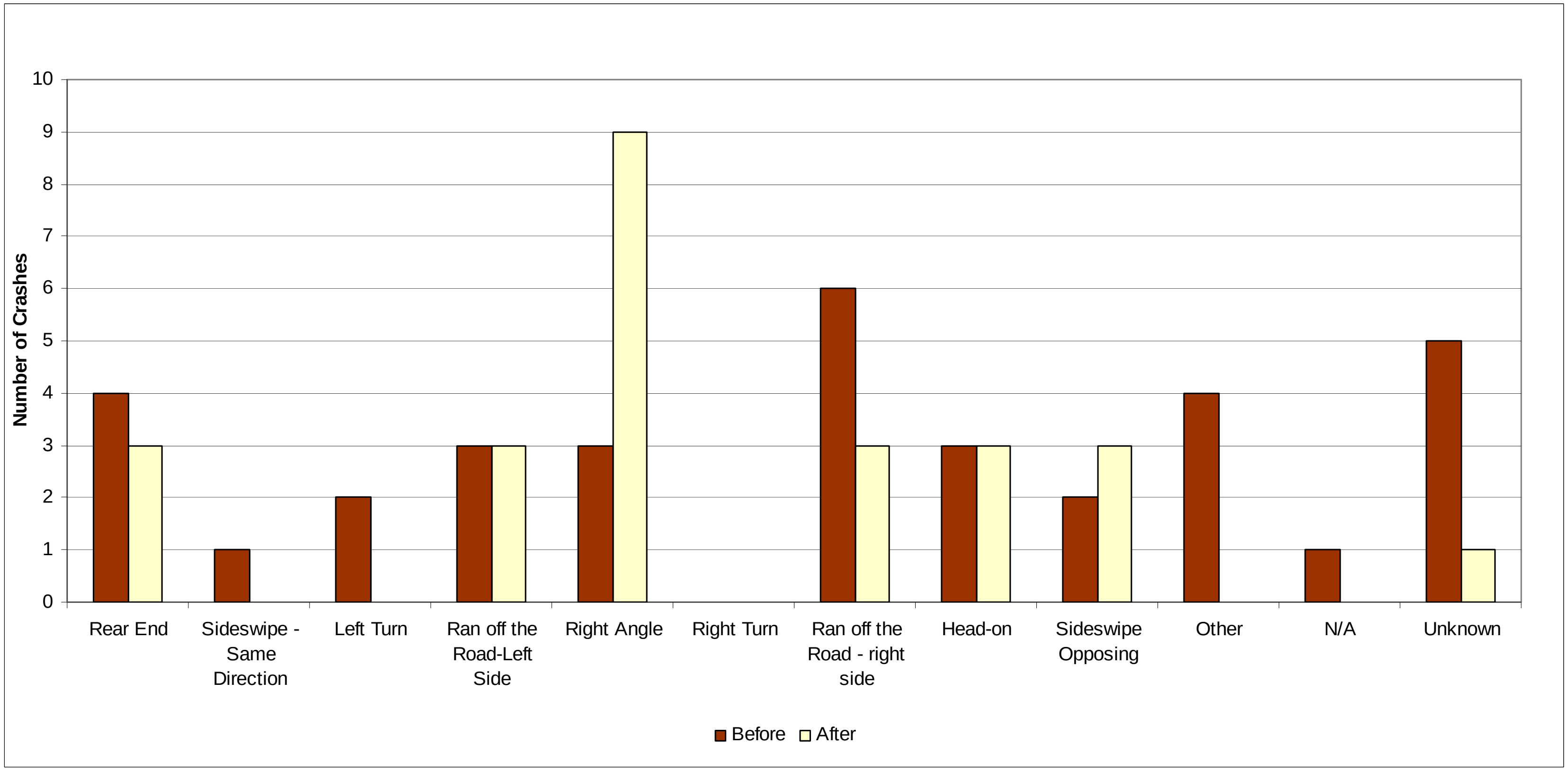


**Figure P.1. Nighttime crash types for all intersections**

# APPENDIX Q: SAS OUTPUT FOR LINEAR REGRESSION (BEFORE-AND-AFTER)

Ratio of Night to Total Crashes
Weighted by YEARS

The Mixed Procedure

Convergence criteria met.

Covariance Parameter Estimates

| Cov Parm | Subject | Estimate |
|---|---|---|
| CS | ID | 0.01335 |
| Residual | | 0.3639 |

Solution for Fixed Effects

| Effect | PERIOD | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|---|
| Intercept | | 0.03958 | 0.09956 | 46.6 | 0.40 | 0.6927 |
| PERIOD | 0 | 0.1545 | 0.08596 | 33.8 | 1.80 | 0.0812 |
| PERIOD | 1 | 0 | . | . | . | . |
| DEVNAVE | | 0.000239 | 0.000083 | 33.3 | 2.87 | 0.0070 |

Type 3 Tests of Fixed Effects

| Effect | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| PERIOD | 1 | 33.8 | 3.23 | 0.0812 |
| DEVNAVE | 1 | 33.3 | 8.25 | 0.0070 |

# APPENDIX R: SAS OUTPUT FOR POISSON REGRESSION (BEFORE-AND-AFTER)

NIGHT CRASH RATE
The GENMOD Procedure
Parameter Information

| Parameter | Effect | PERIOD |
|---|---|---|
| Prm1 | Intercept | |
| Prm2 | PERIOD | 0 |
| Prm3 | PERIOD | 1 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 66 | 68.4624 | 1.0373 |
| Scaled Deviance | 66 | 68.4624 | 1.0373 |
| Pearson Chi-Square | 66 | 67.6574 | 1.0251 |
| Scaled Pearson X2 | 66 | 67.6574 | 1.0251 |
| Log Likelihood | | -53.6390 | |

Analysis Of GEE Parameter Estimates
Empirical Standard Error Estimates

| Parameter | | Estimate | Standard Error | 95% Confidence Limits | | Z | Pr > \|Z\| |
|---|---|---|---|---|---|---|---|
| Intercept | | -0.3178 | 0.1934 | -0.6969 | 0.0613 | -1.64 | 0.1004 |
| PERIOD | 0 | 0.4324 | 0.2572 | -0.0716 | 0.9364 | 1.68 | 0.0927 |
| PERIOD | 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |

DAY CRASH RATE
The GENMOD Procedure
Analysis Of GEE Parameter Estimates
Empirical Standard Error Estimates

| Parameter | | Estimate | Standard Error | 95% Confidence Limits | | Z | Pr > \|Z\| |
|---|---|---|---|---|---|---|---|
| Intercept | | -0.9380 | 0.2277 | -1.3843 | -0.4917 | -4.12 | <.0001 |
| PERIOD | 0 | -0.2748 | 0.2857 | -0.8348 | 0.2851 | -0.96 | 0.3361 |
| PERIOD | 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |

TOTAL CRASH RATE
The GENMOD Procedure
Analysis Of GEE Parameter Estimates
Empirical Standard Error Estimates

| Parameter | | Estimate | Standard Error | 95% Confidence Limits | | Z | Pr > \|Z\| |
|---|---|---|---|---|---|---|---|
| Intercept | | -0.7569 | 0.1843 | -1.1180 | -0.3957 | -4.11 | <.0001 |
| PERIOD | 0 | 0.0394 | 0.2269 | -0.4053 | 0.4841 | 0.17 | 0.8622 |
| PERIOD | 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | . | . |