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Final Report

Safety Impacts Of Street Lighting at Isolated Rural Intersections – Part II

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16. Abstract (Limit: 200 words)

Several research efforts indicate that rural intersection lighting reduces nighttime crashes and is a cost-effective crash mitigation strategy. However, many Minnesota agencies do not routinely install streetlights at rural intersections. This study evaluated the effectiveness of rural street lighting in reducing nighttime crashes at isolated rural intersections to provide more information to Minnesota agencies in making lighting decisions.

A comparative analysis was used to evaluate 3,622 rural lighted and unlighted intersections from the Mn/DOT intersection database (US or Minnesota trunk highways). A linear regression model indicated relevant variables affecting the ratio of nighttime to total crashes are presence of street lighting, volume, and number of intersection approaches. The expected ratio of night to total crashes was 7% higher for unlighted intersections and was statistically significant.

A before-and-after study was also used to evaluate the impact of lighting at 48 intersections. A 13% reduction in night crash frequency and a 36% decrease in the ratio of night to day crash rate occurred after lighting was installed. A Poisson regression model evaluated the change in night crash rate after installation of lighting. Only 33 of the 48 intersections were used in this analysis since initial results were not conclusive when intersections with fewer than 3 years of before or after crash data were included. Final results indicated that the night crash rate was lower after lighting was installed and was statistically significant. The expected night crash rate before lighting was installed was 59% higher than after lighting was installed.

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Safety Impacts of Street Lighting at Isolated Rural Intersections – Part II

Final 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. Both statistical models used a 10% level of significance for the analysis.

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 night to total crash ratio was 27% higher at unlighted intersections than lighted intersections while the average night crash rate was only slightly higher, at 3%, for unlighted intersections compared to lighted intersections. The daytime crash rate was lower than the nighttime crash rate which confirms that there are still an un-proportional number of crashes occurring at night relative to the nighttime daily entering volume (DEV). The ratio of nighttime to total crash rate was 26% higher at unlighted intersections than at lighted intersections. 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, based on this dataset, 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. The best fit model includes presence of lighting; day or night condition and the interaction between lighting and the day or night condition; approach speed; and number of approach legs. The expected night crash rate at unlighted intersections was 6% lower than the night crash rate at lighted intersections but was not significant, while the day crash rate was 35% 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 28% higher than approaches with at least one approach with a posted speed limit less than 55 mph. Intersections with four-approaches had night crash rates 51% higher than three-approach intersections. This implies that lighting may be more beneficial at intersections with higher approach speeds.

For this model, the unlighted intersections cannot be treated well as a control group for the lighted intersections (treated group). Two hypothesized reasons for this conclusion are the differences in the number of intersections analyzed and the average DEV between the two groups. First, it is suspected that the difference in the number of lighted (223) vs. unlighted (3,399) intersections in the database may have skewed the model and results. Second, the average DEV for the lighted intersections is approximately 40% higher than the average DEV at the unlighted intersections. For this reason a before- and after- model was also used.

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 48 intersections.

When possible, a three-year before and three-year after analysis period were used. However, since lighting was installed at different times, in some cases intersections had only a two year before or two year after analysis period.

Comparing locations before-and-after installation of street lighting indicated that after lighting was installed, there was a 13% reduction in night crash frequency. Additionally, 35% of the intersections had a reduction in the number of nighttime crashes and 40% of the intersections had a reduction in the number of daytime crashes. The nighttime to total and nighttime to daytime crash ratios also decreased by approximately 21% and 35%, respectively, 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 19% after installation of lighting while daytime crash rate increased by 26%. The ratio of night crash rate to day crash rate decreased by 36% in the after condition. It is still a concern that the total number of crashes increased as a result of the increase in the number of day crashes. Two intersections accounted for 18 of the day crashes in the after condition which was 17% of the total number of crashes at the 48 intersections.

A linear regression model was used to evaluate whether the ratio of night to total crashes had decreased. The expected ratio of night to total crashes was reduced by 10% from the before to the after period but results were not statistically significant at the 10% level of significance.

A Poisson regression model was used to evaluate the change in crash rate from the before to after period. Initially the Poisson regression analysis included all 48 intersections. However model results were not conclusive and after consultation with a statistician it was determined that given that crashes are rare events, inclusion of intersections with short analysis periods may have skewed the results. Consequently, it was determined that the Poisson regression analysis would only include intersections with three years of before and three years of after data. A total of 33 intersections met these criteria. Model results indicated that the night crash rate from the before to the after period was lower and statistically significant. and that the expected crash rate in the before period (unlighted) was 59% higher than the estimated crash rate in the after period (lighted) during the night. Additionally, the estimation of the crash rates during the day was 71% less than at night in the before period, while the estimation in the day is 52% less than at night in after period.

The total number of nighttime crashes decreased in the after period. Results of the Poisson regression analysis suggests that there is a significant difference in the night crash rate between the before and after periods and the difference is significant at the 10% level. The night crash rate in the before period was 59% higher than the crash rate in the after period. The linear regression model indicated that the ratio of night to total crashes decreased in the after period but that the difference was not significant at the 10% level. Comparing these results to the increase in the number of daytime crashes and day crash rate also infers that the lighting at these intersections may have contributed to these reductions, as no other significant changes occurred at the intersections.

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 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.

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 "first 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. The second analysis evaluated isolated rural intersections before and after installation of 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 the effectiveness of rural lighting in reducing nighttime crashes at isolated rural intersections
- 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 first 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 48 intersections 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.

The first LRRB study (Preston and Schoenecker, 1999) using a sample size of 12 intersections 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 lighting 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 lighting. The researchers report that lighting 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 an analysis before and after lighting was installed 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 first 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 were 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

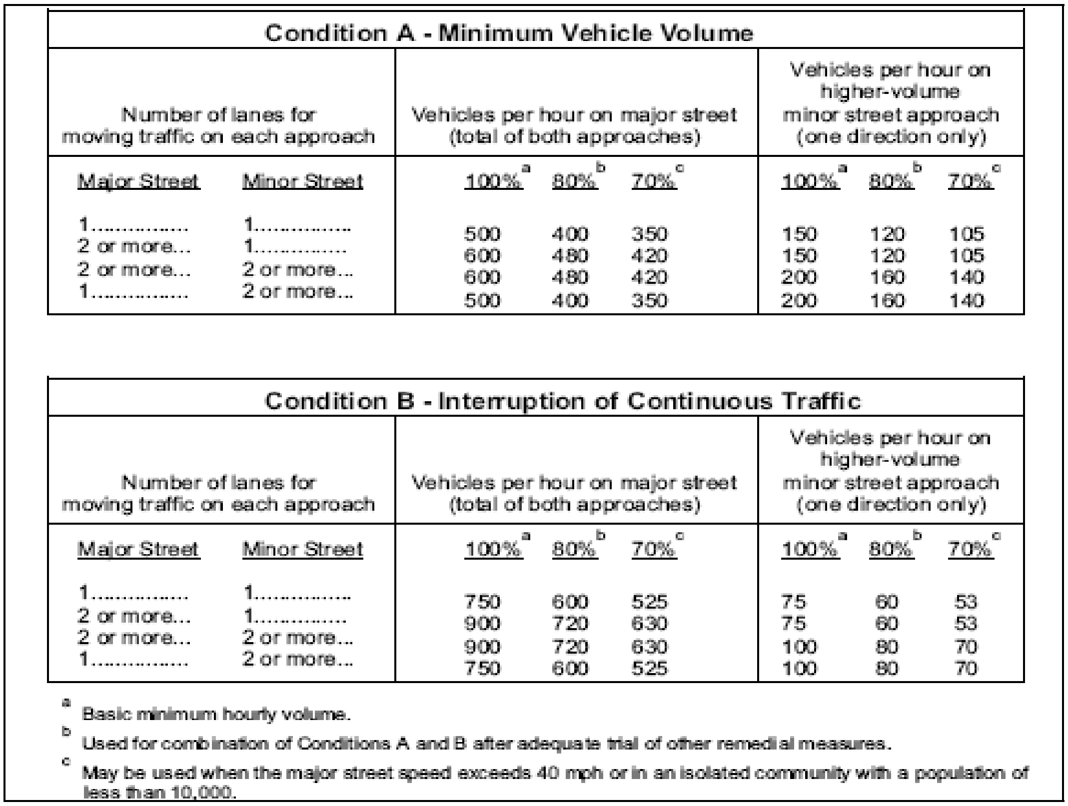
3. WARRANTS

Warrants for installation of street lighting were discussed in detail in the first LRRB study. From the study, it was concluded that the existing 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** **Traffic signal warrants for the following:** **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**
Crashes	**3 or more crashes per year occurring during conditions other than daylight**
Intersecting roadway	**Intersecting roadway is lighted**
Channelization	**The intersection is channelized and the 85th percentile approach speed exceeds 40 mph (a continuous median is not considered channelization for the purpose of this warrant).**
School crossing	**Certain events that result in pedestrian volumes ≥ 100 pedestrians/hour during non-daylight hours**
Signalization	**Intersection is signalized**
Flashing beacons	**Flashing beacons are present in advance of the intersection**

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 in many cases. 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: Major Street	Minor Street	Vehicles per hour on major street (total of both approaches): 100%[a]	80%[b]	70%[c]	Vehicles per hour on higher-volume minor street approach (one direction only): 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: Major Street	Minor Street	Vehicles per hour on major street (total of both approaches): 100%[a]	80%[b]	70%[c]	Vehicles per hour on higher-volume minor street approach (one direction only): 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 first 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 first 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 first 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 ≥ 2.0 accidents/MEV/yr and ≥ 4.0 accidents/yr in 3 consecutive years, or ≥ 3.0 accidents/MEV/yr and ≥ 7.0 accidents/yr in 2 consecutive years
Iowa	See Table 3.4
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 Intersections: 4.0 nighttime accidents in 1 year or ≥ 6.0 in 2 years, or ≥ 6.0 total accidents in ≤ 3 years and night-to-day crash rate ratio is ≥ 1.5
Oklahoma	ADT ≥ 6,000 for 2 lane highway, or ADT ≥ 12,000 for 4 lane roadway, or ADT ≥ 4,000 for rural intersection mainline, or 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 “T” configuration, or Major route changes direction	**ADT ≥ 1750 entering vehicles, and channelized, or “T” configuration, or 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 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. As discussed both a comparative and before and after analysis were conduced. The comparative analysis compared crashes at both lighted and unlighted existing rural intersections in Minnesota to determine whether locations with lighting had proportionately less nighttime crash experience.

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 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

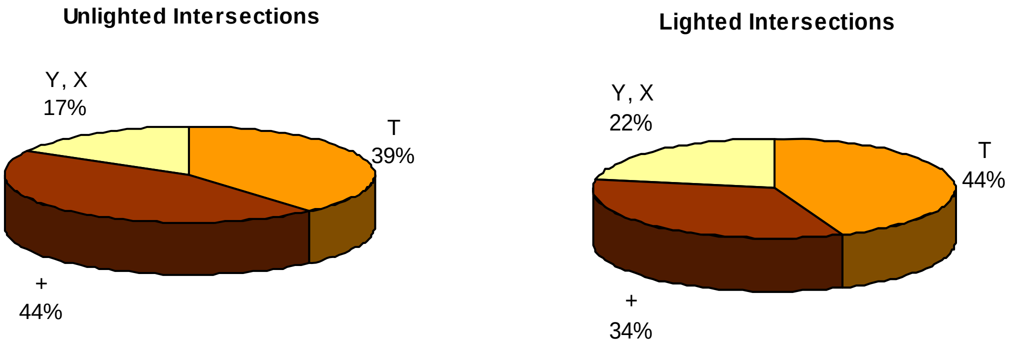


Figure 4.1. Rural intersections by geometry

4.1.2 Crash Data

Crash data were provided by Mn/DOT from the Intersection Accident Listing database. Crash data are coded and maintained by the Minnesota Driver Vehicle Services Department. 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

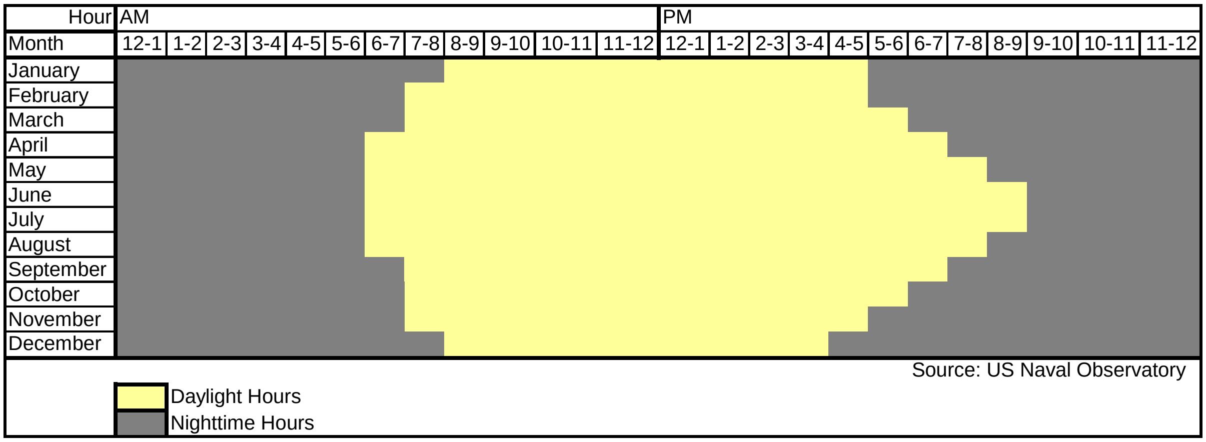
Volume data were allocated to nighttime and daytime periods so that both daytime and nighttime crash rates could be calculated. Average daily traffic (ADT) was available by approach in the intersection attribute database. Approach ADT was used to calculate daily entering volume (DEV), which reflects 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.

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

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.



Hour	AM												PM											
Month	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
January	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛	⬛
February	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛	⬛
March	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛
April	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛
May	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛
June	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛
July	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛
August	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛
September	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛
October	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛
November	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛	⬛
December	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛

Source: US Naval Observatory

🟨 Daylight Hours
⬛ Nighttime Hours

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 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 first 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	

As shown in Table 4.4, 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 factors, 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 27% 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:

$$Crash\ \ Rate = \frac{(Number\ \ of\ \ Crashes\ )x10^{6}}{(DEV_{i}\ )x(n\ \ years)x\left(365\ {}^{days}\!\big/_{year}\right)} \qquad (4.4)$$

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 at unlighted intersections was about 3% higher than lighted intersections. 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 Total crashes	%	Lighted intersections 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.

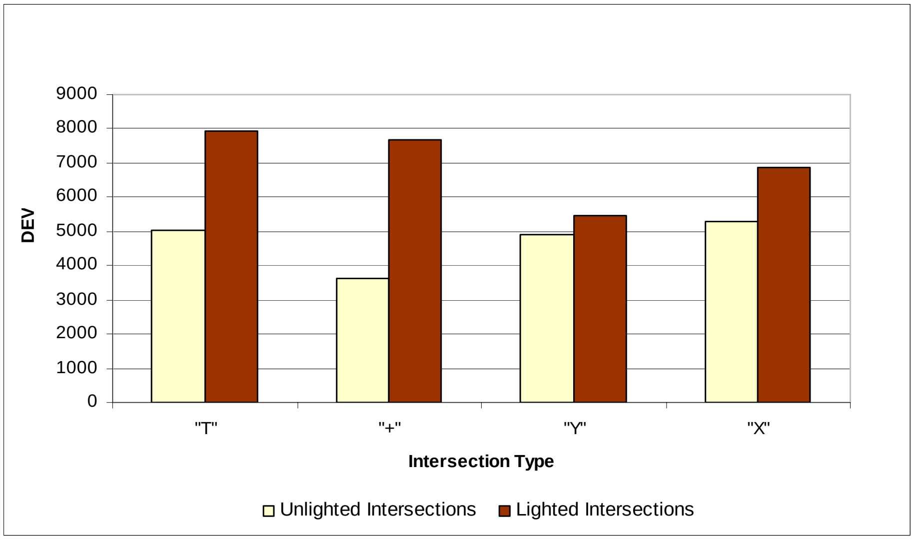


Figure 4.3. Average DEV by intersection geometry

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 1–lighted
	Daily entering volume	Value
	Number of approach legs	0–Four 1–Three
	Posted speed limit[1]	0 - = 55 mph 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 SAS output for 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. In order to compare mean crash rates at lighted intersections with unlighted intersections during day or night or in total, the model must consider lighting, day or night and their interactions. The interaction between two variables shows the effect of one variable on the other variable. Therefore four combinations needed to be considered (lighted-day, lighted-night, unlighted-day, unlighted-night) in the model. The best fit model includes presence of lighting; day or night condition; the interaction between lighting and the day or night condition; approach speed; and number of approach legs. The presence of lighting was the only variable that was not statistically significant at the 10% level. This was not unexpected because the mean night crash rates were very similar (0.59/MEV and 0.57MEV). Table 4.14 summarizes the level of significance for each variable in the model. Consequently, the Poisson regression model suggests that night crash rates at unlighted intersections was 6% lower than lighted intersections and not significant, when posted speed and number of approach legs are constant. Intersections with all posted approach speeds equal to 55 mph have crash rates 28% higher than approaches with at least one leg less than 55 mph. Lastly, intersections with four-approaches have crash rates 51% higher than three-approach intersections. The SAS output for the best fit model in presented in Appendix G.

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

Explanatory variables	Level of significance (p-value)
Day/night	<0.0001
Lighting	0.4893
Interaction of day/night and lighting	<0.0001
Approach speed	<0.0001
Number of approach legs	<0.0001

As shown in Table 4.15, the results are consistent to the descriptive statistics in Table 4.6. The crash rate is 41% lower during the day than during night and 22% lower for unlighted sites than lighted sites for the comparative analysis and both are significant. Looking at individual intersections, day crash rate is 51% lower than night crash rate at unlighted sites and 29% lower than night crash rate at lighted sites.

The day crash rate at unlighted sites is 35% lower than lighted sites and is statistically significant, while the night crash rate at unlighted intersections is 6% lower than at lighted intersection. During the day, while lights have no effect on crash rates, unlighted intersections still have 35% lower crash rates compared to lighted intersections. This 6% estimation of difference is not statistically significant, because the p-value of this difference is larger than 10%. The total crash crate was significant with unlighted intersections having a 39% lower crash rate.

Table 4.15. Comparison of mean crash rates in the comparative model

Difference in mean crash rates in percentage	Estimate of the difference in percentage (%)	Level of significance (p-value)
Day vs. Night	- 41%	<0.0001
Unlighted vs. Lighted	- 22%	0.0009
(Day vs. Night) at Unlighted	-51%	<0.0001
(Day vs. Night) at Lighted	- 29%	<0.0001
(Unlighted vs. Lighted) at Day (day crash rate)	- 35%	<0.0001
(Unlighted vs. Lighted) at Night (night crash rate)	-6%	0.4893
(Unlighted vs. Lighted) Day and Night (total crash rate)	-39%	0.0009

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 the variables lighting, day or night, posted speed, and number of approach legs, all variables except lighting were statistically significant. The expected night crash rate at unlighted intersections was 6% lower than lighted intersections. Intersections with all posted approach speeds equal to 55 mph have crash rates 28% higher than approaches with at least one leg less than 55 mph and intersections with four-approaches have crash rates 51% 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.

For this model, the unlighted intersections cannot be treated well as a control group for the lighted intersections (treated group). Two hypothesized reasons for this conclusion are the differences in the number of intersections analyzed and the average DEV between the two groups. First, it is suspected that the difference in the number of lighted (223) vs. unlighted (3,399) intersections in the database may have skewed the model and results. Second, the average DEV for the lighted intersections is approximately 40% higher than the average DEV at the unlighted intersections.

It is difficult to deduce robust conclusions from the statistical comparative analysis, as the results are not overwhelmingly conclusive. The night to total crash ratio was higher at lighted intersections and statistically significant, while the night crash rate at unlighted intersections was not statistically significant despite a 6% lower crash rate at lighted intersections.

Due to the difference in the number of the intersections and average DEV between the lighted and unlighted intersections in the dataset, the confidence in the comparative analysis results are low and another statistical analysis may provide more robust results. Another method of analyzing the effect of lighting at intersections is to collect data at the same intersections for years both before and after lighting has been installed. In this case, crash rates in before and after periods would be comparable because they are collected from same intersections, and hence intersections in before period can be a good control group for intersections in after period.

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 were 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 could not be determined
- Lighting was installed prior to 1985, when reliable crash data were not available
- Other significant improvements to the intersection had been made in addition to lighting

The final list was reduced to 48 intersections in 17 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	10
2002	2
2001	2
2000	2
1995–1999	7
1990–1994	19
1986–1989	3
1985	3

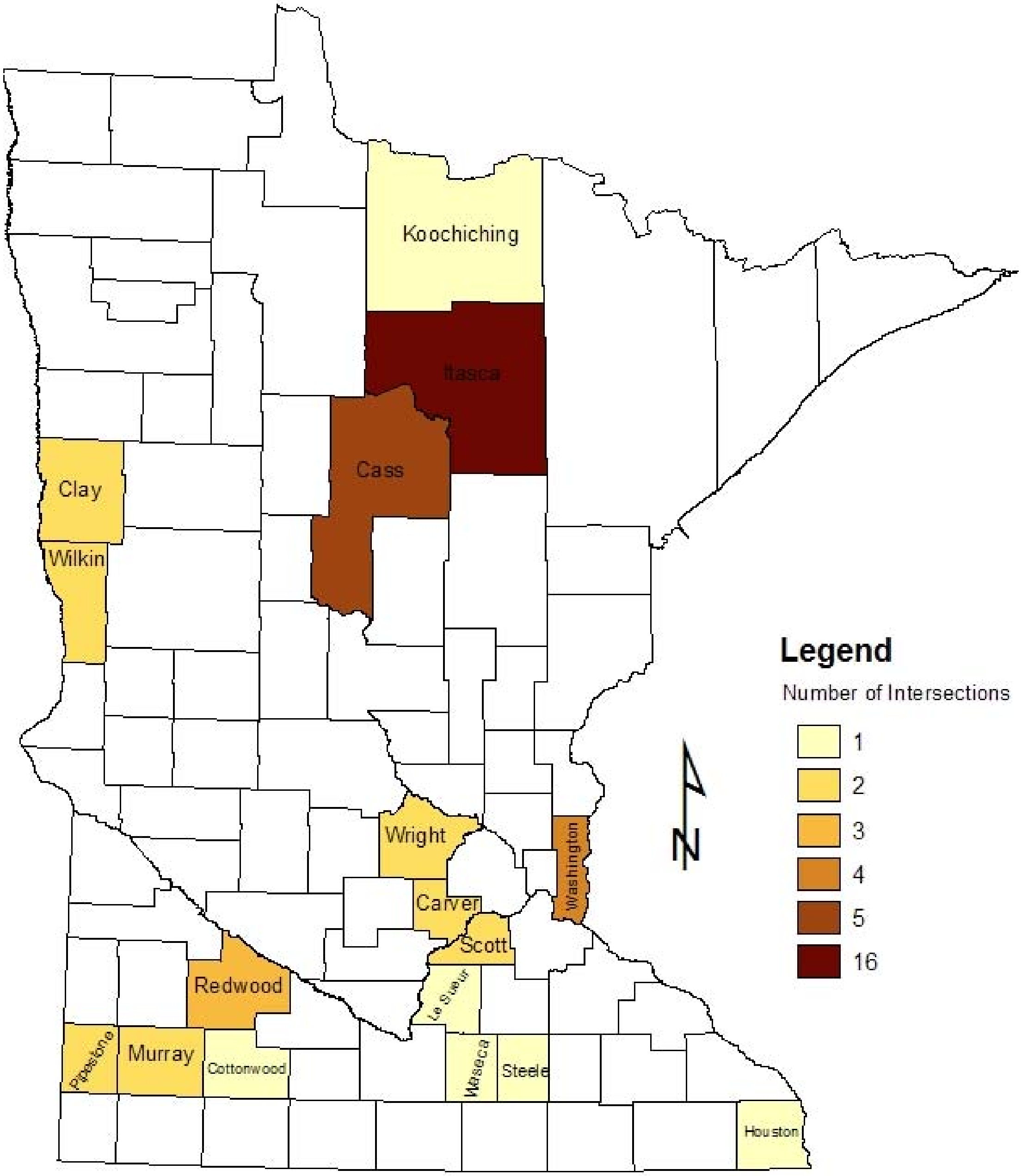


Figure 5.1. Counties with intersections included in before-and-after study

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 48 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 22 have the state trunk highway system as the major route. Approximately 46% 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 intersections in 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	26	25	16	10
3 legs	22	18	10	12
Total	48	43	26	22

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	18

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 2005 was obtained from the Mn/DOT for each of the 48 intersections. Mn/DOT reported that crash data prior to 1984 was not reliable and as a result data prior to 1984 was not included. The crash inventory was queried to include only those crashes that occurred within 300 feet of the intersection, which were assumed to be intersection related for this analysis.

5.4.3 Analysis Periods

For the majority of intersections, a three year before and three year after period was used. As discussed previously, data prior to 1984 were not included. As a result three intersections had only two years of before data. Twelve intersections were installed more recently and as a result, only two years of after data were available. Since the before and after analysis periods were not

always consistent, 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 were analyzed 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	Intersections
3 years before/3 years after	33
3 years before/2 years after	12
2 years before/3 years after	3

Table 5.5. Street light installation years for analysis

Year of installation	Number	Analysis year of installation	Number
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 updates 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	26		22		48	
	Before	**After**	**Before**	**After**	**Before**	**After**
Day exposure	65,490	80,890	69,446	76,946	134,936	157,836
Night exposure	19,562	24,162	20,744	22,983	40,306	47,146
Total exposure	85,053	105,052	90,189	99,929	175,242	204,981
Day exposure/intersection	2,518	3,111	3,157	3,498	2,811	3,288
Night exposure/intersection	752	929	943	1,045	840	982
Total exposure/intersection	3,271	4,040	4,100	4,542	3,651	4,270

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

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 15% and 11%, respectively, with an overall decrease of 13%. The reduction in crashes was lower than the first LRRB study that concluded a 25–40% reduction for 12 rural intersections; however, the sample size for this study was almost 3 times larger.

Table 5.7. Crash frequency by roadway type

Before-and-after crash data	County intersections		State intersections		All intersections	
Number of intersections	26		22		48	
	Before	**After**	**Before**	**After**	**Before**	**After**
Day crashes	32	43	19	25	51	68
Night crashes	20	17	27	24	47	41
Total crashes	52	60	46	49	98	109
% Day crashes	62%	72%	41%	51%	52%	62%
Day crashes/intersection/year	.42	.67	.29	.39	.36	.54
Night crashes/intersection/year	.27	.28	.41	.42	.33	.34
Total crashes/intersection/year	.69	.94	.70	.80	.69	.88

[1] It should be noted that two county intersection accounted for18 daytime crashes in the after period, an increase of 16 crashes from the before period.

During the same period, the number of daytime crashes increased by 11%. 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.

$$Expected\ \ Night\ Crashes_{after} = \frac{Day\ Crashes_{after}}{Day\ Crashes_{before}} x\ Night\ Crashes_{before} \tag{5-1}$$

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

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

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

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

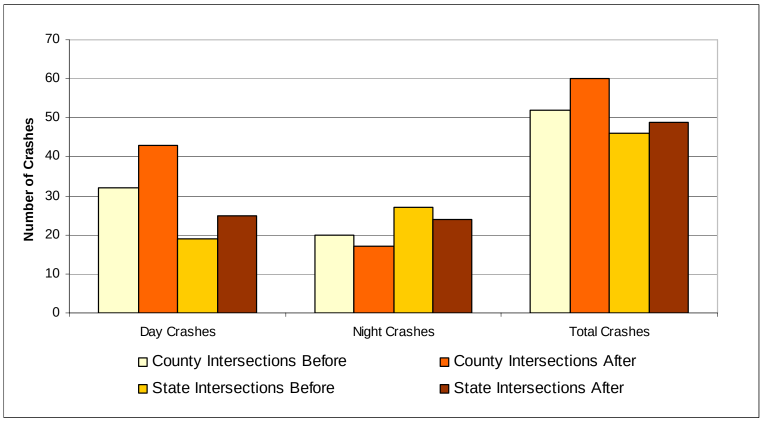


Figure 5.2. Crash frequency

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 27. A total of 17 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 24 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 (observed)	After (observed)	After (expected)
County	**20**	**17**	**27**
State	**27**	**24**	**36**
All	**47**	**41**	**63**

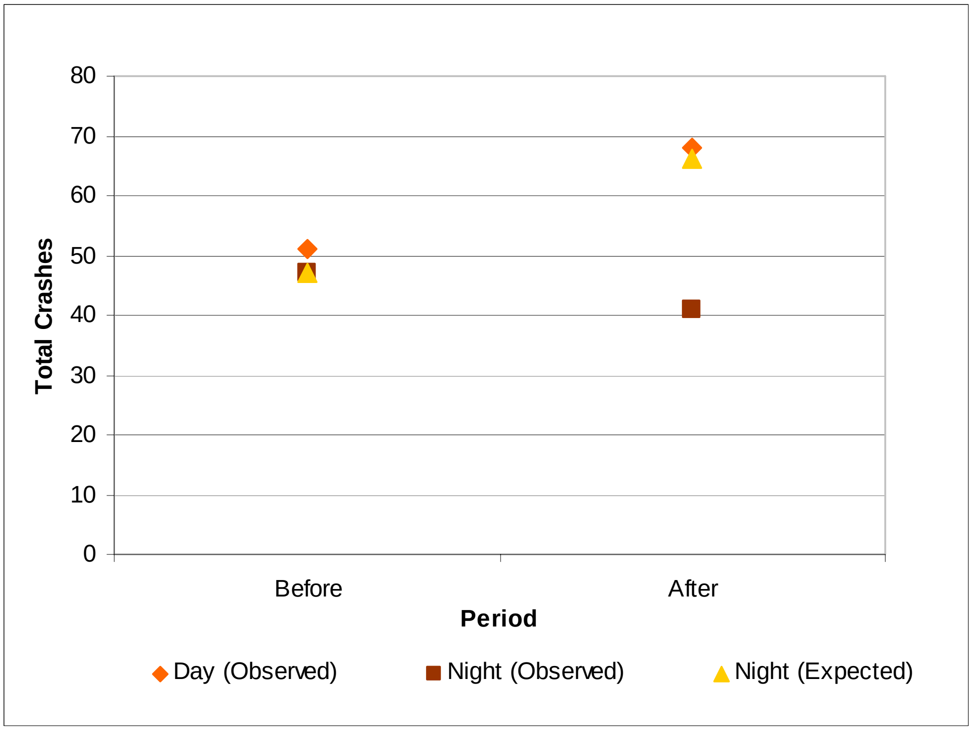


Figure 5.3. Crashes observed and nighttime crashes expected based on day crash trend

Considering intersections on an individual basis, 35% of the intersections had a reduction in the number of nighttime crashes and 38% showed no change. The number of daytime crashes decreased at 40% of the intersections and remained unchanged at 25%. 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 21% and 35%, respectively, 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	0.38	0.28	0.59	0.49	0.48	0.38
Night/day crashes	0.63	0.40	1.42	0.96	0.92	0.60

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.

$$\text{Crash Rate} = \frac{\left(\sum_{l} \#\text{ of Crashes}_{l}\right) \times 10^{6}}{\left(\sum_{l} \text{DEV}_{\text{ave},l} \times \text{n}_{l}\, years\right) \times 365\, \frac{\text{days}}{\text{year}}} \qquad (5.2)$$

where l = *ID of the intersection*

n_l = *analysis time period, taking on values of 1,2,3 years*

$DEV_{ave,l}$ = *average daily entering volume for the* l^{th} *intersection (day or night or total)*

 # of $Crash_l$ *=number of crashes at* l^{th} *intersection*

The crash rates at night decreased by 19% in the after period for all intersections. Results are presented in Table 5.10. Day crash rates increased in the after period by 26% and the total crash rate increased by approximately 4%. The ratio of night crash rate to day crash rate decreased by 36% 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	0.46	0.57	0.25	0.32	0.35	0.44
Night crash rate	0.97	0.75	1.19	1.07	1.09	0.88
Total crash rate	0.58	0.61	0.47	0.47	0.52	0.54
Ratio of night to day crash rate	2.11	1.32	4.76	3.24	3.11	2.00

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 no change for personal injury and fatal crashes compared to a 15% decrease for the state intersections. Overall, there was an 11% reduction in the number of personal injury and fatal crashes at night for all intersections as shown in Table 5.11 and Figure 5.4. The ratio of nighttime personal injury and fatal crashes to total crashes, including property damage, increased by 13% overall. Property damage crashes occurring at night were reduced by 14%. 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 38% and 30% 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 decreased slightly from 1.13 to 1.06.

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	15	12	14	13	29	25
Personal injury[1]	4	5	13	11	17	16
Fatal	1	0	0	0	1	0
Ratio of personal injury and fatal crashes/total crashes	0.33	0.42	0.93	0.85	0.62	0.64
Day						
Property damage	13	22	11	11	24	33
Personal injury[1]	18	21	7	14	25	35
Fatal	1	0	1	0	2	0
Ratio of personal injury and fatal crashes/total crashes	1.46	0.95	0.73	1.27	1.13	1.06

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

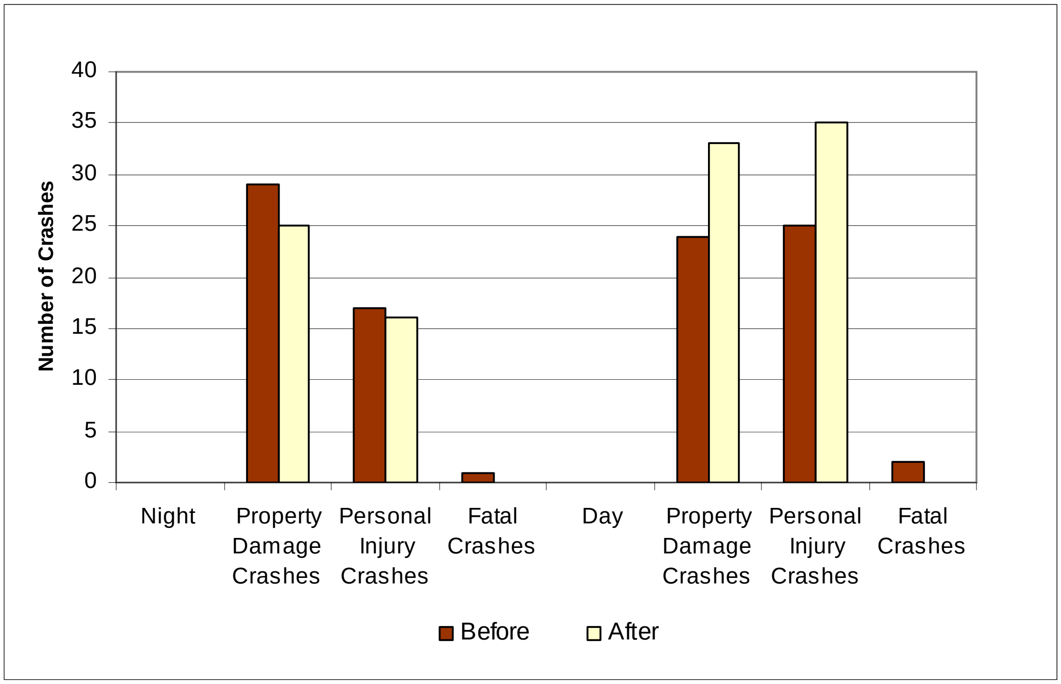


Figure 5.4. Crash severity for all intersections

5.5.4 Crash Types

Mn/DOT categorizes crashes into 12 different collision types. All crashes for these categories are 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 one intersection accounted for 9 of these crashes.

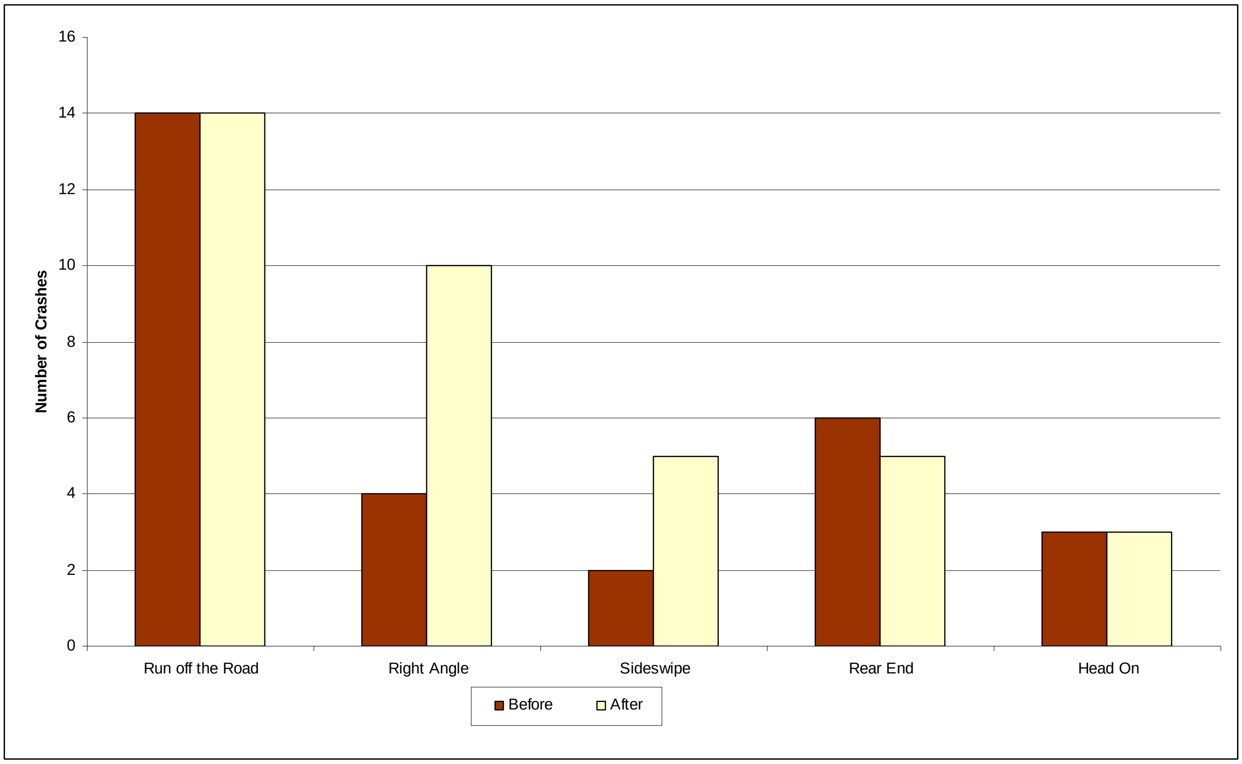


Figure 5.5. Nighttime collision types for all intersections

Single vehicle crashes occurring at night were reduced by 19% and multiple vehicle crashes by 5%. The results are presented in Table 5.12. Multiple vehicle crashes accounted for slightly less crashes at night than single vehicle crashes in the after period, while almost 74% of the crashes during the day involved multiple vehicles in the after condition.

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	12	10	14	11	26	21
Multiple vehicle crashes	8	7	13	13	21	20
Day						
Single vehicle crashes	6	12	3	6	9	18
Multiple vehicle crashes	26	31	16	19	42	50

5.5.5 Crashes by Intersection Geometry

Three-approach T intersections account for 36% and 55% 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 (21% and 27%) in night crashes after lighting was installed while day crashes increased. Overall, 3-approach intersections (11%) and 4-approach intersections (8%) show approximately the same decrease in the number of night crashes. 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						
3 Approach	9	7	15	14	24	21
4 Approach	11	10	12	10	23	20
Day						
3 Approach	3	12	10	9	13	21
4 Approach	29	31	9	16	38	47

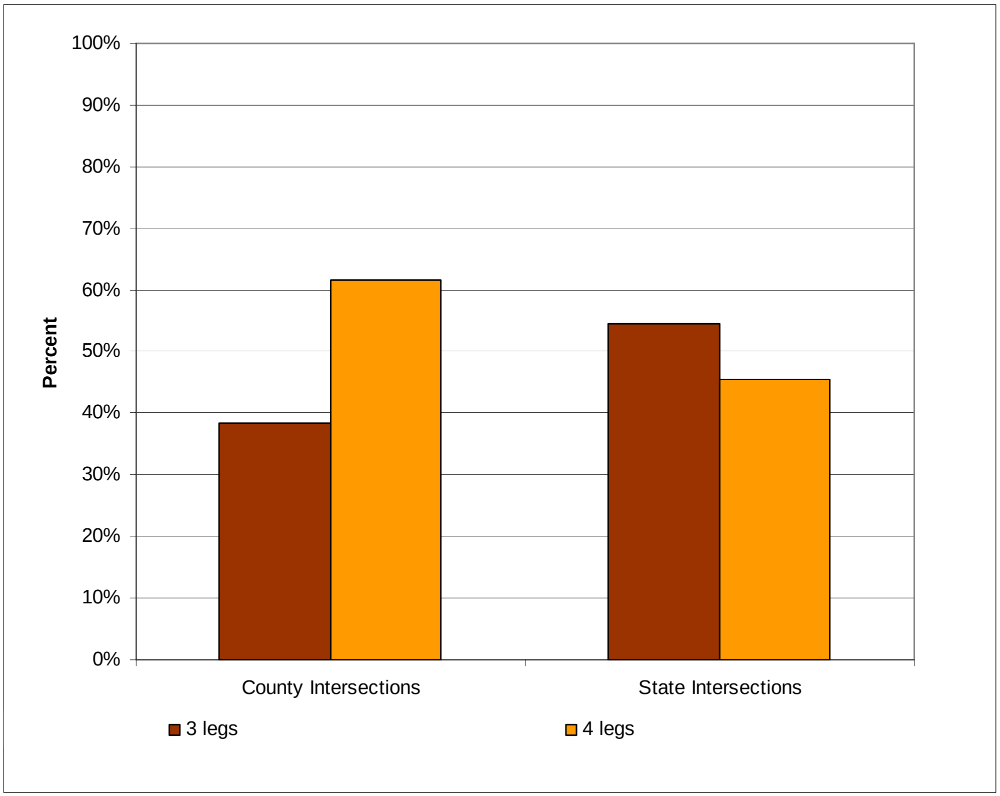


Figure 5.6. Percentage of intersections by geometry

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. For the before-and-after analysis, the model was adjusted to account for the repeated measurement for each intersection that represented the before and after periods and also for day and night. This is necessary since each intersection is sampled twice (before during night and after during night) for linear regression model, and four times (once in the before period during day, once in the before period during night, once in the after period during day, and once in the after period during night) for Poisson regression model.

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 whether the crash occurred during the day or night, 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 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.

Table 5.14. Before and after model parameters tested

Variables	Definition	Parameters	Values
Response Variables	Crash rate (Poisson)	CRTOTDN*[1], DEV[2]	Predicted
	Ratio of night to total crashes (mixed linear)	RATNTOT	Predicted
Explanatory Variables	Day/Night	DN	0 – day 1 – night
	Period	Period	0 – Before 1 – After
	Daily entering volume	DEVDNAVE	Value
	Number of approach legs	APPR	0 – 4 1– 3
	Posted speed limit[3]	SPD	0 - = 55 mph 1 - < 55 mph
	Intersection control	INTCNTRL	0 – AWSC [4] 1 – OWSC/TWSC
	Presence of turn lanes	TURN	0 – No 1 – Yes
	Number of lanes in one direction	LANESNUM	0 – 1 1 – 1+,2
	Type of lighting pole	POLE	1 – Power pole 2 – Light Pole
	Presence of a curve	CURVE	0 – No 1 – Yes
	Number of years in the period	YEARS	1, 2, 3
	Repeated variable	ID	1, 2,. . ., n

[1] The night crash rates and day crash rates were analyzed together.

[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

5.6.3 Linear Regression Model

A mixed linear regression model compared the means for the ratio of night to total crashes. In the model, the number of years in the period was weighted to account for the before and after periods with unequal number of years. All of the explanatory variables were considered in the linear model. The best fit model only included period and nighttime DEV. The ratio of night to total crashes model shows that the DEV is significant between the before and after periods, which is expected since the traffic volumes increased during this time period. The expected ratio of night to total crashes was reduced by 10% in the after period; however, the results indicated that the reduction in the ratio of night to total crashes from the before period to the after period is not statistically significant at the 10% level. The results are presented in Table 5.15.

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

Explanatory Variables	Level of Significance (p-value)
Period	**0.189**
DEV	**0.034**

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. Originally the analysis included all 48 intersections. However, after examining initial model results and consulting with a statistician, it was determined that use of before and after periods that were shorter than three years affected model results given that crashes are rare events. Several intersections had only two years of after data and three only had two years of before data. As a result, for the Poisson regression model, only the 33 intersections which had a three full years of before and three full years of after data were included in the final model.

All of the explanatory variables were considered in the model; however, it was determined that the best fit model included only day and night, period, and the interaction of day and night. The explanatory variables day/night, period, and the interaction between day/night and period indicated they were significant at the 10% level. The night crash rate is 59% higher in the before period than the after period and is statistically significant. Table 5.16 below shows the statistical significance of explanatory variables for crash rate in the before and after analysis.

Table 5.16. Statistical significance of explanatory variables for crash rate in the before and after model

Explanatory variables	**Level of significance (p-value)**
Day/night	0.001
Period (before or after)	0.095
Interaction of day/night and period	0.100

Other statistical significance comparisons are shown in Table 5.17. The crash rate is 62% lower during day than during night and is statistically significant. The estimated crash rate is 24% higher for the before period than after period for all crashes but is not significant at the 10% level of significance. The estimation of the crash rates during the day is 71% less than at night in before period, while the estimation in the day crash rate is 52% less than at night in after period. Both of these estimations are significant. The day crash rate and total crash rates in the before periods are 4% lower and 53% higher, respectively, than in the after period but neither are significant at the 10% level of significance.

Table 5.17. Comparison of mean crash rates in the before and after model

Difference in mean crash rates in percentage	**Estimate of the difference in percentage (%)**	**Level of significance (p-value)**
Day vs. Night	- 62%	<0.0001
Before vs. After	24%	0.3698
(Day vs. Night) in Before	-71%	<0.0001
(Day vs. Night) in After	- 52%	0.0010
(Before vs. After) at Day (day crash rate)	- 4%	0.8847
(Before vs. After) at Night (night crash rate)	59%	0.0953
(Before vs. After) at Day and Night (total crash rate)	53%	0.3698

5.7 Summary of Before-and-After Analysis

The before-and-after analysis evaluated the effects of street lighting on crashes at 48 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 13% after lighting was installed. The same measurements for day crashes showed an increase by 11% in the after period. A 21% reduction was also found for the night to total crash ratio and a 35% reduction for the day to night crash ratio. The night crash rate was reduced by 19% and the ratio of night to day crash rate was reduced by 36% in the after period. Again, the day crash rate increased by 26% 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 11% in the after period and day crash severity increased by 30%. Single vehicle night crashes were reduced by 19% and multiple vehicle night crashes were reduced by 5%.

Two statistical models were also used to test the statistical significance between the before and after periods. Since this study considers both statistics with and without DEV, a more in depth examination can be made for the effectiveness of lighting on nighttime crashes. 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 variable that was statistically significant was nighttime DEV. Although the period was not statistically significant, the expected ratio of night to total crashes was reduced by 10% in the after period.

Poisson regression was also used to compare mean crash rates during the before-and-after periods to determine statistical significance. As indicated, the analysis originally included all 48 intersections. However, after examining initial model results and consulting with a statistician, it was determined that use of before and after periods that were shorter than three years affected model results given that crashes are rare events. Consequently, for the Poisson regression model, only the 33 intersections which had three full years of before and three full years of after data were included in the final model.

The explanatory variables day/night, period, and the interaction between day/night and period were all statistically significant in the model. The expected night crash rate in the before period was 59% higher than the after period.

The statistical results for the Poisson model suggests that there is a significant difference in the night crash rate between the before and after periods at the 10% level and despite the lack of statistical significance for the night to total crash ratio at the 10% level, a reduction in the night to total crash ratio occurred between the before and after period. In summary, the total number of nighttime crashes decreased in the after period, the ratio of night to total crashes decreased in the after period, and the night crash rate decreased in the after period. In fact, the Poisson regression model showed that the night crash rate in the before period was higher (59%) than the crash rate in the after period. Comparing these results to the increase in the number of daytime crashes and day crash rate also infers that the lighting at these intersections may have contributed to these reductions, as no other significant changes occurred at the intersections.

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 another study evaluated crash data for 48 intersections before and after installation of street lighting. 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, determined by descriptive statistics, was 3% lower at lighted intersections. 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. The best fit model includes presence of lighting, day or night condition and the interaction between lighting and the day or night condition, approach speed, and number of approach legs. The presence of lighting was the only variable that was not statistically significant. The Poisson regression model suggests that night crash rates at unlighted intersections were 6% lower than lighted intersections. During the day, while lights have no effect on crash rates, unlighted intersections still have 35% lower crash rates compared to lighted intersections and this is statistically significant at the 10% significance level.

Intersections with all posted approach speeds equal to 55 mph had night crash rates that were 28% higher than approaches with at least one leg less than 55 mph. Intersections with four-approaches had night crash rates 55% higher than 3 approach intersections. This implies that lighting may be more beneficial at intersections with 55 mph posted approach.

For this model, the unlighted intersections cannot be treated well as a control group for the lighted intersections (treated group). Two hypothesized reasons for this conclusion are the differences in the number of intersections analyzed and the average DEV between the two groups. First, it is suspected that the difference in the number of lighted (223) vs. unlighted (3,399) intersections in the database may have skewed the model and results. Second, the average DEV for the lighted intersections is approximately 40% higher than the average DEV at the unlighted intersections. It is difficult to deduce robust conclusions from the statistical comparative analysis, as the results are not overwhelmingly conclusive. Table 6.1 provides a summary of the comparative results.

Table 6.1 Comparative analysis summary

	Unlighted	**Lighted**	**Change**	**Statistical Significance**
Night to Total Crash Ratio	0.38	0.30	27% higher at unlighted	YES Expected night to total crash ratio is 7% higher at unlighted
Night Crash Rate	0.59	0.57	3% higher at unlighted	NO Expected night crash rate was 6% lower at unlighted
Overall the crash rate during the day was 41% lower than during the night.				
Overall the crash rate is 22% lower for unlighted intersections than lighted intersections.				
Day crash rate at unlighted intersections is 35% lower than lighted intersections.				

6.1.2 Before-and-After Analysis

The reduction of night-time crashes after the installation of street lighting was evaluated at 48 rural intersections. The before-and-after analysis showed a 13% reduction in night crash frequency, a 21% reduction for the ratio of night to total crashes and a 19% reduction in the night crash rate. Day crash frequency and rate increased by 11% and 26%, respectively, from the before to after periods. The number of intersections that had a reduction in the frequency of night crashes was 35% after lighting was installed. Crash severity (for fatal and severe crashes) decreased at night by 11% in the after period and day crash severity increased by 30%.

A linear regression model was used to evaluate the reduction in the ratio of night to total crashes at the 48 rural intersections. The model indicated that the reduction in the ratio between the before and after analysis periods was not statistically significant even though the expected ratio of night to total crashes was reduced by 10% in the after period.

A Poisson regression analysis was also used to evaluate crash rate before and after lighting was installed. Initially the Poisson regression analysis included 48 all intersections. However model results were not conclusive and after consultation with a statistician it was determined that given that crashes are rare events, inclusion of intersections with short analysis periods skewed results. Consequently, it was decided that the Poisson regression analysis would only include intersections with three years of before and three years of after data. A total of 33 intersections met this criteria. Final model results showed that the estimated crash rate in the before period (unlighted) was 59% higher than the estimated crash rate in the after period (lighted), and was significant at the 10% level of significance. The estimation of the crash rates during the day were 71% less than at night in before period, while the estimation in the day is 52% less than at night in after period. Lastly, the day crash rate in the before period was 4% lower than the after period.

The statistical results for the Poisson model suggests that there is a significant difference in the night crash rate between the before and after periods at the 10% level. A reduction in the night to total crash ratio occurred from the before and after period although it was not statistically significant at the 10% level of significance. Additionally, the total number of nighttime crashes decreased in the after period. Comparing these results to the increase in the number of daytime crashes and day crash rate also infers that the effect of the lighting at these intersections may have contributed to these reductions. Table 6.2 provides a summary of the before and after analysis.

Table 6.2 Before and After Summary

	Before	After	Change
Night Crash Frequency	47	41	13% reduction
Day Crash Frequency	51	68	11% increase

	Before	After	Change	Statistical Significance
Night to Total Crash Ratio	0.48	0.38	21% reduction	NO Expected night to total crash ratio was reduced by 10% in the after period
Night Crash Rate	1.09	0.88	19% reduction	YES Expected crash rate in the before period was 59% higher than the after period
Overall the crash rate is 62% lower during the day than during the night.				
Overall the crash rates during the day is 71% and 52% less than at night for the before period and after periods, respectively, and both are significant.				
Day crash rate is 4% lower in the before period.				

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 first LRRB study that reported a 25–40% reduction in crash frequency for 12 intersections before-and-after installation of intersection lighting. As presented above, this research found a statistically significant reduction in the night crash rate in the before and after analysis, but did not find statistically significant reduction in the ratio of night to total crashes in the before-and-after analysis. Conversely, a reduction in night crash frequency, ratio of night total crashes and night crash rate were found. This suggests that the installation of street lighting may contribute to the reduction in the frequency of crashes, night to total crash ratio, and nighttime crash rates. The results of this dataset are consistent with the findings of the first LRRB 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 first 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 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 existing 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			Unlit Weight (A)	Lighted Weight (B)	Diff (A-B)	Score Rating x(A-B)
	1	2	3	4	5				
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

Classification for Intersection Lighting

Classification Factor	Rating					Unit Weight (A)	Lighted Weight (B)	Diff (A-B)	Score Rating x(A-B)
	1	2	3	4	5				
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 ______________

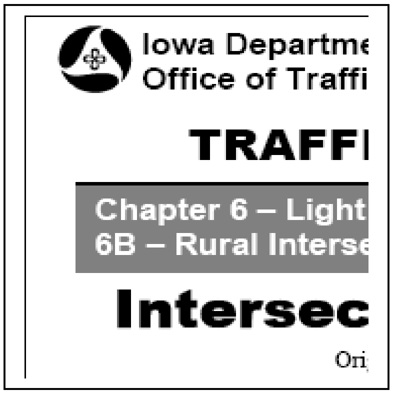
Environmental Total ______________

Accident Total ______________

Sum ______________ Points

Warranting Condition = 75 points

APPENDIX C: IOWA DOT INTERSECTION LIGHTING WARRANTS



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- 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 D: MN/DOT ATR VOLUMES BY TIME OF DAY

	County State Aid Highway (CSAH)					
2002	**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%

	Rural Trunk Highway																		
2002	**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

In analyzing the data, there are two interests: the first is crash ratio (night crashes/total crashes) and the second is crash rate (number of crashes with respect to traffic volume). Two different statistical models were used to analyze the crash data and determine the statistical significance, a linear regression model and a Poisson regression model.

The linear regression model was used to compare the ratio of night to total crashes. This 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 and determine statistical significance of the explanatory variables in this model. 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 a different 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's (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. Moreover, if a dataset with crash rates is classified into day and night groups and before and after groups, this proposed model is also sufficient to compare the mean crash rates for day and night; before and after periods; and interactions of these two classification variables. This applies when the covariance structure is designed for repeated measurements to account for correlations among observations from the same intersection. SAS 9.1, a statistical software package, was used for the statistical analyses.

The linear regression model

$$y_{ij} = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \gamma_i + \varepsilon_{ij} \tag{E-1}$$

where:

$i = 1, 2, \ldots, \text{k}$, site and $j = 0, 1$, lighted or unlighted

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

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

β_0 = Unknown intercept

$\beta_1, \beta_2, \ldots, \beta_\text{k}$ = Unknown effect paramter

γ_i = Random error due to repeated measuremen t (if needed)

ε_{ij} = Unknown error

If the response variable is observed repeatedly at each site, then the model requires γ_i, as a modification to validate the assumptions for this model. If γ_i is not included to adjust the model for repeated measurements, then the distribution for assumption y_{ij} may not be the real distribution that y_{ij} follows, and hence parameter estimations would be not accurate, or robust, or even wrong. If the response variable is observed repeatedly at each site, and the model includes γ_i as a modification, the variance-covariance structure for this model is:

$$Cov(y_{il}, y_{jk}) = \begin{cases} 0, \text{if } i \neq j \\ \gamma_i, \text{if } i = j, l \neq k \\ \gamma_i + \varepsilon_{il}, \text{if } i = j, l = k \end{cases} .$$

<u>The Poisson regression models</u>

(I) Comparative analysis:

$$y_{ij} \sim Poisson(\mu_{ij}) \tag{E-2-1}$$

$$\mu_{ij} = e^{\log x_{ij}} e^{\beta_0 + \beta_1 x_{ij1} + \beta_2 x_{ij2} + \ldots + \beta_k x_{ijk} + \varepsilon_{ij}} \tag{1-a}$$

$$\mu_{ij} = x_{ij} \times e^{\beta_0 + \beta_1 x_{ij1} + \beta_2 x_{ij2} + \ldots + \beta_k x_{ijk} + \varepsilon_{ij}} \tag{1-b}$$

$$\text{Crash} \quad \text{Rate}_{\text{ij}} = \frac{\mu_{ij}}{x_{ij}} = e^{\beta_0 + \beta_1 x_{ij1} + \beta_2 x_{ij2} + \ldots + \beta_k x_{ijk} + \varepsilon_{ij}} \tag{1-c}$$

where:

i = 1,2,...n, site and j = 0,1, day or night

μ_{ij} = Response variable (Expected number of crashes)

$$\text{x}_{\text{ij}} = \frac{\left(\text{DEV} \times \text{m years} \times 365(\text{days}/\text{year})\right)}{1{,}000{,}000}$$

$\text{x}_{\text{ij1}}, \text{x}_{\text{ij2}}, \ldots, \text{x}_{\text{ijk}}$ = Known explanatory variables

β_0 = Unkown intercept

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

ε_{ij} = Error, due to repeated measurements, errors may be correlated

(II) Before and after analysis:

$$y_{ijl} \sim Poisson(\mu_{ijl}) \tag{E-2-2}$$

$$\mu_{ijl} = e^{\log x_{ijl}} e^{\beta_0 + \beta_1 x_{ijl1} + \beta_2 x_{ijl2} + \ldots + \beta_k x_{ijlk} + \varepsilon_{ijl}} \tag{2-a}$$

$$\mu_{ijl} = x_{ijl} \times e^{\beta_0 + \beta_1 x_{ijl1} + \beta_2 x_{ijl2} + \ldots + \beta_k x_{ijlk} + \varepsilon_{ijl}} \tag{2-b}$$

$$\text{Crash} \quad \text{Rate}_{\text{ij}} = \frac{\mu_{ijl}}{x_{ijl}} = e^{\beta_0 + \beta_1 x_{ijl1} + \beta_2 x_{ijl2} + \ldots + \beta_k x_{ijlk} + \varepsilon_{ijl}} \tag{2-c}$$

where:

i = 1,2,...n, site and j = 0,1, lighted or unlighted and l = 0,1, day or night

μ_{ijl} = Response variable (Expected number of crashes)

$$x_{\text{ijl}} = \frac{\left(\text{DEV} \times \text{m years} \times 365\left(\text{days}/\text{year}\right)\right)}{1{,}000{,}000}$$

$x_{\text{ijl1}}, x_{\text{ijl2}}, \ldots, x_{\text{ijlk}}$ = Known explanatory variables

β_0 = Unkown intercept

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

ε_{ijl} = Error, due to repeated measurements, errors may be correlated

Similar to the linear regression model, the response variable is observed repeatedly at each site. The model above needs modification to validate the assumptions. If the model is not adjusted for repeated measurements, the distribution for assumption y_{ij} or y_{ijl} may not be the real distribution that y_{ij} or y_{ijl} follows, and hence parameter estimations would be not accurate, robust, or even wrong again. If the response variable is observed repeatedly at each site, and the model is modified, the variance-covariance structures for the comparative analysis and the before and after model, respectively will be,

$$Corr(y_{il}, y_{jk}) = \begin{cases} 0, \text{if } i \neq j \\ \alpha, \text{if } i = j, l \neq k \\ 1, \text{if } i = j, l = k \end{cases} \text{, and}$$

$$Corr(y_{ilm}, y_{jkn}) = \begin{cases} 0, \text{ if } i \neq j \\ \alpha, \text{if } i = j, l \neq k \text{ or } m \neq n \\ 1, \quad \text{if } i = j,\ l = k, m = n \end{cases}.$$

Comparative Analysis

Methodology

The test hypothesis of interest for the model was that the mean for the lighted intersections at night was equal to the mean of the unlighted intersections at night, written as H_0: $\mu_{.0,1} = \mu_{.1,1}$ or H_0: $\mu_{.0,1}/\mu_{.1,1=1}$. 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 ratio of night to total crashes for the linear regression and crash rate during day or night at lighted or unlighted intersection for the Poisson regression model. The explanatory variables used to compare the lighted and unlighted intersections include day/night, lighting, DEV, number of approach legs and posted speed limit. Table E.1 shows the variables and values for the models. Except for DEV, which is a continuous variable, all other variables are dummy variables, which indicate there are only two possible values (0 or 1).

Table E.1. Comparative model parameters tested

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

[1] The night crash rates and day crash rates were analyzed together in Poisson regression model.

[2] The Poisson model requires an "offset" term for this model to estimate rate in SAS.

[3] The night daily entering volumes and day daily entering volumes were used for night and day crash rates respectively. The Poisson model requires an "offset" term for this model in SAS.

[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.

$$\begin{aligned} \textit{Expected Ratio of Night to Total Crashes} &= \beta_0 + \beta_1 \textit{Period}(0,1) + \beta_2(\textit{DEV}) + \beta_3 \textit{APPR\_LEG}(0,1) \\ &= 0.1447 + (0.0691,0) + 0.000047(\textit{DEV}) + (-0.03591,0) \end{aligned} \qquad \text{(E-3)}$$

Poisson Regression Model

The Poisson regression model was used to compare the mean crash rates at lighted and unlighted intersections during night and day to determine statistical significance. In order to compare mean crash rates at lighted intersections with unlighted intersections during day or night or in total, the model must consider lighting, day or night and their interactions. The interaction between two variables shows the effect of one variable on the other variable. Therefore four combinations needed to be considered (lighted-day, lighted-night, unlighted-day, unlighted-night). For example, the meaning of β_3 in equation E-4, is the effect of day or night depending on lighting. It can be considered as the difference in crash rates between the difference of day and night at unlighted intersections and the difference at lighted intersections. For the model below, it includes lighting, day or night and their interactions. The model did not result in a statistically significant difference in all the explanatory variables.

Simple Model

The prediction equation for crash rate only considering lighting and day/night is shown in Equation E.4.

$$\begin{aligned} \text{Crash Rate} &= e^{\beta_0 + \beta_1 DN(0,1) + \beta_2 LIT(0,1) + \beta_3 DN \times LIT((0,0),(0,1),(1,0),(1,1))} \\ &= e^{-0.5635 + (-0.3492,0) + (0.0387,0) + (-0.3627,0,0,0)} \end{aligned} \qquad \text{(E-4)}$$

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

Explanatory variables	Level of significance (p-value)
Day/night	<0.0001
Lighting	0.676
Interaction of day/night and Lighting	<0.0001

The main effect of day and night was significant with p-value less than 0.0001, but the main effect of lighting at the intersection was not significant at level 10%. The interaction between day or night and lighting was, however, significant. The results infer that whether it is day or night has an effect on number of crashes and the effect of lighting is also dependent on whether it is day or night. This is consistent to our intuition, that crash rate may be significantly different during day and night, and that lighting may have an effect on reducing the night crash rate. Table E.4. shows the results of comparisons among all mean crash rates.

Table E.4. Comparison of mean crash rates in the simple comparative model

Difference in mean crash rates in percentage	Estimate of the difference in percentage (%)	Level of significance (p-value)
Day vs. Night	- 41%	<0.0001
Unlighted vs. Lighted	- 13%	0.0552
(Day vs. Night) at Unlighted	-51%	<0.0001
(Day vs. Night) at Lighted	- 29%	<0.0001
(Unlighted vs. Lighted) at Day (day crash rate)	- 28%	<0.0001
(Unlighted vs. Lighted) at Night (night crash rate)	4%	0.6756
(Unlighted vs. Lighted) Day and Night (total crash rate)	-25%	0.0552

As shown in Table E.4, the results here are consistent to the descriptive statistics in Table 4.6 of Section 4. The crash rate is 41% lower during the day than during night and 13% lower for unlighted sites than lighted sites for the comparative analysis and both are significant. Looking at individual intersections, day crash rate is 51% lower than night crash rate at unlighted sites and 29% lower than night crash rate at lighted sites.

The day crash rate at unlighted sites is 28% lower than lighted sites and is statistically significant, while the night crash rate at unlighted intersections is 4% higher than at lighted intersection. During the day, while lights have no effect on crash rates, unlighted intersections still have 28% lower crash rates compared to lighted intersections. This 4% estimation of difference is not statistically significant, because the p-value of this difference is larger than 10%. The total crash crate was, however, significant with unlighted intersections having a 25% lower crash rate.

Best Fit Model

The best fit model for the comparison analysis includes all of the parameters. Lighting was the only variable in the model that was not statistically significant, similar to the basic model above. This model is considered the best fit model also includes two more reasonable and significant explanatory variables to help to explain our data, number of approach legs and approach speed. The prediction equation for the best fit model for crash rate is shown in Equation E.5.

$$\text{Crash Rate} = e^{\beta_0+\beta_1 DN\,(0,1)+\beta_2 LIT\,(0,1)+\beta_3 DN\times LIT\,((0,0),(0,1),(1,0),(1,1))+\beta_4 SPD\,(0,1)+\beta_5 APPR\,(0,1)}$$

$$= e^{-0.8515+(-0.3492,0)+(-0.0646,0)+(-0.3627,0,0,0)+(0.4107,0)+(0.2474,0)} \qquad \text{(E-5)}$$

Table E.5. Statistical significance of explanatory variables for crash rate in the best fit comparative model

Explanatory variables	Level of significance (p-value)
Day/night	<0.0001
Lighting	0.489
Interaction of day/night and lighting	<0.0001
Approach speed	<0.0001
Number of approach legs	<0.0001

Using the best fit model, the effect of day and night and the interaction between day or night and lighting on crash rate are still statistically significant. Table E.6. shows the results of comparisons of mean crash rates corresponding to this model.

Table E.6. Comparison of mean crash rates in the best fit comparative model

Difference in mean crash rates in percentage	Estimate of the difference in percentage (%)	Level of significance (p-value)
Day vs. Night	- 41%	<0.0001
Unlighted vs. Lighted	- 22%	0.00109
(Day vs. Night) at Unlighted	-51%	<0.0001
(Day vs. Night) at Lighted	- 29%	<0.0001
(Unlighted vs. Lighted) at Day (day crash rate)	- 35%	<0.0001
(Unlighted vs. Lighted) at Night (night crash rate)	-6%	0.4893
(Unlighted vs. Lighted) Day and Night (total crash rate)	-39%	0.0009

As shown in table E.4, the results here are consistent to the descriptive statistics in Table 4.6 of Section 4. The crash rate is 41% lower during the day than during night and 22% lower for unlighted sites than lighted sites for the comparative analysis and both are significant. Looking at individual intersections, day crash rate is 51% lower than night crash rate at unlighted sites and 29% lower than night crash rate at lighted sites.

The day crash rate at unlighted sites is 35% lower than lighted sites and is statistically significant, while the night crash rate at unlighted intersections is 6% lower than at lighted intersection. During the day, while lights have no effect on crash rates, unlighted intersections still have 35% lower crash rates compared to lighted intersections. This 6% estimation of difference is not statistically significant, because the p-value of this difference is larger than 10%. The total crash crate was significant with unlighted intersections having a 39% lower crash rate.

The results of this model for the comparative analysis are inconclusive as to whether lighting is useful in reducing crash crates at night. For this model the unlighted intersections cannot be treated well as a control group for the lighted intersections (i.e. treated group). It is suspected that the difference in the number of lighted (223) vs. unlighted (3,399) intersections in the database may have skewed the analysis. Another method of analyzing the effect of lighting at intersections is to collect data at the same intersections for years both before and after lighting has been installed. In this case, crash rates in before and after periods would be comparable because they are collected from same intersections, and hence intersections in before period can be a good control group for intersections in after period. The before and after analysis method is discussed below.

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.

For the before-and-after analysis, the model was adjusted to account for the repeated measurement for each intersection that represented the before and after periods and also for day and night. This is necessary since each intersection is sampled twice (before during night and after during night) for linear regression model, and four times (once in the before period during day, once in the before period during night, once in the after period during day, and once in the after period during night) for Poisson regression model. 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.

The hypothesis tested is whether the mean in the before period is equal to the mean in the after period, written as H_0: $\mu_{.0,1}=\mu_{.1,1}$ or H_0: $\mu_{.0,1}/\mu_{.1,1}=1$. The linear regression was used to compare the means for the ratio of night to total crashes. A Poisson regression model was used to compare the mean crash rates during the two periods. 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 ratio of night to total crashes and crash rate for the linear regression and Poisson regression models, respectively. The explanatory variables used in the before-and-after model include day or night, DEV, before or after (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.7 shows these variables and values for the models. Except for crashes and DEV, all other variables are dummy variables (i.e. coded as a 0 or 1). Another variable introduced into the equations was the random ID variable which accounts for repeated measurements, as discussed above.

Table E.7. Before and after model parameters tested

Variables	**Definition**	**Parameters**	**Values**
Response Variables	Crash rate (Poisson)	CRTOTDN*[1], DEV[2]	Predicted
	Ratio of night to total crashes (mixed linear)	RATNTOT	Predicted
Explanatory Variables	Day/Night	DN	0 – day 1 – night
	Period	Period	0 – Before 1 – After
	Daily entering volume	DEVDNAVE	Value
	Number of approach legs	APPR	0 – 4 1– 3
	Posted speed limit[3]	SPD	0 - = 55 mph 1 - < 55 mph
	Intersection control	INTCNTRL	0 – AWSC [4] 1 – OWSC/TWSC
	Presence of turn lanes	TURN	0 – No 1 – Yes
	Number of lanes in one direction	LANESNUM	0 – 1 1 – 1+,2
	Type of lighting pole	POLE	1 – Power pole 2 – Light Pole
	Presence of a curve	CURVE	0 – No 1 – Yes
	Number of years in the period	YEARS	1, 2, 3
	Repeated variable	ID	1, 2,. . ., n

[1] The night crash rates and day crash rates were analyzed together.
[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

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. The expected ratio of night to total crashes was reduced by 10% in the after period; however, the results indicated that the reduction in the ratio of night to total crashes from the before period to the after period is not statistically significant at the 10% level. The results are presented in Table E.8.

Table E.8. Statistical Significance of Explanatory Variables for Ratio of Night to Total Crashes

Explanatory Variables	Level of Significance (p-value)
Period	0.189
DEV	0.034

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

$$\begin{aligned}\text{Expected Ratio of Night to Total Crashes} &= \beta_0 + \beta_1 Period(0,1) + \beta_2(DEV) \\ &= 0.1231 + (0.09487,0) + 0.000149(DEV) \qquad \text{(E-6)}\end{aligned}$$

Poisson Regression Model

The Poisson regression model compared the mean crash rates during the before-and-after periods to determine statistical significance. All of the explanatory variables were considered in the model; however, it was determined that the best fit model included only day and night, period, and the interaction of day and night.

The explanatory variables day/night, period, and the interaction between day/night and period indicated they were significant at the 10% level. The estimated crash rate for the period in the before period (unlighted) being 59% higher than the estimated crash rate in the after period (lighted) during the night. Table E.9 below shows the statistical significance of explanatory variables for crash rate in the before and after analysis.

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

$$\begin{aligned}\text{Crash Rate} &= e^{\beta_0 + \beta_1 DN\,(0,1) + \beta_2 PERIOD\,(0,1) + \beta_3 DN \times PERIOD\,((0,0),(0,1),(1,0),(1,1))} \\ &= e^{-0.9971 + (-0.7330,0) + (0.4657,0) + (-0.5071,0,0,0)} \qquad \text{(E-7)}\end{aligned}$$

Table E.9. Statistical significance of explanatory variables for crash rate in the before and after model

Explanatory variables	Level of significance (p-value)
Day/night	0.001
Period (before or after)	0.095
Interaction of day/night and period	0.100

The estimation of difference in all mean crash rates for the best fit model is quite close to the one for simple prediction model. The crash rate is 62% lower during the day than during night and is statistically significant. The crash rate is 24% higher for unlighted (before) sites than lighted (after) sites and is not statistically significant. Looking at individual intersections, day crash rate is 71% lower than night crash rate before lighting is installed and 52% lower than night crash rate after lighting is installed and both are statistically significant

The day crash rate in the before period is 4% lower than the after period and is not statistically significant, while the night crash rate at in the before period is 59% higher than in the after period and was statistically significant. During the day, while lights have no effect on crash rates, unlighted intersections still have 4% lower crash rates compared to lighted intersections. The total crash crate was not significant with the before period having a 53% higher crash rate than the after crash rate.

Table E.10 shows the analysis results of difference among all mean crash rates.

Table E.10. Comparison of all mean crash rates in the before and after model

Difference in mean crash rates in percentage	Estimate of the difference in percentage (%)	Level of significance (p-value)
Day vs. Night	- 62%	<0.0001
Before vs. After	24%	0.3698
(Day vs. Night) in Before	-71%	<0.0001
(Day vs. Night) in After	- 52%	0.001
(Before vs. After) at Day (day crash rate)	- 4%	0.8847
(Before vs. After) at Night (night crash rate)	59%	0.0953
(Before vs. After) at Day and Night (total crash rate)	53%	0.3698

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

                                    Standard
Effect     LIT  APPR_NUM  Estimate     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

                          Num     Den
            Effect         DF      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


                Analysis Of GEE Parameter Estimates
                 Empirical Standard Error Estimates

                         Standard   95% Confidence
 Parameter     Estimate    Error       Limits            Z Pr > |Z|

 Intercept      -0.8515   0.0897  -1.0273  -0.6757   -9.50   <.0001
 DN        0    -0.3492   0.0824  -0.5107  -0.1878   -4.24   <.0001
 DN        1     0.0000   0.0000   0.0000   0.0000     .       .
 LIT       0    -0.0646   0.0934  -0.2476   0.1184   -0.69   0.4893
 LIT       1     0.0000   0.0000   0.0000   0.0000     .       .
 DN*LIT    0 0  -0.3627   0.0878  -0.5348  -0.1905   -4.13   <.0001
 DN*LIT    0 1   0.0000   0.0000   0.0000   0.0000     .       .
 DN*LIT    1 0   0.0000   0.0000   0.0000   0.0000     .       .
 DN*LIT    1 1   0.0000   0.0000   0.0000   0.0000     .       .
 APPR_NUM  0     0.4107   0.0425   0.3274   0.4940    9.67   <.0001
 APPR_NUM  1     0.0000   0.0000   0.0000   0.0000     .       .
 SPD       0     0.2474   0.0488   0.1517   0.3431    5.07   <.0001
SPD       1     0.0000   0.0000   0.0000   0.0000     .       .
```

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

Major Rd.___________ **Speed Limit:** _________

Minor Rd.___________ **Speed Limit:** _________

Lighting Added: a.) Up to 1990 **b.)** After 1990

Pavement structure (major/minor):
a.) asphalt/concrete
b.) asphalt/asphalt **c.)** concrete/concrete
d) gravel (one or more approaches)

Configuration: a.) 4 legs - skew or 90°
b.) 3 legs - T or Y
Control: a.) two way stop **b.)** all way stop
c.) yield **d.)** none

Facility: a.) divided (one or more approaches)
b.) undivided (all approaches)

Channelization:
left a.) turn lanes **b.)** none
right a.) turn lanes **b.)** bypass lanes
c.) none

Other Significant Improvements within 3 years before or 3 years after installation of lighting:
a.) addition of turn lanes
b.) sight triangles cleared
c.) horizontal or vertical grade adjustments
d.) other
____

Major Rd.___________ **Speed Limit:** _________

Minor Rd.___________ **Speed Limit:** _________

Lighting Added: a.) Up to 1990 **b.)** After 1990

Pavement structure (major/minor):
a.) asphalt/concrete
b.) asphalt/asphalt **c.)** concrete/concrete
d) gravel (one or more approaches)

Configuration: a.) 4 legs - skew or 90°
b.) 3 legs - T or Y
Control: a.) two way stop **b.)** all way stop
c.) yield **d.)** none

Facility: a.) divided (one or more approaches)
b.) undivided (all approaches)

Channelization:
left a.) turn lanes **b.)** none
right a.) turn lanes **b.)** bypass lanes
c.) none

Other Significant Improvements within 3 years before or 3 years after installation of lighting:
a.) addition of turn lanes
b.) sight triangles cleared
c.) horizontal or vertical grade adjustments
d.) other
____

Major Rd.___________ **Speed Limit:** _________

Minor Rd.___________ **Speed Limit:** _________

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

Major Rd.___________ **Speed Limit:** _________

Minor Rd.___________ **Speed Limit:** _________

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

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 Mn/DOT – Transportation Department 395 John Ireland Boulevard St. Paul, Minnesota 55155-1899 Phone: 651-282-2691 Fax: 651-297-2354e-mail: dan.warzala@state.mn.us	Mr. Roger Gustafson Carver County Engineer 11360 Hwy 2121 West PO Box 300 Cologne, MN 55322 Phone: 952-466-5200 Fax: 952-466-5223 e-mail: rgustafs@co.carver.mn.us	Dr. Shauna Hallmark Iowa State University, Center for Transportation Research and Education 2901 South Loop Drive, Suite 3100 Ames, IA 50010-8632 Phone: 515-294-5249 Fax: 515-294-0467 e-mail: 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;** **ADT > 1000 vpd on all approaches;** **Local request;** **LRRB 1999-17;** **LRRB 1999-17, ambient light and channelization warrants from Mn/DOT;** **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	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
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 Before	Total 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	2
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
35	CSAH 10	CSAH 43 S (east int)	1	1
36	CSAH 10	CSAH 43 N (west int)	4	14
37	CSAH 77	CSAH 70	0	3
38	CSAH 77	CSAH 18 N	3	1
39	CSAH 77	CSAH 18 S	0	0
40	CSAH 5	CSAH 10	0	1
41	CSAH 3	CSAH 67 (Wendigo Road)	0	0
42	CSAH 13	CR 104	1	1
43	CSAH 59	CR 66	3	2
44	CSAH 35	CR 134	7	7
45	TH 64	CSAH 33	1	0
46	TH 200/371	CSAH 38	5	7
47	US 169	Bear Creek Road/ CR 222 - 8 Mile Road	0	1
48	CSAH 34	CR 134	9	0
Total			98	109

	Intersection Location		Night		Day	
			Total Before	Total After	Total Before	Total After
1	CSAH 22[1]	CSAH 3	0	0	1	0
2	CSAH 22[1]	CSAH 1	0	1	2	1
3	CSAH 3	CSAH 64 (Harris Town Road)	0	0	1	2
4	CSAH 3	Wendigo Park Road	0	0	1	0
5	CSAH 64 (Harris Town Road)	Wendigo Park Road	0	0	0	0
6	CSAH 64 (Harris Town Road)	Sunny Beach Road	2	0	0	2
7	CSAH 2	CSAH 13	1	0	0	0
8	CSAH 7	CSAH 9	0	0	1	0
9	CSAH 101	CSAH 25	1	0	1	0
10	CSAH 21	CSAH 91	3	1	5	1
11	CSAH 19	CR 59	1	0	0	1
12	CSAH 19	CSAH 20	0	4	0	3
13	CSAH 18	CSAH 19	1	2	2	9
14	CSAH 20	CSAH 13	1	0	0	2
15	CSAH 20	Woodlane Drive	0	0	0	1
16	TH 44	TH 76/Ewald Road	2	1	2	0
17	US 169	Mishawaka Road	1	0	1	2
18	US 169	CSAH 64 (Harris Town Road)	3	2	0	3
19	US 169	Harbor Heights Road	2	1	1	5
20	US 169	Lakeview Road	4	1	1	1
21	US 169	CR 437 (Crystal Springs Road)	1	2	2	4
22	US 169	Gary Drive	1	2	1	2
23	US 169	CSAH 66 (Laplant Rd)/CR 437 (Shadywood Rd)	2	1	0	0
24	US 169	Ethel Street	1	0	2	1
25	TH 65	Badavinac Road	0	0	1	0
26	TH 65	West Bay Drive	0	0	0	0
27	US 53[1]	TH 332	0	1	0	1
28	TH 60	CSAH 62 (CSAH 3 Waseca)	0	1	1	2
29	US 59	CSAH 13/CSAH 48	0	0	1	0
30	TH 23[1]	CSAH 18	0	0	0	0
31	TH 30[1]	CSAH 18	1	1	0	1
32	US 14	CR 27	5	2	3	1
33	US 75[1]	CSAH 22	0	2	0	0
34	TH 210[1]	CSAH 19	1	0	0	1
35	CSAH 10	CSAH 43 S (east int)	1	1	0	0
36	CSAH 10	CSAH 43 N (west int)	4	5	0	9
37	CSAH 77	CSAH 70	0	1	0	2
38	CSAH 77	CSAH 18 N	1	0	2	1
39	CSAH 77	CSAH 18 S	0	0	0	0
40	CSAH 5	CSAH 10	0	0	0	1
41	CSAH 3	CSAH 67 (Wendigo Road)	0	0	0	0
42	CSAH 13	CR 104	0	1	1	0
43	CSAH 59	CR 66	0	0	3	2
44	CSAH 35	CR 134	1	1	6	6
45	TH 64	CSAH 33	0	0	1	0
46	TH 200/371	CSAH 38	3	6	2	1
47	US 169	Bear Creek Road/ CR 222 - 8 Mile Road	0	1	0	0
48	CSAH 34	CR 134	3	0	6	0
Total			47	41	51	68

APPENDIX N: EXAMPLE CALCULATIONS FOR HISTORIC ADT

Wit

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

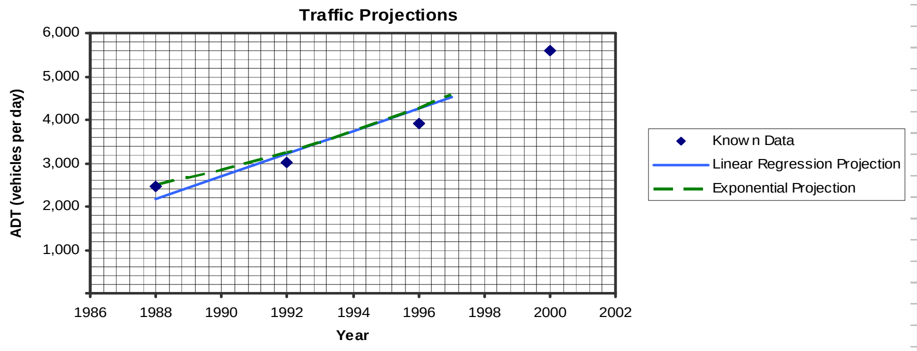
Projected Data

	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:

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

Source: Owen Ayres & Associates

APPENDIX O: SEVERITY OF CRASHES BY COLLISION TYPE

h 33

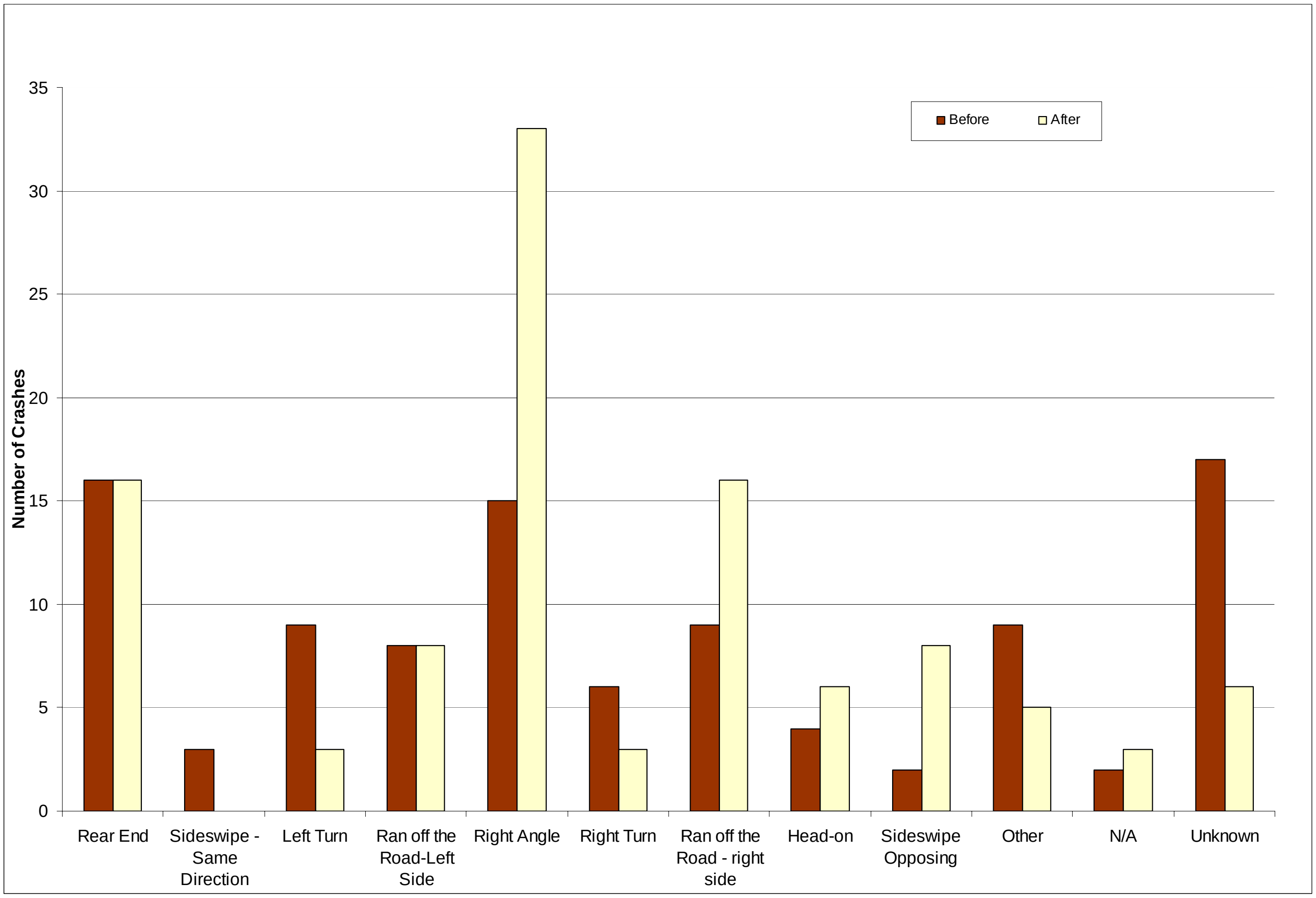


Figure O.1. Nighttime crash types for all intersections

APPENDIX P: 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          0.04408
                     Residual                  0.3403


                        Solution for Fixed Effects

                                   Standard
Effect       PERIOD    Estimate       Error      DF    t Value    Pr > |t|

Intercept                0.1231     0.08526    67.1       1.44      0.1535
PERIOD       0          0.09487     0.07119    48.7       1.33      0.1889
PERIOD       1                0           .       .        .         .
DEVNAVE                0.000149    0.000068      49       2.18      0.0344


                      Type 3 Tests of Fixed Effects

                            Num     Den
              Effect         DF      DF    F Value    Pr > F

              PERIOD          1    48.7       1.78    0.1889
              DEVNAVE         1      49       4.74    0.0344
```

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

```
                           NIGHT CRASH RATE

                         The GENMOD Procedure



                Analysis Of GEE Parameter Estimates
                 Empirical Standard Error Estimates

                            Standard   95% Confidence
Parameter       Estimate     Error        Limits            Z Pr > |Z|

 Intercept       -0.9771    0.4470  -1.8532  -0.1010   -2.19   0.0288
DN         0     -0.7330    0.2226  -1.1693  -0.2967   -3.29   0.0010
DN         1      0.0000    0.0000   0.0000   0.0000     .       .
PERIOD     0      0.4657    0.2792  -0.0815   1.0129    1.67   0.0953
PERIOD     1      0.0000    0.0000   0.0000   0.0000     .       .
DN*PERIOD 0 0    -0.5071    0.3086  -1.1119   0.0978   -1.64   0.1004
DN*PERIOD 0 1     0.0000    0.0000   0.0000   0.0000     .       .
DN*PERIOD 1 0     0.0000    0.0000   0.0000   0.0000     .       .
DN*PERIOD 1 1     0.0000    0.0000   0.0000   0.0000     .       .
 INTCTRL          0.6601    0.3109   0.0508   1.2694    2.12   0.0337
```