Final Report 1999-17

Research

Safety Impact of Street Lighting at Isolated Rural Intersections

Minnesota Local Road Research Board

SAFETY IMPACTS OF STREET LIGHTING AT ISOLATED RURAL INTERSECTIONS

Final Report

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April 1999

Published by

Minnesota Department of Transportation
Office of Research Administration
200 Ford Building Mail Stop 330
117 University Avenue
St Paul MN 55155

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
1999-17		

4. Title and Subtitle	5. Report Date
Safety Impacts of Street Lighting at Isolated Rural Intersections	April 1999
	6.
7. Author(s) Howard Preston, PE Ted Schoenecker, EIT	8. Performing Organization Report No.
9. Performing Organization Name and Address BRW, Inc. 700 Third Avenue South Minneapolis, MN 55415	10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard, Mail Stop 330 St. Paul, Minnesota 55155	13. Type of Report and Period Covered Final Report 1998 - 1999 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The primary objective of this report is to present statistically reliable conclusions relative to the changes in crash frequencies and other crash characteristics at isolated rural intersections associated with the installation of street lighting.

It was found through a comparative analysis of over 3,400 rural intersections and a Before versus After analysis of a sample of 12 intersections that the installation of street lighting reduced both nighttime crash frequencies (25% to 40%) and crash severity (8% to 26%). A Benefit – Cost analysis using statistics from the Before versus After analysis found that crash reduction benefits associated with the installation of street lighting at rural intersections outweigh the costs by a wide margin.

As a result of the analysis, it was concluded that the installation of street lighting at rural intersections is a low cost and very effective strategy for mitigating nighttime crashes. This strategy should be added to the traffic engineer's toolbox and agencies should be encouraged to increase the use of streetlights at rural intersections in order to reduce crashes and improve motorist guidance.

It was also concluded based on a comparison to the results for other recent research that the use of street lighting to reduce nighttime crashes at rural intersections would likely be far more effective than either rumble strips or flashing overhead beacons.

17. Document Analysis/Descriptors		18. Availability Statement
Warrant Analysis for the Installation of Street Lighting Benefit – Cost Analysis of Street Lighting	Crash Reduction due to the Installation of Street Lighting	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

Table of Contents

List of Tables

List of Figures

Executive Summary

The Minnesota Department of Transportation (MnDOT) and the Local Road Research Board (LRRB) are interested in increasing the number of strategies in the traffic engineer's toolbox that have proven effective at mitigating safety deficiencies at rural intersections. Staff at MnDOT and various city and county highway agencies has suggested that the installation of streetlights have proven effective at addressing nighttime safety issues at a limited number of isolated rural intersections. However, neither of these organizations was aware of any definitive studies using either local data from MnDOT's crash records system or information documented in nationally published research reports.

In order to address this information gap relative to the safety effects of intersection lighting, BRW, Inc. was retained to conduct a comprehensive study of the issue. The primary objective of the study is to present statistically reliable conclusions relative to the changes in crash frequencies and other crash characteristics at isolated rural intersections associated with the installation of streetlights.

The study identified the following conclusions:

Literature Search

- A number of previously published research reports documented the safety effectiveness of intersection lighting. These reports found that the installation of intersection lighting resulted in a 25 to 50 percent reduction in the night time crash rate and a 20 to 30 percent reduction in the night crash / total crash ratio. In addition, a report prepared by the Federal Highway Administration documenting the effectiveness of various types of intersection and traffic control improvements found that intersection lighting had the highest benefit-cost ratio (21:1).

Survey of Usage

- A survey of usage sent to counties and cities in Minnesota found that most agencies do not operate or maintain street lights at rural intersections and most have no warrants or guidelines for installation of streetlights. In addition, the most frequently used strategies for addressing rural intersection safety are signing, rumble strips and flashing beacons. The survey also found that the primary positive effects associated with street lighting include nighttime crash reduction and improved motorist guidance.

Warrants/Guidelines for Installation

- Most agencies use MnDOT warrants/guidelines for the installation of streetlights. The two primary guidelines deal with minimum intersection traffic volumes and nighttime crash frequencies. A review of the traffic volumes and crash frequencies cited in the guidelines found that these values are exceeded in only about 5% to 10 % of the unlighted rural intersections in Mn/DOT's crash records system. This may help explain why streetlights have been installed at less than 10% of the rural intersections in MnDOT's database.

∉ It is recommended that consideration be given to reducing the values for the traffic volume and crash frequency warrants / guidelines in order to encourage the installation of streetlights at more locations. For example, by reducing the crash frequency warrant from the current three nighttime crashes per year to three over a three-year period, the number of intersections potentially meeting the warrant / guideline would increase by a factor of two and one-half. Likewise, by changing the traffic volume warrants / guidelines from being tied to traffic signal warrant thresholds to values that are more representative of a functionally classified rural system, the number of intersections potentially meeting the warrant / guideline would increase.

Technical Analysis

∉ The results of both a comparative analysis of over 3,400 rural intersections along the state's trunk highway system and a Before vs. After analysis of a sample of 12 intersections found that the installation of street lights reduced both the nighttime crash frequency (25% to 40%) and nighttime crash severity (8% to 26%) and that these reductions are statistically significant.

∉ A Benefit vs. Cost analysis using crash statistics from the Before vs. After analysis and lighting costs from the survey of usage found that the crash reduction benefits associated with the installation of street lighting at rural intersections outweigh the costs by a wide margin. The average Benefit / Cost ratio was approximately 15:1.

Final Conclusions

∉ The installation of streetlights at rural intersections is a low cost and very effective strategy for mitigating nighttime crashes. This strategy should be added to the traffic engineer's toolbox and agencies should be encouraged to increase the use of streetlights at rural intersections in order to reduce crashes and improve motorist guidance.

∉ A number of Minnesota counties indicated (in the survey of usage) that rumble strips and overhead flashing beacons were frequently used strategies for addressing rural intersection safety issues. It should be noted that recent case study research found that neither of these strategies has resulted in statistically significant crash reductions. Therefore, the data suggests that the use of street lighting to reduce night time crashes at rural intersections would likely be far more effective than either rumble strips or overhead flashing beacons.

1.0 Introduction

The Minnesota Department of Transportation (Mn/DOT) and the Local Road Research Board (LRRB) are interested in increasing the number of strategies in the traffic engineer's toolbox that have proven effective at mitigating safety deficiencies at rural intersections. Staff at Mn/DOT and various city and county highway agencies has suggested that the installation of street lighting has proven effective at addressing nighttime safety issues at a limited number of isolated rural intersections. However, neither of these organizations was aware of any definitive studies using local data, from Mn/DOT's crash record system or in nationally published research reports.

In order to address this information gap relative to the safety effects of street lighting, BRW, Inc. was retained to conduct a comprehensive study of the issue. The primary objective of the study is to present statistically reliable conclusions relative to the changes in crash frequencies and other crash characteristics at isolated rural intersections associated with the installation of street lighting. The basic work tasks associated with the study included the following:

- A literature search and review of nationally published research reports.
- A survey of usage of street lights by local units of government in Minnesota.
- Documentation and evaluation of warrants for street lighting from a variety of published sources.
- A comprehensive safety analysis using Mn/DOT crash records consisting of both a comparative analysis of rural intersections with and without street lighting and a before versus after analysis of a select sample of identified intersections.

In addition to these specific tasks, the research process also included coordination with a Technical Advisory Board that consisted of the following individuals:

Name	Title	Agency
Rick Beck	Traffic Operations Research Engineer	Mn/DOT
Loren Hill	State Traffic Safety Engineer	Mn/DOT
Wei Zhang	Program Development Engineer	Mn/DOT
Roger Gustafson	Carver County Engineer	Carver County
David Robley	Douglas County Engineer	Douglas County
Wayne Fingalson	Wright County Engineer	Wright County
Howard Preston	Vice President of Traffic Engineering	BRW, Inc
Ted Schoenecker	Traffic Engineer I	BRW, Inc

2.0 Literature Search

The purpose of this chapter is to document the findings of previously published research reports regarding the safety impacts of roadway lighting at isolated rural intersections.

2.1 Research Articles

Research of available literature revealed six reports and/or articles that pertained to roadway lighting and safety at rural intersections. Those articles are:

1. "*The 1994 Annual Report on Highway Safety Improvement Programs*," U.S. Department of Transportation Federal Highway Administration – Office of Highway Safety, May 1994.
2. Lipinski, M. E. and R.H. Wortman, *Effect of Illumination on Rural At-Grade Intersection Crashes*.
3. Roberts, Stephen E. and Fred W. Walker*, Influence of Lighting on Accident Frequency at Highway Intersections*, Iowa Department of Transportation.
4. *Rural Arterial Roads (Non Freeway) Lighting of Junctions Only*, <u>Road Lighting as an Accident Countermeasure</u>, CIE – International Commission on Illumination, 1992.
5. <u>Roadway Lighting Handbook</u>, US Department of Transportation – Federal Highway Administration, Washington D.C., 1978.
6. <u>Value of Public Roadway Lighting</u>, Illuminating Engineering Society, New York, NY, 1989.
7. *Costs and Benefits of Roadway Lighting* (Author Unknown).

2.2 Summary of Articles

A summary for each report and/or article is included in the following paragraphs.

1. "*The 1994 Annual Report on Highway Safety Improvement Programs*," U.S. Department of Transportation Federal Highway Administration – Office of Highway Safety, May, 1994.

The 1994 report provides data on the reduction of crash rates, cost-per-crash reduced, and the benefit-cost ratios for each type of highway safety improvement. The data in the report is based upon information submitted by the states and territories, information obtained within the Federal Highway Association (FHWA), and other sources as noted.

The FHWA evaluates information submitted by the states and territories to determine the effectiveness of individual highway safety improvement programs and projects. These evaluations examine changes in the number and severity of crashes where safety improvements were implemented. A benefit-cost ratio is then calculated based on the percent reduction for fatal, nonfatal-injury, and fatal-plus-nonfatal injury crashes. Table 2.1 was recreated from the 1994 report to show the safety improvements with highest benefit-cost ratio. Of these safety improvements, the installation of illumination had the greatest benefit-cost ratio at 21.0.

2. **Lipinski, M. E. and R. H. Wortman, *Effect of Illumination on Rural At-Grade Intersection Crashes*.**

For this study, the database used to measure the relation between illumination and crash experience consisted of data collected at rural at-grade intersections in Illinois.

The method of analysis used in this study compared illuminated and non-illuminated intersections on the basis of crash experience. Seven measures of effectiveness were considered:

1. Night crashes per year
2. Day crashes per year
3. Total crashes per year
4. Ratio of night crashes to total crashes per year
5. Night crash rate
6. Day crash rate
7. Total crash rate.

The ratio of night crashes to total crashes per year was used because the ratio greatly reduces the possibility of error since the decision to install the lighting was not randomized.

For each intersection, information was collected that pertained to illumination conditions, physical characteristics, traffic volume data, and crash data. Intersections in the sample were categorized according to (a) presence or absence of illumination or (b) presence or absence of channelization. From this information, each intersection could be placed into one of four categories:

1. No illumination with no channelization
2. Illumination with no channelization
3. No illumination with channelization
4. Illumination with channelization

Results

The night crash / total crash ratio, night crash rate, and total crash rate had significantly better crash statistics for the illuminated intersections. When both illumination and channelization are present, the night crashes / total crashes ratio (0.238) is lower than either for illumination without channelization (0.277), channelization without illumination (0.306), or no illumination and no channelization (0.354).

Conclusion

- ∉ Before installing street lighting for safety purposes, the engineer must first weigh the benefits of lighting against other intersection improvements such as channelization, delineation, signalization, or geometric changes.

- ∉ The night crash / total crash ratio is the most reliable measure because it measures changes in crash totals that are related directly to differences in visibility conditions and accounts for variations in traffic volume.

- ∉ Night crashes are significantly reduced at rural at-grade intersections when illumination is installed.

- ∉ Illumination results in a 45 percent reduction in the night crash rate and a 22 percent reduction in the night crash / total crash ratio.

- ∉ Simultaneous introduction of channelization and illumination at locations experiencing a high number of crashes should be encouraged.

- ∉ Other safety improvements of rural at-grade intersections may reduce both day and night crash potential at these locations.

3. Roberts, Stephen E. and Fred W. Walker, *Influence of Lighting on Crash Frequency at Highway Intersections*, Iowa Department of Transportation.

This study was performed in Iowa and was limited to rural intersections for which it was possible to obtain crash records for a 3-year period before operation of design lighting and for a 3-year after period. Other variables that were examined for their effect in lighting and no-lighting situations included raised channelization, a primary route turning at the intersection and the difference between 3-leg and 4-leg intersections.

Analysis

There were a total of 47 intersections that were analyzed over a six-year period. Before the installation of street lighting, 90 night crashes were recorded at these intersections, and after lighting, 46 crashes were recorded. This represented a statistically significant 49 percent reduction in the number of night crashes. Taking into consideration traffic volumes, the average crash rates before and after the installation of lighting were 1.89 and 0.91 crashes / million entering vehicles (MEV) respectively.

For channelization, the sample included 19 intersections without channelization and 28 intersections with some form of raised channelization. The analysis for the channelized intersections showed a highly significant (99 percent level) overall reduction in the night crash rate when lighting was installed. However after lighting was installed, no significant difference was noted between channelized and non-channelized intersections.

Twenty-one intersections were recorded as having had one or more routes entering in one direction and departing in another direction. Crash history for the intersection after lighting was installed indicated that intersections with and without turns showed a reduction in the day and night crash rate.

Of the original sample of intersections, 15 were 3-leg intersections and 32 were 4-leg intersections. Crash rates for intersections having four approaches showed a reduction in the night crash rate from 1.96 night crashes / MEV without lighting to 0.74 night crashes / MEV with lighting. This is a 62 percent reduction in the number of night crashes. There were no significant reductions in the night crash rate at three legged intersections after lighting was installed.

Conclusion

∉ Installation of lighting with no regard for other effects results in a significant reduction in the average night crash rate (from 1.89 crashes / MEV to 0.91 crashes / MEV).

∉ With the addition of lighting, specific situations showing improvement included intersections with channelization, a primary route changing direction, and four legged intersections.

4. *Rural Arterial Roads (Non Freeway) Lighting of Junctions Only*, Road Lighting as an Accident Countermeasure – CIE: International Commission on Illumination, 1992.

Salminen, J., *Traffic Safety Effects of Road Lighting*, Roadways and Waterways Administration Traffic Office, Helsinki, 1978.

> This study used the day crash / night crash ratio and the before lighting/after lighting crash ratio to indicate the effectiveness of road lighting. The study found that lighting reduces the crashes at night by 25 percent on average.

Onser, *The Efficiency of Lighting at Intersections*, National Organization for Road Safety, 1973.

> The statistical test used in this study was the night crash / total crash ratio to indicate the effectiveness of road lighting. The study found that lighting reduces crashes in darkness by 25 percent in comparison with unlit junctions.

5. Roadway Lighting Handbook, US Department of Transportation – Federal Highway Administration, Washington, D.C., 1978.

There are three major benefits to be derived from lighting an intersection:

1. The presence of a luminaire in the dark establishes a discrete uniqueness to the area, alerts the driver, and draws attention to the intersection.
2. The light reveals the physical features of the roadway so that the driver may plan the driving task more deliberately.
3. Other vehicles and pedestrians in the intersection will be visible to the approaching driver.

Most studies have shown that the principal warranting criterion for intersection lighting is crash experience, but the only warrants that are in place are based on the daily traffic volume of the particular roadways.

If lighting is deemed necessary, the use of two luminaires at a basic rural intersection is recommended because of the combination of silhouette and surface detail methods of seeing made available.

Analyzing the Economics of the Lighting System

The cost-effectiveness procedure involves a detailed economic evaluation of the following:

a. Level of illumination
b. Type of light source
c. Type of support
d. Electrical materials and installation
e. Mounting height
f. Energy requirements
g. Maintenance schedule

The procedure may be summarized as:

1. Specifying several lighting designs that give the desired level of lighting effectiveness, illumination level, and uniformity
2. Specifying circuit alternatives that are feasible for each lighting design
3. Summarizing the effectiveness and cost for each feasible lighting design and choosing the best design

6. Value of Public Roadway Lighting, Illuminating Engineering Society, New York, NY, 1989.

The crash savings can justify the cost of modern lighting to the nation's economy. In a National Safety Council study, the 1986 estimated costs in motor vehicle crashes were:

Per death: $240,000
Per disabling injury: $10,800
Property damage (including minor injuries): $1600

7. Costs and Benefits of Road Lighting (Author Unknown)

The costs involved in a lighting scheme include:

- The cost of installation
- The annual cost of maintenance (including lamp replacements)
- The annual cost of electric energy

Other possible costs are increased operating costs in darkness (due to higher speed) and increased severity of some run-off the road crashes (due to the lighting columns).

The benefits include:

- Reduced number and severity of crashes therefore reduced crash costs
- Reduced travel times (due to higher speed)
- Reduced vehicle operating costs (due to more constant speed)
- Increased feeling of comfort in night-time driving (this cannot be quantified)

In order to set the total benefits against the total costs, all made equivalent in terms of time by discounting, the net present value (NPV) of a lighting scheme can be calculated.

NPV = Discounted Benefits – Discounted Costs

$$NPV = \sum_{i=1}^{j} e_i * B_i - \left(\sum_{i=1}^{j} e_i' * M_i + \sum_{i=1}^{j} e_i'' * E_i + I\right)$$

where e_i, e_i', e_i'' = the discount factors for the year i. The factors depend on the discount rate, the expected growth of B, M, and E over the expected lifetime j.

B = the benefit in year i
M = the maintenance cost in year i
E = the energy cost in year i
I = the initial investment cost

If the obtained NPV is positive, the lighting scheme is a profitable investment from a strictly economic point of view.

Another cost associated with the installation of lighting units is the expected crash costs for vehicles hitting the lighting installations. To calculate this, the following formula is used:

AC = (ADT / XDT) EA * C

AC = the expected average crash cost from vehicles hitting lighting units in dollars/mile/year

ADT = the design average daily traffic
XDT = the number of vehicles of ADT that it takes to generate one out-of-control vehicle running off the road per mile per year
EA = the expected number of lighting units per vehicle running off the road for the appropriate spacing and width of units from the nearest traffic lane (found in a table)
C = the average cost of a vehicle-lighting unit crash (found in a table)

Crash Warrants

If the number and percent of crashes in darkness are high or if the crash rate in darkness or the ratio between crash rates in darkness and in daylight is high, installation of lighting is a suitable crash countermeasure. In order to be able to use this formally in planning, it is necessary to fix some crash limits above which improved lighting should be considered. One way of deducing such limits is to determine how many crashes are necessary to justify lighting from an economic point of view.

A crash warrant (N) can be deduced by replacing (B) in the above Net Present Value equation

where B = N K CA per km / year

N is the number of night casualty crashes/km/year
K is the expected fractional decrease in crashes after lighting
CA is the cost of a casualty crash

In the Swedish public lighting recommendations, it is stated that road lighting is probably a suitable measure if the number of all crashes in darkness at rural intersections exceeds 0.7 per year.

2.3 Summary of the Published Research

- The night crash / total crash ratio is the most reliable measure of effectiveness because it measures changes in crash totals that are related directly to differences in visibility conditions and accounts for variations in traffic volume.

- Night crashes are significantly reduced at rural at-grade intersections when lighting is installed. This lighting resulted in a 25 to 50 percent reduction in the night crash rate and a 20 to 30 percent reduction in the night crash / total crash ratio.

- Other safety improvements of rural at-grade intersections may reduce both day and night crash potential at these locations; therefore for example, simultaneous introduction of channelization and illumination at locations experiencing a high number of crashes should be encouraged.

∉ The costs involved in a lighting scheme include: the cost of installation, the annual cost of maintenance, the annual cost of electric energy, increased operating costs in darkness, and increased severity of some run-off the road crashes (due to the possibility of crashing into the light pole).

∉ The benefits of illumination include: reduced number and severity of crashes therefore reduced crash costs, reduced travel times, reduced vehicle operating costs, increased feeling of comfort in night-time driving.

∉ A crash warrant for lighting can be deduced by replacing "B" (B represents the benefit of street lighting) in the net present value equation (NPV), where:

  Benefit = (number of night casualty crashes) * (expected fractional decrease in crashes after lighting) * (cost of a casualty crash) per km / year

  If the benefits are greater than the costs associated with street lighting, street lighting may be warranted.

∉ Most warrants for rural intersection lighting are based on the daily traffic volume of the roadways.

Table 2.1

Highway Safety Improvements
With the Highest Benefit - Cost Ratios

1974 - 1993

Rank	Construction Classification	Benefit - Cost Ratio
1	Illumination	21.0
2	Relocated Breakaway Utility Poles	17.2
3	Traffic Signs	16.3
4	Upgrade Median Barrier	13.7
5	New Traffic Signals	8.3
6	New Median Barrier	8.3
7	Remove Obstacles	8.3
8	Impact Attenuators	7.6
9	Upgrade Guardrail	7.8
10	Upgraded Traffic Signals	7.4
11	Upgrade Bridge Rail	7.1
12	Sight Distance Improvements	7.0
13	Groove Pavement for Skid Treatment	5.6
14	Replace or Improve Minor Structure	5.2
15	Turning Lanes and Traffic Channelization	4.4
16	New RR Crossing Gates	3.9
17	Construct Median for Traffic Separation	3.3
18	New RR Crossing Flashing Lights	3.2
19	New RR Flashing Lights & Gates	3.0
20	Upgrade RR Flashing Lights	2.9
21	Pavement Markings and Delineators	2.6
22	Flatten Side Slopes	2.5
23	New Bridge	2.2
24	Widen or Improve Shoulder	2.1
25	Widen or Modify Bridge	2.0
26	Realign Roadway	2.0
27	Overlay for Skid Treatment	1.9

Source: FHWA, Highway
Safety Evaluation System

3.0 Survey of Agencies

The purpose of this chapter is to document and summarize the results of the surveys that were distributed by Mn/DOT's Office of Traffic Engineering to determine both the usage and any documented safety effects of street lighting at isolated rural intersections. A copy of the survey that was distributed and a complete summary of the responses from the city and county agencies is included in Appendix A.

3.1 Survey Response

Mn/DOT distributed the survey form entitled "Street Lighting Safety at Rural Intersections" to 125 city engineers and all 87 county engineers throughout the State. Of the 125 surveys sent to the city engineers, 32 completed surveys were received, giving a response rate of 26%. For the county engineer responses, 59 were received, giving a response rate of 68%.

3.2 Summary of Response Data

The number of lighted intersections that are presently operated and maintained by the county and city agencies are shown in Figure 3-1. Note that 66% (21 out of 32) of the cities and 78% (46 out of 59) of the counties operate and maintain no street lights at rural intersections. In the matter of the agency having any warrants for the installation of roadway lighting at rural intersections, only one county agency and two cities have any warrants. If there is a warrant for installation, the agencies generally follow Mn/DOT design criteria for lighting patterns.

None of the county agencies or cities that responded have performed a before/after study on the safety effects of street lighting at isolated rural intersections.

The typical installation, operation, and maintenance costs that were given by the city and county engineers for street lighting are summarized below in Table 3-1.

Table 3.1 Street Lighting Costs at Rural Intersections

	County	City
Installation Costs	\$400 - \$1500	\$300 - \$3500
Operation Costs (per light per year)	\$15 - \$270	\$85 - \$1050
Maintenance Costs (per light per year)	\$20 - \$230	\$25 - \$50
Operation and Maintenance Costs (per light per year)	---	\$85 - \$6000

Note: The range of cost values for county and city agencies were taken directly from the surveys that were returned. These cost values may vary due to the different estimates calculated by each agency.

If street lighting is installed, 93% (13 out of 14) of the counties and 80% (8 out of 10) of the cities would install a single light. The one remaining county agency and two cities that responded would install two lights at the intersection. Figure 3-2 indicates the wattage and type of lamp that is typically used in the installation of a street light for both the county and city agencies. The data indicates that most agencies use 250 watt, high-pressure sodium (HPS) luminaires.

Other methods that are used by the county and city agencies to address safety issues at rural intersections are shown in Figure 3-3. Many of the agencies chose more than one type of improvement for implementation at these intersections. For the county and city agencies, the most frequent improvement is the use of advance signing (STOP AHEAD, INTERSECTION AHEAD, etc.) approaching the intersection. The county agencies used more of a variety of safety improvements for each intersection, than the city agencies did.

When the surveys were returned, most of the agencies chose to utilize the last section to write opinions and observations regarding the use of street lighting at rural intersections. In the 59 surveys that were returned by county agencies, most of the comments made were in favor of street lighting, for example:

1. Lighting makes it easier to find the intersection especially during adverse weather conditions (fog, rain, snow, etc.).
2. They alert the motorist to a change in the roadway.
3. Most useful at high ADT intersections especially in areas with aging populations.
4. Lighting in certain areas is helpful in reducing the number of accidents.

Some of the other comments made by county agencies that were not in favor of street lighting at rural intersections were:

1. Is the cost justified?
2. Traffic volumes are too low to warrant the installation
3. If a light is installed in one location, how do you justify denying other requests?

Of the 32 city agencies that returned the survey, most of the comments made were along the same lines, both positive and negative, as the county agencies' responses. A complete summary of all comments made by both the county and city agencies is given at the end of this memorandum.

3.3 Summary

- Most counties (78%) and cities (66%) do not operate and/or maintain any streetlights at rural intersections.

- Almost all of the counties and cities that responded have no warrants for the installation of street lighting at rural intersections. For those that have warrants, most of them follow Mn/DOT design criteria for lighting intersection patterns.

- The installation costs of a street light range from $300 to $3500; the operation costs range from $15 to $1050 per light per year; and the maintenance costs range from $20 to $230 per light per year. These cost values form a range due to the different estimates calculated by each agency.

∉ 93% of the counties and 80% of the cities would install a single street light at a rural intersection and 50% of both the counties and cities use a 250-Watt, High Pressure Sodium lamp upon installation.

∉ The other method that the counties (83%) and cities (28%) use most frequently to address the safety at rural intersections is the use of signing. For the counties, the next most frequent method of improvement is the use of rumble strips (61%) with lane delineation only 2% less.

∉ The primary positive impacts of the installation of street lighting, cited in the surveys, included crash reduction and motorist guidance.

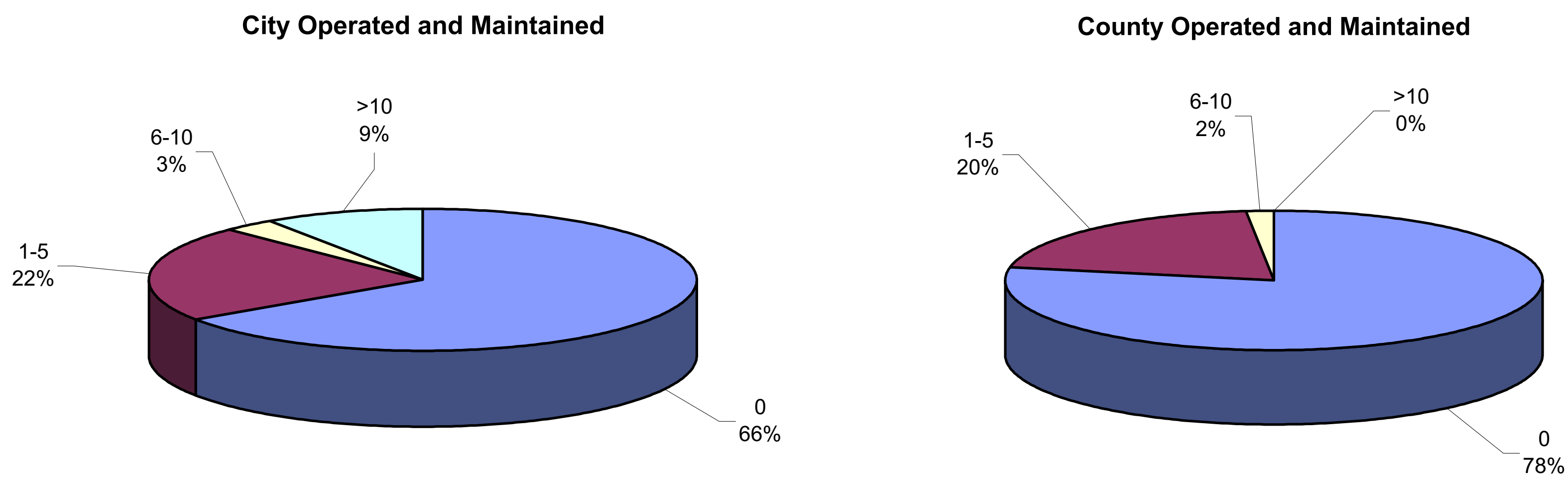
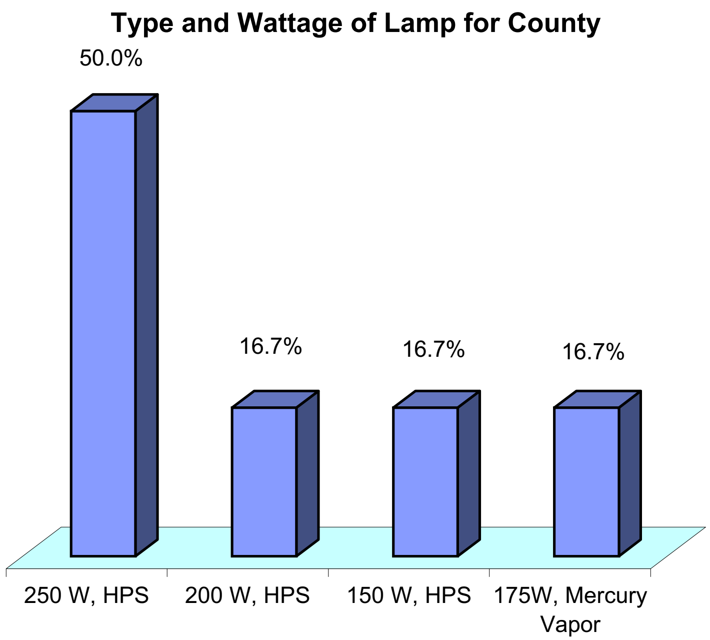
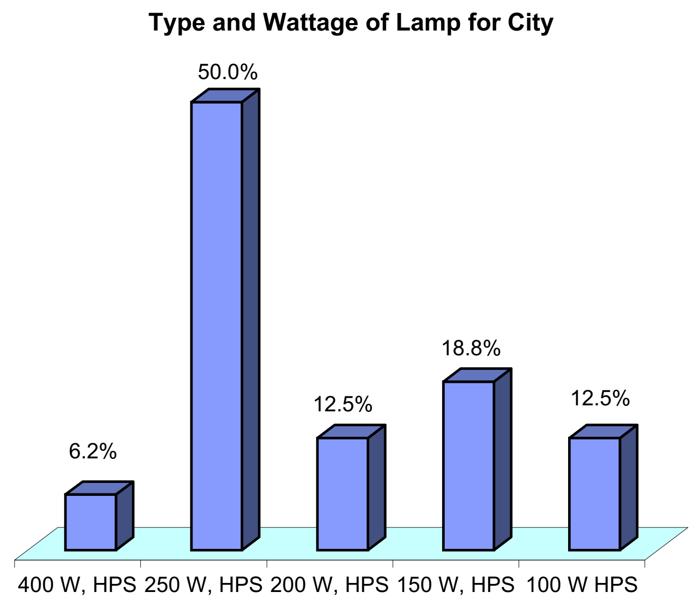


Figure 3.1

Percent of Lighted, Rural Intersections by the Number of Intersections Operated and Maintained by Each Agency

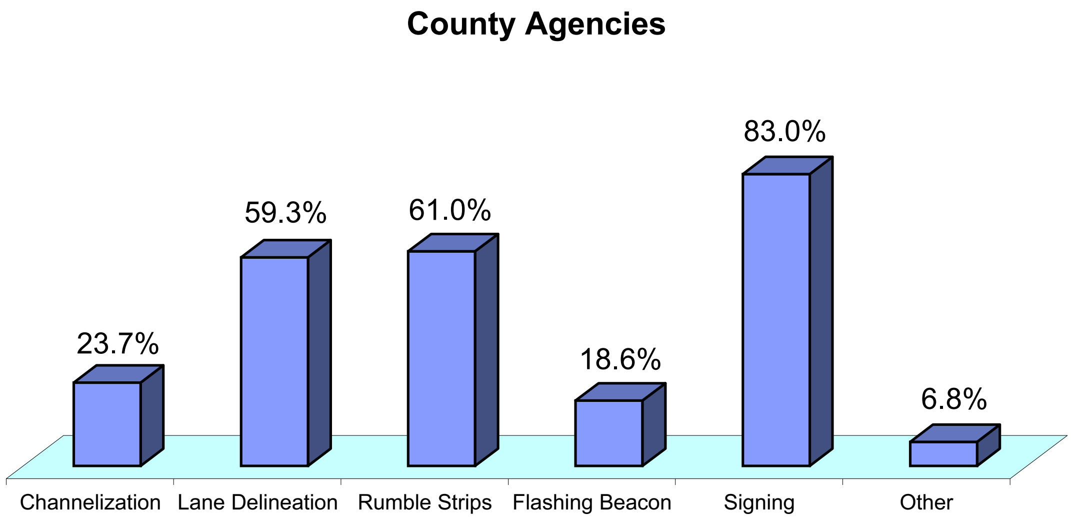




Note: HPS - High Pressure Sodium

Figure 3.2

Wattage and Type of Lamp Used in Street Lighting Installation



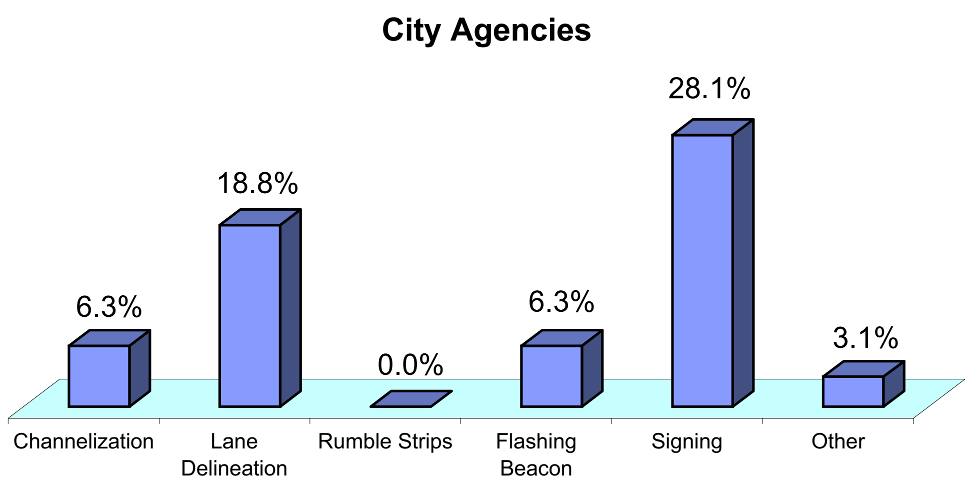


Figure 3.3

Safety Improvement Strategies at Rural Intersections

4.0 Warrants for the Installation of Street Lighting

The purpose of this chapter is to document existing warrants / guidelines that are currently in use and to recommend new or improved warrants for the installation of street lighting at rural intersections.

4.1 Minnesota Department of Transportation

The Minnesota Department of Transportation's warrants for installing street lighting at rural intersections are documented in Chapter 10 of the Traffic Engineering Manual. A summary of the warrants is outlined below.

Lighting of at-grade intersections is warranted if one or more of the following conditions exist:

a. 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.).

b. Crashes – There are three or more crashes per year occurring during conditions other than daylight.

c. Ambient Light – Illumination in areas adjacent to the intersection adversely affects the drivers' vision.

d. Channelization – The intersection is channelized and the 85th percentile approach speed exceeds 60 km/hr (40 mph).

e. Flashing Beacon – The intersection has a flashing beacon.

4.2 Other Sources

There are several additional sources that include warrants for roadway lighting. Two of the main sources are: "An Informational Guide for Roadway Lighting" from The American Association of State Highway and Transportation Officials (AASHTO) and the other is from the National Cooperative Highway Research Program (NCHRP) Report No. 152.

4.2.1 AASHTO

AASHTO illumination warrants are based on experience. Most of these warrants are designed for freeway ramp terminals but they can be treated similarly for rural intersections.

Partial Interchange Lighting - Freeways

1. 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 area exceeds 1,000 for rural conditions.

2. Case PIL-3. Partial interchange lighting is considered to be warranted when the ratio of night to day accident rate is at least 1.25 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night accident rate.

Other Warranting Conditions – Non-Freeway

1. Lighting may be considered for those locations where the respective governmental agencies concur that lighting will contribute substantially to the efficiency, safety, and comfort of vehicular or pedestrian traffic.

2. Lighting may be provided for locations where the ratio of the night to day accident rate is higher than the statewide average for similar locations, and a study indicates that lighting may be expected to significantly reduce the night accident rate.

3. Lighting may be considered at locations where severe or unusual weather or atmospheric conditions exist.

4. Lighting may be considered where the local government agency finds sufficient benefit in the form of convenience, safety, policing, community promotion, or public relations to pay an appreciable percentage of the cost of, or wholly finance the installation, maintenance, and operation of the lighting facilities.

5. Lighting of spot locations in rural areas should be considered whenever the driver is required to pass through a section of road with complex geometry and/or raised channelization.

4.2.2 NCHRP

The NCHRP Report No. 152 applies an analytical approach to illumination warrants. This analytical approach to roadway lighting warrants is embodied in four comprehensive evaluation forms that apply to non-controlled access facilities, intersections, freeways, and interchanges. The sheet titled "Classification for Intersection Lighting" (Table 14 – Appendix B) will be focused on for this report.

Through a research effort, the justification for roadway lighting has been related to driver visual information needs. The first step was to identify the various driver visual information needs that can be satisfied with roadway lighting (Appendix B). Table 2 (Appendix B) lists the characteristics of the traffic facility that contribute to each of the informational needs listed in Table 1.

To achieve an analytical approach to warrants, a quantitative measure, or rating system, of these characteristics must be hypothesized. This permits a numerical rating of each characteristic based on the extent to which the characteristic influences driver informational needs. Because some of the characteristics have a greater effect on driver informational needs than others, each of the characteristics for lighted and unlighted conditions is "weighted."

A minimum WARRANTING CONDITION was established that identified a minimum numerical level where lighting would be justified. This Minimum Warranting Condition as established is not firm, but simply a starting point.

4.2.3 Transportation Research Record No. 502," Walton and Messer– Informational Needs Approach to Warrants

Walton and Messer developed an analytical model for evaluating fixed roadway lighting needs. Fixed lighting is warranted at intersections when the information demand exceeds the information supply without fixed roadway lighting. The information demand is the time required to fulfill the sequence of positional, situational, navigational, and redundant positional information searches. Demand is given as:

$$D = \text{—}(P_i + S_i + N_i + P_{i+1})$$

where:

- D = information demand in seconds on a section of roadway
- P_i = time required to obtain a positional information on cycle i
- S_i = time required to obtain a situational information on cycle i
- N_i = time required to obtain a navigational information on cycle i
- P_{i+1} = next required positional information search update on cycle i+1, which must be achieved within the section of roadway visible during P_i

The positional informational supply, C, depends on the suitability of the night driving environment without fixed roadway lighting. This factor is computed considering visibility distance, headlight condition, glare sources, degree of curvature, oncoming vehicle spacing, and traffic volume. To check a section of roadway to determine if fixed roadway lighting is warranted, the information index, I, is given by the following relationship:

$$I = \frac{D \text{ (information demand)}}{C \text{ (information supply)}}$$

If the information index, I, is greater than one, fixed roadway lighting is warranted.

4.2.4 Wortman: University of Illinois – Warrants for Rural Intersection Lighting

Rural intersections should be considered for lighting if the average number of night accidents (N) per year exceeds the average number of day accidents (D) per year divided by three. If N is greater than D/3, the likely average benefit should be taken as N - D/3 accidents/year.

The estimated cost of lighting the intersections, which shows a benefit using the above criteria, should be computed. The lighting program should then be based on the resulting list of intersections ranked in priority order by means of the benefit/cost ratio (expressed as annual reduction in accidents/annual cost).

4.3 Warrant / Guideline Analysis and Recommended Revisions

The two primary warrants/guidelines for the installation of streetlights at rural intersections in Minnesota (as noted in Chapter 10 of MnDOT's Traffic Engineering Manual and summarized in Section 4.1 of this report) suggest minimum values for both intersection traffic volumes and nighttime crash frequencies. The traffic volume thresholds are based on the guidance for traffic signal installation in the Manual on Uniform Traffic Control Devices (MUTCD) and equate to major street volumes in the range of 7,000 to 12,000 vehicles per day. For comparison purposes, the average daily traffic volume at over 3,200 rural intersections without streetlights (included in the analysis for this project) was approximately 2,000 vehicles per day. A further review of rural intersection traffic volumes found that the recommended threshold values needed to meet the signal warrants in the MUTCD would be exceeded at only about 5% to 15% of rural intersections on the state's system and ever fewer intersections along county highways and roads.

The suggested crash frequency value is three or more nighttime crashes per year. No rationale is presented to support this level of nighttime crashes. However, it should be noted that the average annual number of nighttime crashes at the 3,200 unlighted rural intersections was 0.2 and that the value of 3 crashes per year would be exceeded at only about 4% of the intersections.

A further review of the technical data, presented in Chapter 5.0, indicates that fewer than 8% of the rural intersections in Mn/DOT's database have streetlights. It appears that this limited use may be due to the very high threshold values documented in the warrants/guidelines for streetlight installation. However, the conclusions of the technical analysis suggest that the installation of streetlights at rural intersections is a low cost and very effective strategy for mitigating nighttime crashes. Therefore, it is recommended that consideration be given to reducing the values for the traffic volume and crash frequency guidelines in order to encourage agencies to install streetlights at more locations.

The current traffic volume warrants/guidelines are based on threshold volumes for traffic signal installation. This concept seems inappropriate when considering trunk highways in rural areas and particularly inappropriate when considering county and local road applications. However, given the very wide range of volumes on rural roadways it would be difficult to select a single volume threshold that would be appropriate in all situations. Therefore, it may be reasonable to prioritize the installation of streetlights at rural intersections based on a consideration of roadway functional classification, a range of typical volumes (as determined from a review of published Mn/DOT data from statewide Automatic Traffic Recording stations), and an estimate of the cross street traffic volume as noted in the following matrix:

	Major Street Functional Classification (Major Street Volumes in Vehicles per Day)			
Priority	**Principal Arterial (TH)**	**Minor Arterial (TH or CSAH)**	**Collector (CSAH or CR)**	**Local (CR or Twp Rd)**
Low	0 – 2,000 (10%)	0 – 1,000 (10%)	0 – 500 (10%)	0 – 250 (10%)
Moderate	2,000 – 5,000 (15 %)	1,000 – 2,000 (15%)	500 – 1,000 (15%)	250 – 500 (15%)
High	> 5,000 (20%)	>2,000 (20%)	> 1,000 (20%)	> 500 (20%)

Note: The value in parentheses is the percent of the major street traffic that is recommended on the minor crossing street for the warrants/guidelines to be met.

This approach addresses the inherent differences in traffic volume characteristics between state, county and local roadways. In addition, based on the available traffic volume data, this would result in about 25% of the intersections in any system being considered a high priority. This would represent about a five fold increase over the number of rural intersections on the state system that would meet the current traffic volume warrants and would for the first time present realistic values for the county and local road systems.

Because there was only a minimal amount of data that was available, it is not suggested that the traffic values contained in the matrix are the only possible values. However, it is suggested that these values are more representative of actual conditions than the current traffic signal warrant based guidance and that the lower volume threshold will allow agencies to increase their use of street lights at rural intersections. The best measure of the effectiveness of any kind of guidance for design or installation is the test of time. If after some period of usage the recommended values prove to be inappropriate, then action should be taken to change the values in order to achieve the desired outcome – optimizing safety at the lowest level of reasonable investment.

The current safety related warrant/guideline has a threshold value of three nighttime crashes per year. This is fifteen times greater than the average number of nighttime crashes and is exceeded by fewer than 4% of the rural unlighted intersections in the Mn/DOT database. As a result, it is recommended that consideration be given to lowering the crash threshold from three nighttime crashes in one year to a minimum of three nighttime crashes in a three-year period. This average of one nighttime crash per year represents about the 75th percentile value for unlighted intersections in Mn/DOT's database.

5.0 Technical Analysis

The purpose of this chapter is to document the system-wide and before versus after crash statistics and discuss the observed trends in the data.

5.1 System-Wide Comparative Crash Analysis

A general system-wide comparative analysis using Mn/DOT crash records was conducted for all isolated, rural, two-lane, through-stop intersection locations from 1995 to 1997. These intersections in the crash records were divided into two categories:

1. Intersections with street lights
2. Intersections without street lights

These two categories of intersections were then divided into four categories of crashes:

1. Daytime crashes at intersections with street lights
2. Nighttime crashes at intersections with street lights
3. Daytime crashes at intersections without street lights
4. Nighttime crashes at intersections without street lights

Because of the difficulty of distinguishing dusk and dawn from daytime or nighttime, this crash data was omitted from the study. From the daytime and nighttime crash data, the following statistics were documented for each category (based on the three years of crash data):

- Total number of intersections
- Total number of crashes
- Average number crashes per intersection per year
- Distribution of total crashes by type (rear end, right angle, head-on, etc.)
- Distribution of total crashes by severity (property damage, personal injury and fatal)
- Percentage of daylight versus night crashes
- Distribution of daylight versus night crashes by type
- Distribution of daylight versus night crashes by severity
- Total, daylight, and night exposure rates (million entering vehicles)

The results of the comparative analysis are presented in Table 5-1 and discussed in the following sections.

5.1.1 Total Nighttime Crash Frequency / Rate

The following analysis will focus on crashes that occur during nighttime hours. There were a total of 259 intersections with street lighting and 3,236 intersections without street lighting. During nighttime hours, there were a total of 227 crashes at intersections with street lighting and 1926 crashes at intersections without street lighting. This resulted in 0.29 nighttime crashes per intersection per year with lighting and 0.20 nighttime crashes per intersection per year without lighting (Figure 5-1).

To determine daytime and nighttime crash rates, the exposure rates (the number of vehicles travelling during daytime and nighttime hours) and average daily traffic (ADT) for each intersection were needed. A total exposure rate was found from the crash data provided; however, the crash data did not separate these exposure rates into daytime and nighttime hours. Therefore, these exposure rates were calculated from the Minnesota Automatic Traffic Recorder (ATR) Data. The ATR Data gave a breakdown of average daily traffic volumes by month (Table 5-2) and a percent of average daily traffic volumes by hour (Table 5-3). The average daily traffic values by month were changed to a percent of monthly traffic by year. From the percent of monthly traffic and the percent of hourly traffic, the total percent of daily traffic by month and by hour was determined. The average times of sunrise and sunset (daytime and nighttime) for each month were found on the WCCO Weather Internet Site. Combining all of this information, the total percent of traffic traveling during daylight hours (daylight exposure percentage) was approximately 77 percent (Table 5-4).

After these percentages were multiplied by the total exposure rate, the nighttime crash rate per million entering vehicles for lighted intersections was 0.47 and for unlighted intersections it was 0.63 (Figure 5-2). Therefore, intersections with street lighting had approximately a 25 percent lower nighttime crash rate than intersections without street lighting. A statistical analysis indicates that this difference is significant at the 99.5 percent confidence interval.

5.1.2 Crash Severity

A severity index was calculated to determine if there is any reduction in nighttime crash severity due to the installation of street lighting. The severity index was found by dividing the number of personal injury and fatal crashes by the total number of crashes. For intersections with and without street lighting (Figure 5-3) shows the nighttime severity indexes were 0.33 and 0.36, respectively. This represents an 8 percent lower severity index for intersections with street lighting, however, this difference is not statistically significant. (Figures 5-4 and Figure 5-5 show the severity indexes for daytime and total crashes.)

5.1.3 Crash Types

The distribution of nighttime crashes by type for lighted and unlighted intersections is shown in Figure 5-6. Also included in this figure are the Minnesota statewide averages for collisions at rural unsignalized intersections. The percent of "off road" crashes at intersections with street lighting was approximately 34 percent lower than intersections without street lighting;

however, the percent of "right angle" crashes was approximately 24 percent greater at intersections with street lighting. Both of these crash types are statistically significant up to the 90th percentile. (Figure 5-7 and Figure 5-8 show the types of crashes for daytime and total crashes.)

The crash data was also divided into single vehicle crashes versus multiple vehicle crashes. The expectation is that most single vehicle crashes are not related to the installation of street lighting. This is due to the assumption that intersection related crashes involve vehicles travelling through the intersection or turning onto the intersecting roadway and that this movement causes the vehicle to come into conflict with another vehicle, therefore causing a crash. This could lead to an expectation that there is no observed relationship between the installation of street lighting and single vehicle crash rates.

Figure 5-9 shows the total number of nighttime crashes and crash rates for single vehicle and multiple vehicle crashes for intersections with and without lighting. Intersections with street lighting have an approximate 10 percent lower multiple vehicle crash rate than intersections without street lighting. The multiple vehicle crash rate reduction is not statistically significant at the 90th percentile level of confidence. However, the single vehicle crash rate for intersections with street lighting is approximately 53 percent lower than intersections without street lighting, which is statistically significant at the 90th percentile. (Figure 5-10 and Figure 5-11 show the single vehicle versus multiple vehicle crashes for the daytime and total categories.)

5.2 Before vs. After Crash Analysis

A before versus after crash analysis of a sample of rural intersections was also conducted to provide additional information about the safety effects of street lighting. A total of twelve intersections were selected by Mn/DOT based on the availability of data documenting the installation and the fact that the addition of street lighting was the only change at the intersection. A total of six years of crash data was collected from the Minnesota Department of Transportation's crash records. This data included three years before and three years after the installation of the streetlight (not including the year that the street light was installed). The crash data was collected for streetlights that had been installed between 1987 and 1994 because Mn/DOT's crash records only go back to 1984.

The crash data was divided into three different types of measures of effectiveness for nighttime crashes: crash types (rear end, right angle, head on, etc.), single vehicle crashes versus multiple vehicle crashes, and crash severity (fatal plus personal injury and property damage). Also, the Poisson Distribution was used as the measure of statistical significance for the before versus after crash analysis because of the relatively small sample size of the data. The figures used are included in Appendix C.

The results of the before versus after analysis are presented in Table 5-5 and are discussed in the following sections.

5.2.1 Total Crash Frequency / Rate

Overall, there was a decrease in the nighttime crash rate from 6.06 before to 3.61 after the installation of lighting. This represents an approximate 40 percent decrease in the nighttime crash rate due to the installation of street lighting, and this difference is statistically significant at a 95% confidence interval. Also from the total number of crashes, the number of intersections, and the number of years used for the crash data collection, the average number of crashes per intersection per year was determined to be 1.31 before lighting to 0.78 after lighting, a decrease of 0.53 crashes per intersection per year.

5.2.2 Crash Severity

As stated previously, a crash severity frequency of nighttime crashes was calculated to determine the effect that street lighting has on the fatal and personal injury crashes. Figure 5-12 shows the total number of crashes and the crash severity index for fatal and personal injury crashes and property damage crashes. This data includes the fatal and personal injury crashes decreased by approximately 20 percent and this difference is statistically significant at the 90% confidence interval.

5.2.3 Crash Types

The nighttime crash rate and percentage of total crashes for the different types of crashes are shown in Figure 5-13 and Figure 5-14. The two types of crashes with the largest decrease in crash rates, besides “other/unknown”, were “off road” and “right angle.” Off road and right angle crash rates experienced an approximate decrease of 34 and 44 percent, respectively, from before lighting to after lighting. For every crash type category, the crash rate either remained the same or decreased from before lighting to after lighting. However, the crash rate data by crash type is not statistically significant at the 90% confidence interval. Also, the percentages of crashes by crash type were compared to the Minnesota statewide averages for rural intersections. This information was statistically unreliable due to the small size of each sample.

As stated previously, the expectation was that most single vehicle crashes are not related to the installation of street lighting. Figure 5-15 presents the total number of crashes and the crash rates for single vehicle and multiple vehicle crashes for before lighting and after lighting. In reviewing this figure, it was clear that the installation of street lighting and multiple vehicle crashes had a positive observed relationship because the crash rate decreased by approximately 63% after street lighting was installed. It was also shown that there is a positive relationship between the installation of street lighting and single vehicle crashes (a 29 percent decrease) which was due to the large decrease in the number of off road crashes.

The difference in both the single vehicle and multiple vehicle crash data are significant at the 90% confidence interval.

5.3 Benefit – Cost Analysis

Benefit cost analysis examines the benefits generated by a particular project and compares them to the costs incurred by the project over a certain analysis period. If the benefit-cost ratio is greater than one, the project is considered to be cost effective. This study examined only the benefits from crash reduction from before to after the installation of street lighting.

An average crash cost was calculated using the results of the "Before versus After Technical Analysis" and the crash cost values currently used by Mn/DOT. These values were taken from the State of Minnesota Office Memorandum dated February 9, 1999 regarding Revised Crash Costs.

∉ Property Damage	=	$4,000
∉ Personal Injury A	=	$260,00
B	=	$56,000
C	=	$27,000
∉ Fatality	=	$3,400,00

The costs presented for street lighting represent initial capital investment costs annualized over 10 years with a discount rate of 5 %. The installation, operation, and maintenance costs were taken from the "Survey of Agencies" section of this report. Table 5-6 shows the crash reduction benefit-cost ratios for the installation of street lighting. Appendix D contains an example of how the benefit-cost ratio was calculated.

The results of this effort suggest that the crash reduction benefits associated with the installation of street lighting at rural intersections outweigh the costs by a wide margin.

5.4 Summary

The purpose of this chapter was to provide an assessment of the installation of street lighting / crash rate relationship. For both the system-wide comparative crash analysis and the Before versus After crash analysis, there was a positive observed relationship between the installation of street lighting and reduction of nighttime crash rates. Also, the installation of street lighting was effective at reducing the number of nighttime off road crashes and the severity of nighttime crashes for both the system-wide comparative analysis and before versus after analysis.

Table 5.1

Summary of Comparative Crash Analysis

System-Wide Comparative Analysis

	Without Street Lighting	With Street Lighting	Percent Difference	Statistically Significant ? (Confidence Interval)
Number of Intersections	3236	259		
Day Crashes	3766	633		
Night Crashes	1926	227		
Total Crashes	5692	860		
Percent Day Crashes	66.2%	73.6%	11%	
Percent Night Crashes	33.8%	26.4%	-22%	
Day Crashes per Intersection per Year	0.39	0.81	101%	
Night Crashes per Intersection per Year	0.20	0.29	45%	
Total Crashes per Intersection per Year	0.59	1.11	88%	
Day Exposure (vehicles)	9,283,089	1,445,303		
Night Exposure (vehicles)	2,804,266	436,602		
Total Exposure (vehicles)	12,087,355	1,881,905		
Average Day Exposure per Intersection (vehicles)	2869	5580		
Average Night Exposure per Intersection (vehicles)	867	1686		
Average Total Exposure per Intersection (vehicles)	3735	7266		
Day Crash Rate	0.37	0.4	8%	Yes (80%)
Night Crash Rate	0.63	0.47	-25%	Yes (99.5%)
Total Crash Rate	0.41	0.39	-5%	No (80%)
Night Property Damage Crashes (%)	1236 (64.2%)	153 (64.7%)	0.50%	No (90%)
Night Personal Injury Crashes (%)	660 (34.3%)	69 (30.4%)	-11%	No (90%)
Night Fatal Crashes (%)	30 (1.6%)	5 (2.2%)	27%	No (90%)
Night Personal Injury plus Fatal Crashes (%)	690 (35.8%)	74 (32.9%)	-8%	No (90%)
Severity Index	36%	33%	-8%	No (90%)
Night Run Off Road Crashes (%)	450 (23.4%)	35 (15.4%)	-34%	Yes (90%)
Night Right Angle Crashes (%)	442 (22.9%)	68 (30.0%)	31%	Yes (90%)
Night Single Vehicle Crashes (%)	450 (23.4%)	35 (15.4%)	-34%	
Night Multiple Vehicle Crashes (%)	870 (45.2%)	121 (53.3%)	18%	
Night Single Vehicle Crash Rate	0.15	0.07	-53%	Yes (90%)
Night Multiple Vehicle Crash rate	0.28	0.25	-11%	No (90%)

Table 5.3

Hourly Traffic Averages for the Entire Year

System-Wide Cromparative Analysis

Jan, Feb, Mar, Apr, May, Sept, Oct, Nov, and Dec						
	% of volume					
Hour	ATR 50	ATR 52	ATR 57N&S	ATR 100N	ATR 166	Average
AM						
MID-01	0.4	0.7	0.6	1.4	0.5	0.7
01-02	0.2	0.5	0.4	0.8	0.3	0.4
02-03	0.2	0.2	0.1	0.6	0.2	0.3
03-04	0.2	0.2	0.1	0.5	0.2	0.2
04-05	0.5	0.5	0.2	0.3	0.4	0.4
05-06	2	0.7	1.2	0.5	1.8	1.2
06-07	4.8	3.4	4.4	1.5	4.5	3.7
07-08	5.1	6.4	7.6	4.5	6.4	6.0
08-09	4.6	5.9	4.8	9.2	5.1	5.9
09-10	4.7	5.3	4.6	6.8	5.3	5.3
10-11	4.9	5.9	4.9	5.4	5.5	5.3
11-NOON	5.3	5.9	5.4	5.4	5.8	5.6
PM						
NOON-01	5.5	5.9	5.1	5.8	6.1	5.7
01-02	5.8	6.2	5.7	6.2	6.6	6.1
02-03	6.3	7.1	6	6.2	7.1	6.5
03-04	8.2	8	7.7	6.4	9	7.9
04-05	10.3	8.5	8.3	7	8.2	8.5
05-06	9.9	7.3	8.6	7.3	7.6	8.1
06-07	7.3	5.9	6.4	6.7	5.5	6.4
07-08	4.8	4.6	4.9	5.3	3.7	4.7
08-09	3.5	3.7	4.3	3.9	3.2	3.7
09-10	2.7	3.4	3.8	3.1	3.3	3.3
10-11	1.5	2.5	2.8	2.9	2.2	2.4
11-MID	0.9	1.6	2	2.4	1.5	1.7
					Total:	**100.0**

June, July, August						
	% of volume					
Hour	ATR 50	ATR 52	ATR 57N&S	ATR 100N	ATR 166	Average
AM						
MID-01	0.5	0.7	0.7	1.6	0.7	0.8
01-02	0.2	0.5	0.4	0.9	0.3	0.5
02-03	0.1	0.2	0.2	0.6	0.2	0.3
03-04	0.2	0.2	0.1	0.5	0.2	0.2
04-05	0.4	0.2	0.2	0.4	0.4	0.3
05-06	2.1	0.9	1.2	0.5	1.8	1.3
06-07	4.7	3.8	3.9	1.5	4.6	3.7
07-08	4.8	6.1	6.4	4.5	5.4	5.4
08-09	4.3	5.9	4.5	8.1	4.6	5.5
09-10	4.5	5	4.5	6.2	5.2	5.1
10-11	4.9	5.9	5	5.2	5.8	5.4
11-NOON	5.3	5.9	5.6	5.6	6.1	5.7
PM						
NOON-01	5.8	6.1	5.4	6.1	6.4	6.0
01-02	5.7	6.5	5.4	6.5	6.9	6.2
02-03	6	6.8	5.9	6.5	7.1	6.5
03-04	8	7.2	7.6	6.5	8.4	7.5
04-05	9.8	8.1	8.2	6.8	8.1	8.2
05-06	9.8	7.4	8.7	7	7.5	8.1
06-07	7.6	5.9	6.5	6.5	5.6	6.4
07-08	5.2	5.2	5.3	5.2	3.9	5.0
08-09	4.2	4.3	4.7	4	3.4	4.1
09-10	3.1	4.1	4.3	3.5	3.4	3.7
10-11	1.6	2.5	3	3.1	2.3	2.5
11-MID	0.9	1.4	2.1	2.6	1.7	1.7
					Total:	**100.0**

Source: Minnesota Automatic Traffic Recorder

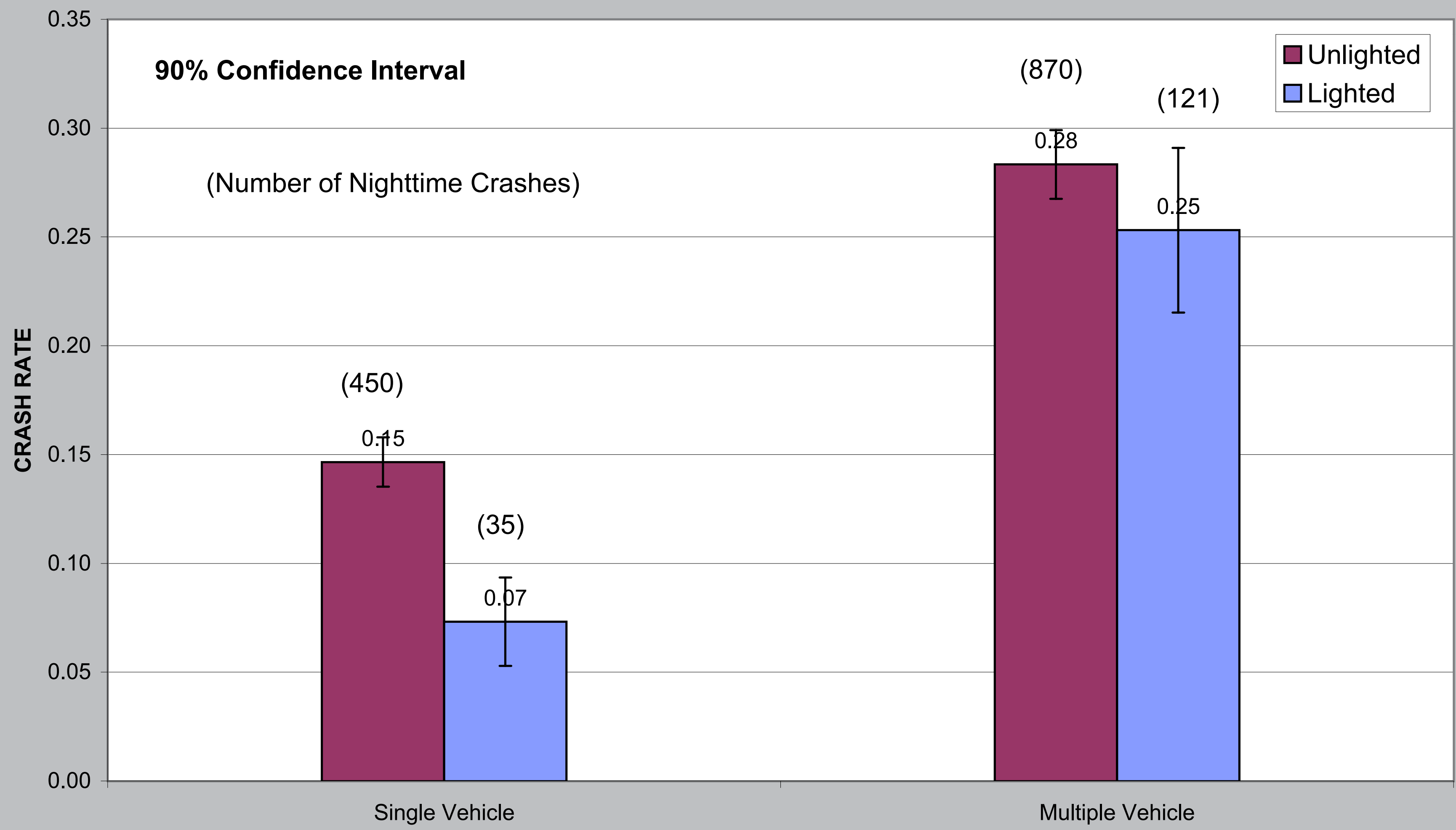


Figure 5.9

Nighttime Crash Rates Based on Single Vehicle vs. Multiple Vehicle

System-Wide Comparative Analysis

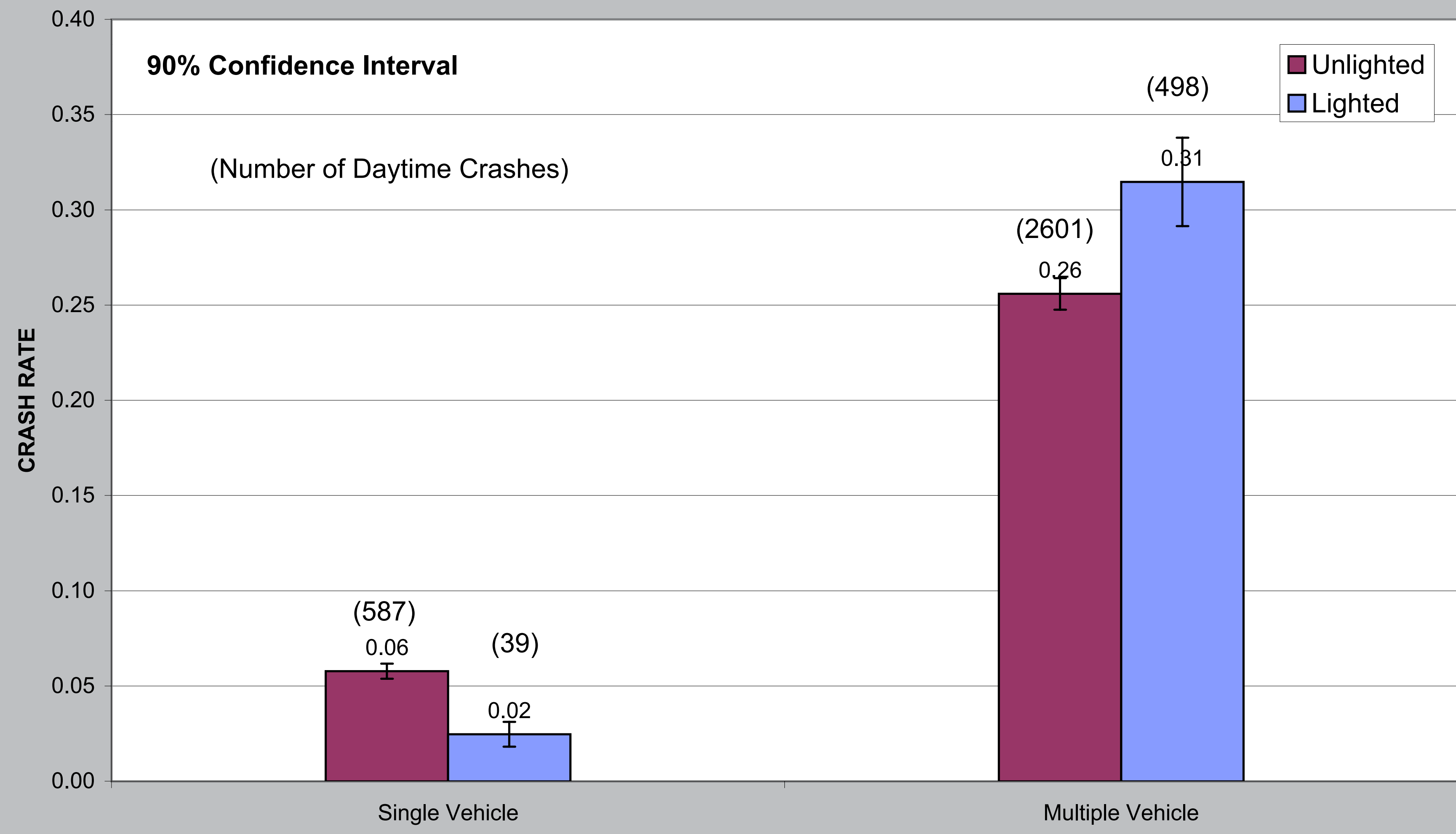


Figure 5.10

Daytime Crash Rates Based on Single Vehicle vs. Multiple Vehicle

System-Wide Comparative Analysis

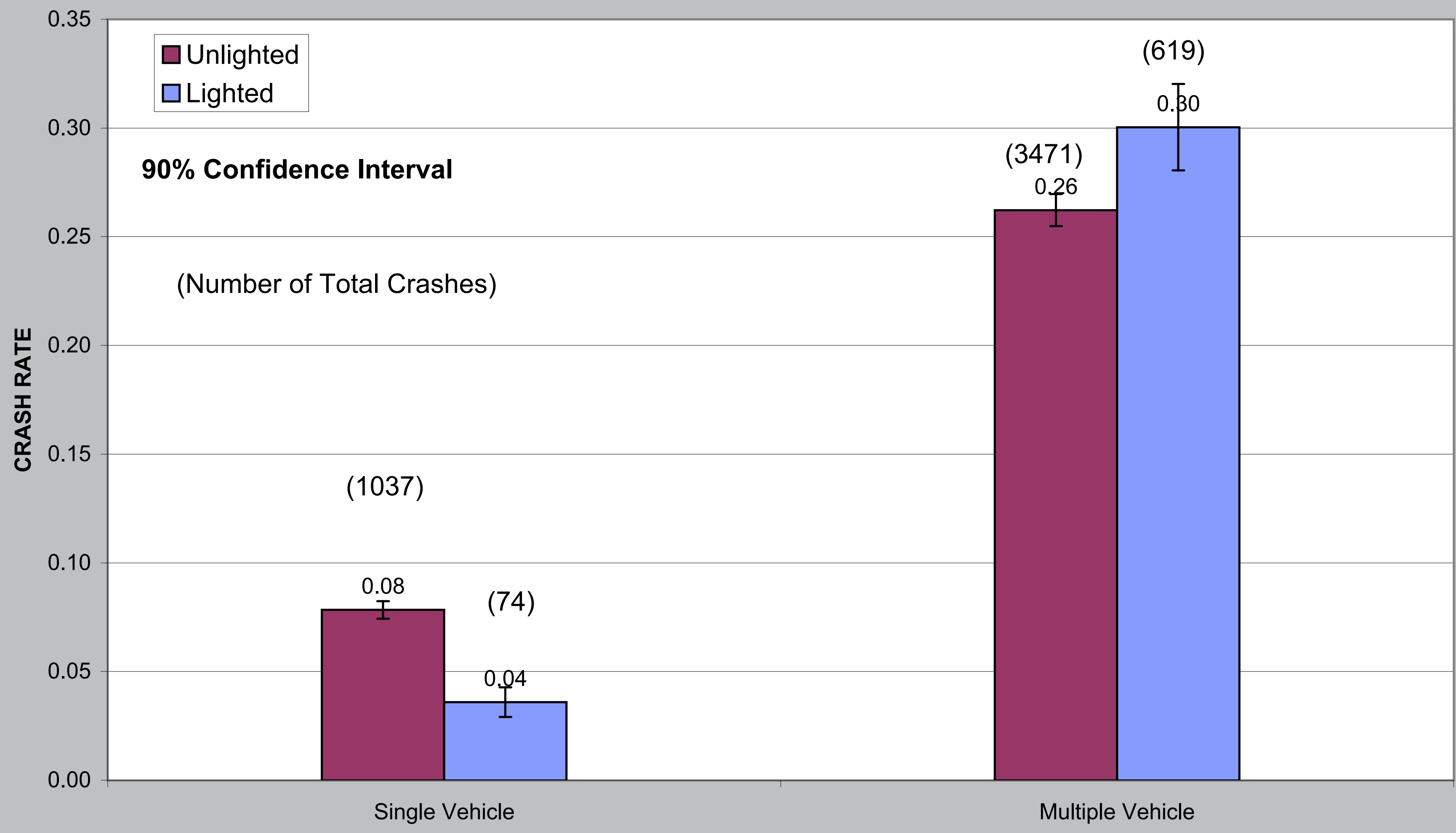


Figure 5.11

Total Crash Rates Based on Single Vehicle vs. Multiple Vehicle

System-Wide Comparative Analysis

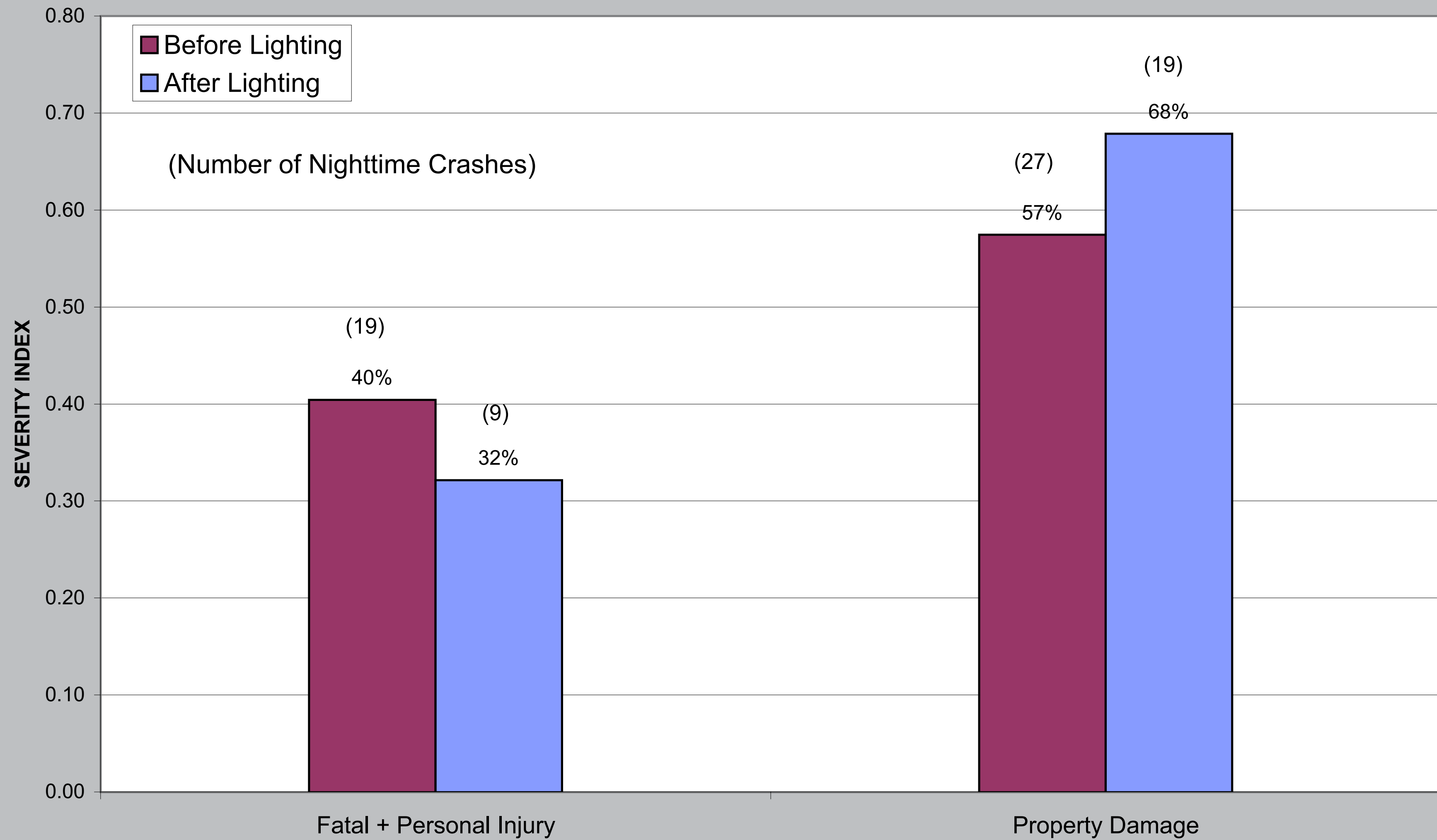


Figure 5.12

Nighttime Crash Severity Rate

Before vs. After Crash Analysis

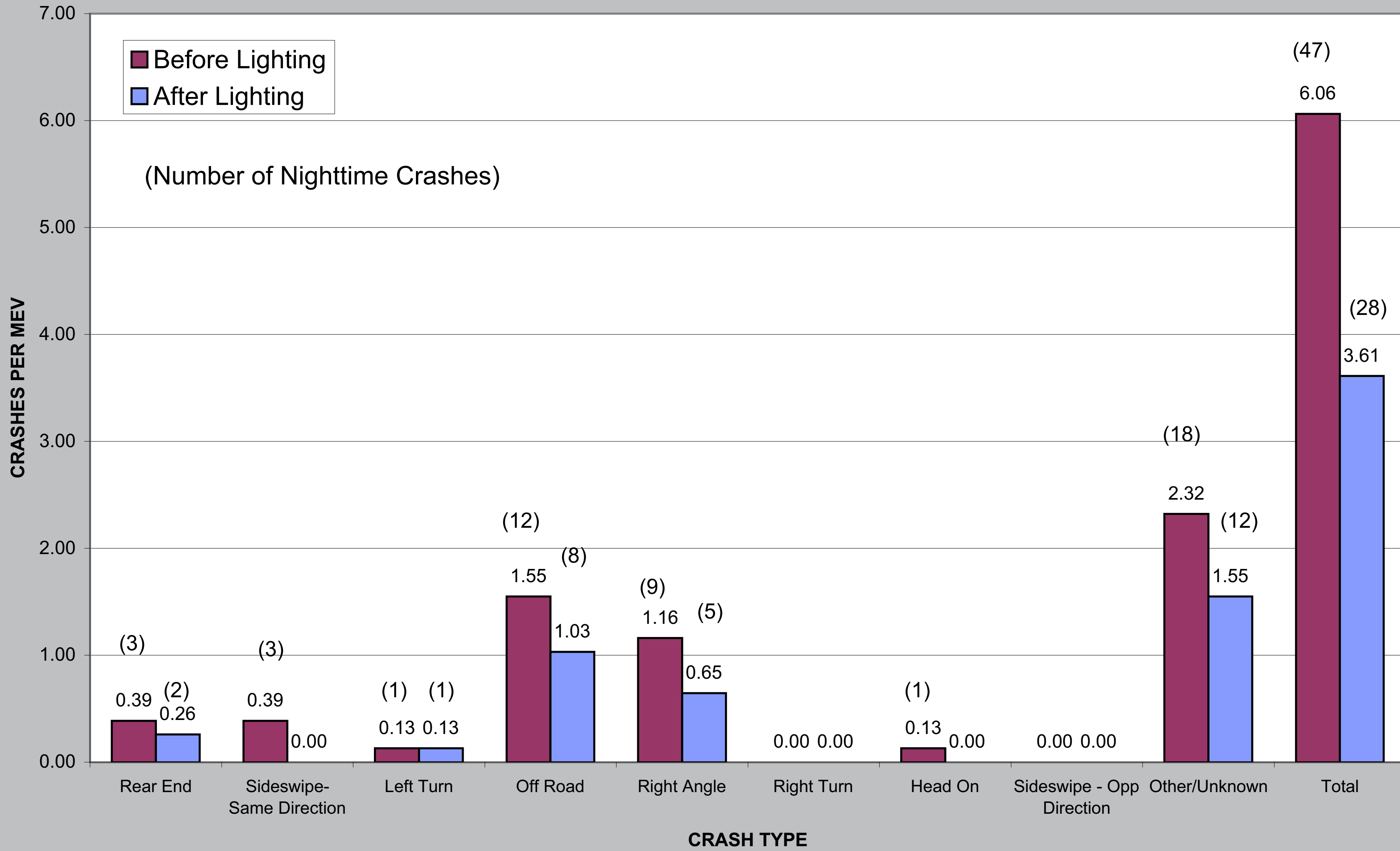


Figure 5.13

Nighttime Crash Rates by Crash Type

Before vs. After Crash Analysis

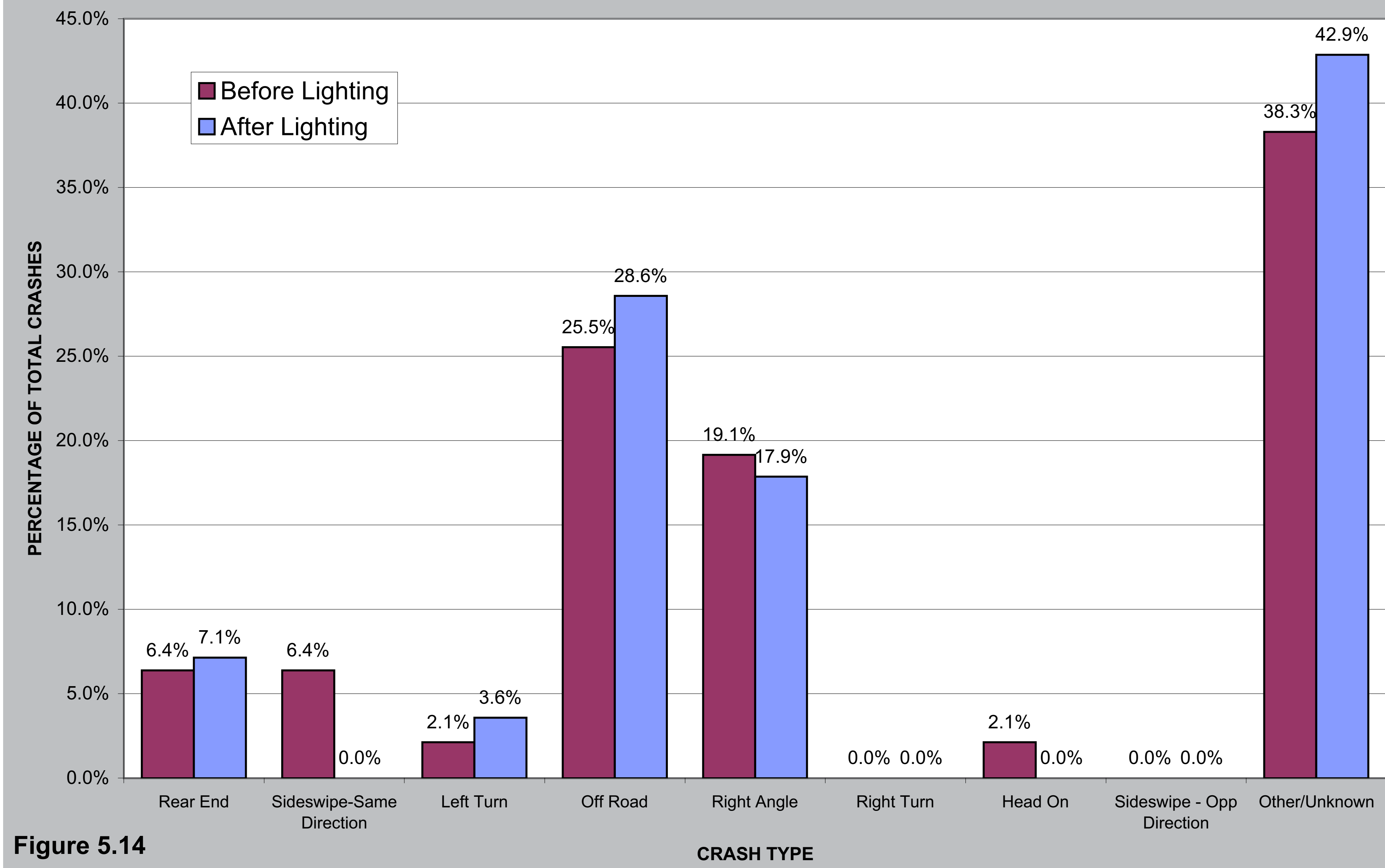


Figure 5.14

Percentage of Nighttime Crashes by Crash Type

Before vs. After Crash Analysis

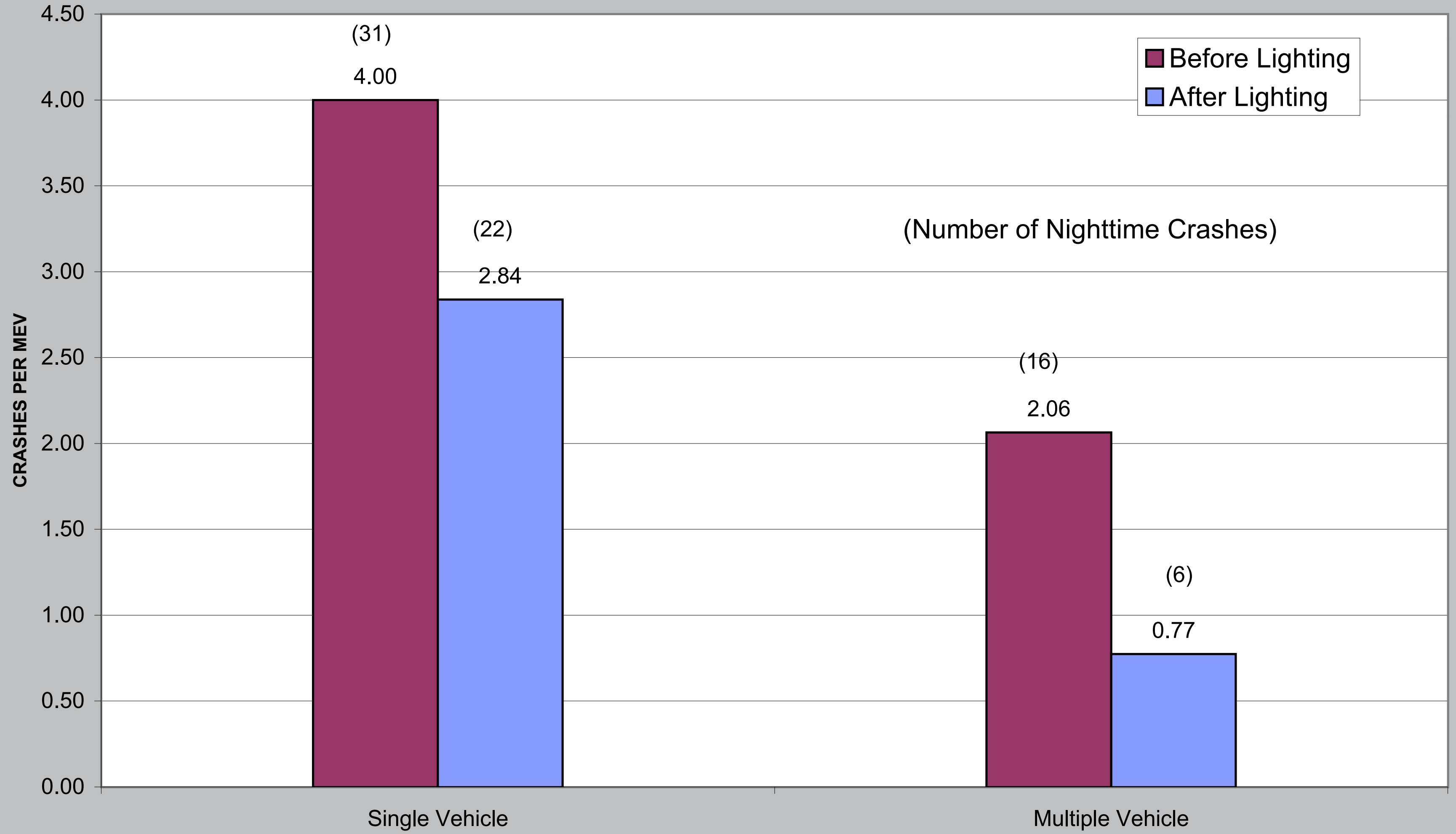


Figure 5.15

Nighttime Crash Rates Based on Single Vehicle vs. Multiple Vehicle

Before vs. After Crash Analysis

6.0 Conclusions

Literature Search

1. The previously published safety research suggested that the installation of intersection lighting has resulted in 25 to 50 percent reductions in the night crash rate and 20 to 30 percent reductions in the night crash / total crash ratio.

2. A report prepared by the Federal Highway Administration documenting the effectiveness of various types of intersection and traffic control improvements found that intersection lighting had the highest benefit-cost ratio (21:1).

Survey of Usage

3. A survey was sent to both city and county engineers around the state of Minnesota regarding the usage of and the safety effects of street lighting at rural intersections. The survey showed that only 26 percent of the agencies have installed street lighting, most agencies have no warrants for installation of street lighting and the observed benefits include crash reduction and improved motorist guidance.

4. The most frequently used strategies for addressing rural intersection safety are signing, rumble strips and overhead flashing beacons.

5. When agencies have installed street lighting at rural intersections, the observed benefits included nighttime crash reduction and improved motorist guidance.

Warrants for Installation

6. The primary source of guidance available to engineers in the State of Minnesota for installing streetlights is the Mn/DOT Traffic Engineering Manual. The basic guidelines include warrants for installation based on meeting the following criteria:

    1. The traffic signal warrant volumes for minimum vehicular volume, the interruption of continuous traffic, or the minimum pedestrian volume are satisfied for any single hour during conditions other than daylight,
    2. More than three crashes per year during hours of darkness,
    3. The intersection is channelized and the 85th percentile approach speeds exceed 60 km/hr.

7. Other sources of warrants for street lighting include:

    - American Association of State Highway and Transportation Officials (AASHTO)
    - National Cooperative Highway Research Program (NCHRP) Report No. 152

    The AASHTO illumination warrants are based on present experience (a description of operational, geometric, and development conditions that must be matched or exceeded) whereas the NCHRP Report No. 152 applies an analytical approach to determining needs and benefits.

8. A review of the traffic volumes and nighttime crashes cited in the Mn/DOT warrants found that these values would be exceeded in only about 5% to 10% of the unlighted rural intersections in Mn/DOT's crash records system. This may help to explain why intersection lighting has been installed in only about 10% of the intersections in Mn/DOT's database.

9. Consideration should be given to reducing the values for the traffic volume and nighttime crash frequency in the guidelines in order to encourage the installation of intersection lighting at more locations. For example, by reducing the crash frequency warrant from three nighttime crashes per year to three over a three-year period, the number of intersections potentially meeting the warrant would increase by a factor of two and one-half. In addition, if the volume warrants were revised to reflect a prioritized approach based on major street functional classification and a typical range of volumes for each classification, the warrants would be more representative of actual conditions along each of the various systems of rural roadways.

Technical Analysis

10. When working with Mn/DOT's crash records system, it is acknowledged that the various roadway segment and intersection categories do not include the entire population in the State's Trunk Highway System. However, it has been assumed that the categories consisted of a random and therefore representative sample. In this study, there is some indication that the crash data for the lighted intersections may be biased based on the District's practice of primarily selecting intersections with a poor safety history for inclusion in the crash records database. As a result of this practice, the sample of intersections in the database may not be random and therefore may not present an accurate picture of the actual safety effects of the installation of street lighting at rural intersections.

11. System-Wide Comparative Crash Analysis

- The system-wide comparative (crashes per million entering vehicles) analysis using Mn/DOT's crash records showed that the nighttime crash rate for intersections with and without street lighting was 0.47 and 0.63, respectively. This represents a 25 percent lower nighttime crash rate at rural intersections with street lighting. This decrease is statistically significant at the 99.5% confidence interval.

- The intersection with street lighting had a nighttime severity rate 8% lower than intersections without street lighting. However, this difference was not statistically significant.

- ∉ Rural intersections with street lighting had a 34 percent lower incidence of single-vehicle off road crashes than intersections without street lighting. This decrease was statistically significant at the 90% confidence interval.

12. Before Versus After Crash Analysis

- ∉ A before versus after crash analysis was completed for a sample of twelve intersections selected by Mn/DOT. The intersections that were examined were those where the only safety mitigation that was applied to the intersection was the installation of the street light and where crash, traffic volume, construction date information was available.

- ∉ At intersections where street lighting was installed, there was an overall decrease in the nighttime crash rate from 1.41 crashes per million vehicles before lighting to 0.84 after lighting. This was a decrease of approximately 40 percent and is statistically significant at a 95% confidence interval.

- ∉ There is a statistically significant positive relationship between nighttime multiple vehicle crashes and the installation of street lighting. After installing street lighting, the nighttime multiple vehicle crash rate declined from 0.48 before lighting to 0.18 after lighting. This is a 63 percent reduction and is statistically significant at a 90% confidence interval.

- ∉ There is a statistically significant positive relationship between nighttime single vehicle crashes and the installation of intersection lighting. After installing intersection lighting, the nighttime single vehicle crash rate declined from 1.55 before lighting to 1.03 after lighting. This is a 29% reduction and is statistically significant at a 90% confidence interval.

- ∉ There is also a positive relationship between nighttime crash severity and the installation of street lighting. The percentage of personal injury and fatal crashes declined from 40 percent before lighting to 32 percent after lighting. This is a 20 percent reduction and is statistically significant at a 90% confidence interval.

- ∉ A Benefit versus Cost analysis found that the crash reduction benefits associated with the installation of street lighting at rural intersections outweigh the costs by a wide margin. The average Benefit to Cost ratio was approximately 15:1.

Final Conclusions

13. The results of the comparative and before versus after crash analyses suggest that street lighting does improve safety at rural intersections by reducing the frequency of all nighttime crashes, by reducing the frequency of both single and multiple vehicle crashes, and by reducing the severity of nighttime crashes. As a result, street lighting at rural intersections should be added to the traffic engineer's toolbox and agencies should be

encouraged to increase the use of this strategy to address safety issues and improve motorist guidance.

14. A number of Minnesota counties indicated (in the survey of usage) that rumble strips and overhead flashing beacons were frequently used strategies for addressing rural intersection safety issues. It should be noted that recent case study research found that neither of these strategies has resulted in statistically significant crash reductions. Therefore, the data suggests that the use of street lighting to reduce nighttime crashes at rural intersections would likely be far more effective than either rumble strips or overhead flashing beacons.

Appendix A

Survey of Agencies

Minnesota Department of Transportation
Survey Form
Street Lighting Safety at Rural Intersections

Agency:______________________________ Date:____________________

Survey Completed By:____
(*Please print*) *Name* *Title*

Phone Number______________________________

Please answer the following questions relating to safety impacts of roadway street lighting at isolated rural non-signalized intersections, including public roads and/or private driveways. A rural area in this survey is defined as being outside the built-up areas of incorporated municipalities.

1) Approximately how many lighted rural intersections do you presently operate and maintain?

____

2) What is this percentage of the total number of intersections?

_______________%

3) If easily obtainable, please provide a list of all intersections with roadway lighting and the date that they were installed.

4) Do you have any warrants for the installation of roadway lighting at rural intersections?
If yes, please attach a copy

a) Yes b) No

5) After the warrant for installation of lighting has been met, do you have any criteria for lighting patterns?
If other, please attach a copy

a) FHWA b) Mn/DOT c) None d) Other

6) Has your agency performed any before and after studies on the effects of roadway lighting at rural intersections? *If so, please provide a copy of the report.*

System-wide Yes _______________ No _______________
Individual case studies Yes _______________ No _______________
Other____

7) What are your typical installation, operation, and maintenance costs for roadway lighting at rural intersections?

Installation: $_________________ per light
Operation: $_________________ per year
Maintenance: $_________________ per year

8) How many lights do you typically install at a rural intersection?

a) 1 b) 2 c) Other _______________________
Please describe

9) What type and wattage of lamp do you typically use?

a) 250 W, High Pressure Sodium
b) 200 W, High Pressure Sodium
c) Other _____________________________________
Please describe

10) What other methods have you applied to improve safety at intersections? (Circle all that apply)

a) Channelization
b) Lane delineation (Pavement Markings)
c) Rumble Strips
d) Flashing beacon
e) Signing (Stop Ahead, Intersection Ahead, etc.)
f) Other ____
Please describe

11) Also needed is a list of potential intersection candidates for a Before/After Analysis of the safety impacts of street lighting. (Street lights only – not combined with other improvements.)

Location: ________________________ at ____________________________
Main Street *Cross Street*

Year installed:_____________________

ADT: __________________ __________________
Main Street *Cross Street*

12) What are your general impressions relative to the advantages and/or disadvantages of lighting at isolated rural intersections?

____
____

13) Do you want to receive a copy of the Final Report?

a) Yes   b) No

Questions? Please contact: Rick Beck
Mn/DOT – Office of Traffic Engineering
1500 W. County Road B2, Suite 250
Roseville, MN 55113
(651) 582-1038

Appendix B

County / City Engineer Survey Responses

COUNTY/CITY ENGINEER SURVEY RESPONSES

1. Number of lighted intersections that are presently operated and maintained:

County

0	1-5	6-10	>10
46 (78.0%)	12 (20.3%)	1 (1.7%)	0

Comments:

I. It is the city's/electrical company's obligation to operate, maintain, etc.

City

0	1-5	6-10	>10
21 (65.6%)	7 (21.9%)	1 (3.1%)	3 (9.4%)

2. What is this percentage of the total number of intersections?

County

0%	0.1%-1%	2%-5%	>5%
46 (78.0%)	10 (16.9%)	3 (5.1%)	0

City

0%	0.1%-1%	2%-5%	>5%
21 (65.6%)	5 (15.6%)	2 (6.3%)	4 (12.5%)

3. List of all intersections with roadway lighting at rural intersections and the date they were installed.

County

a) TH 59-60/CSAH 10: *Installed 1995* – Nobles County
b) CSAH 1/CSAH 12 – Steele County
c) CSAH 6/TH 14 – Steele County
d) CSAH 19/CR 59 – Steele County
e) CSAH 14/UPRR – Steele County
f) CSAH 34/CSAH 45 – Steele County
g) 2nd St/Wall St – Clay County
h) CR 96/CSAH 22 – Clay County
i) CSAH1/CSAH 22 – Clay County
j) TH 75/CSAH 22 – Clay County
k) TH 9/CSAH 52 – Clay County
l) BNRY/CR 76 – Clay County
m) BNRY/CR 75 – Clay County
n) BNRY/CSAH 12 – Clay County
o) CSAH 15/TH 23 : *Installed prior to 1985* – Pipestone County
p) CSAH 18/TH 23 : *Installed prior to 1985* – Pipestone County
q) CSAH 18/TH 30: *Installed prior to 1985* – Pipestone County
r) TH 210/TH 9 – Wilkins County

s) TH 75/CSAH 22 – Wilkins County
t) TH 210/CSAH 19 – Wilkins County

<u>City</u>
a) TH 75/CR 18 – City of Moorhead
b) 375th St./CSAH 30 (Forest Blvd): *Installed Summer 1997* – City of North Branch
c) CSAH 17/CR 82: *Installed May, 1997* – City of Prior Lake
d) CSAH 21/Lords St - City of Prior Lake
e) Raspberry Ridge/Carriage Hills Pkwy: *Installed October 1998* – City of Prior Lake

4. Any warrants for the installation of roadway lighting at rural intersections?

<u>County</u>
Yes – 1 (1.7%)
One attached copy
No – 58 (98.3%)
Comments:

I. Prior to 1976, County Commissioners and/or citizens requested lights. Policy today is no new lights – mainly lighting county road intersections with state highways and state highways through small towns
II. Policy is not to light rural intersections

<u>City</u>
Yes – 2 (6.3%)
One attached copy
No – 30 (93.7%)

5. Any criteria for lighting patterns?

<u>County</u>
FHWA – 0
Mn/DOT – 3 (5.1%)
None – 56 (94.9%)

<u>City</u>
FHWA – 0
Mn/DOT – 1 (3.1%)
None – 29 (90.6%)
Other – 2 (6.3%): Rely on the utility company

6. Has your agency performed any before/after studies on the effects of roadway lighting?

<u>County</u>

System-wide:	Yes – 0	No – 59 (100.0%)
Individual Cases:	Yes – 0	No – 59 (100.0%)

City

System-wide:	Yes – 0	No – 32 (100.0%)
Individual Cases:	Yes – 0	No – 32 (100.0%)

7. Typical installation, operation, and maintenance costs for roadway lighting?

County
Installation - $400 to $1500
Operation - $15 to $270 per light per year
Maintenance - $20 to $330 per light per year
Comments:

I. Power company installed a "yard light" for free, but county pays a flat rate per month for the light
II. Under agreement with power company – they did installation and provide maintenance

City
Installation - $300 to $3500
Operation - $85 to $1050 per light per year
Maintenance - $25 to $50 per light per year
Operation and Maintenance - $85 to $6000 per light per year
Comments:

I. Monthly fee from power company
II. Local power company installed the wood poles and the city pays monthly charge per light – the power company owns the poles

8. How many lights do you typically install at rural intersections?

County
One – 8 (80.0%)
Two – 2 (20.0%)
Other – 0

City
One – 13 (92.9%)
Two – 1 (7.1%)

9. What type and wattage of lamp do you typically use?

County
250 Watt, HPS – 6 (50.0%)
200 Watt, HPS – 2 (16.7%)
150 Watt, HPS – 2 (16.7%)
175 Watt, Mercury Vapor – 2 (16.7%)

City
250 Watt, HPS – 8 (50.0%)
200 Watt, HPS – 2 (12.5%)
150 Watt, HPS – 3 (18.8%)
100 Watt, HPS – 2 (12.5%)
400 Watt, HPS – 1 (6.2%)

10. Other methods to improve safety at intersections?

County
Channelization – 14 (9.4%)
Lane delineation (Pavement Markings) – 35 (23.5%)
Rumble Strips – 36 (24.2%)
Flashing Beacon – 11 (7.4%)
Signing (Stop Ahead, Intersection Ahead, etc.) – 49 (32.9%)
Other: Delineation on Posts – 2 (1.3%)
Removal of Sight Obstructions – 1 (0.7%)
Install Improved Retroreflective Signs – 1 (0.7%)
City
Channelization – 2 (10.0%)
Lane delineation (Pavement Markings) – 6 (30.0%)
Rumble Strips – 0
Flashing Beacon – 2 (10.0%)
Signing (Stop Ahead, Intersection Ahead, etc.) – 9 (45.0%)
Other: None – 1 (5.0%)

11. List of potential intersection candidates for a Before/After analysis.

County
a) TH 23 (6000 ADT)/CSAH 33 (3000ADT) – Lyon County
b) TH 53/TH 332: *installed less than 10 years ago* – Koochiching County
c) TH 30/CSAH 45 (820 ADT) – Steele County
d) TH 30/CSAH 3 (925 ADT) – Steele County
e) TH 59-60 (5500 ADT)/CSAH 10 (910 ADT): *Installed 1995* – Nobles County
f) CSAH 30 (2450 ADT)/CSAH 24 (1300ADT): *Not installed yet* – Wabasha County
g) TH 75 (2650 ADT)/TH 175 (2000 ADT) – Kittson County

City
a) TH 21/TH 3: 1997 – City of Faribault
b) Winnetka Ave (6330 ADT)/101st Ave. N (250 ADT): *no light currently* – City of Brooklyn Park
c) TH 95 (8000 ADT)/CSAH 13: *no light currently* – City of North Branch

12. General impressions relative to the advantages and/or disadvantages of lighting?

County

a) Lighting makes it easier to find the intersection (3). Traffic is delayed by people slowing down to look for their turn.
b) Helps the traveling public by bringing the intersection to their attention especially during adverse weather conditions and darkness (3)
c) They alert drivers to a change (2)
d) Useful
e) Lighting in certain areas are advantageous in reducing the number of accidents (4)
f) Often receive requests for street lighting at various rural intersections and they are referred to the city or electrical company.
g) Overall, since many intersections are without street lighting, the installation of such does tend to be a positive improvement
h) Pedestrians would be more visible
i) Is the cost justified (3)
j) If a light is installed in one location, how do you justify denying any other requests?
k) No real change
l) It seems to help the elderly driver the most
m) The lighting of current intersections has been well received
n) Most useful at high ADT intersections especially in areas with aging populations
o) Not generally needed at rural intersections – maybe more education through driving courses
p) Lighting is only considered in high accident locations because of the economics (2)
q) Lighting was installed as an interim measure prior to signalization
r) Traffic volumes are too low to warrant the installation
s) Probably only appropriate in an "urban" type rural setting
t) No advantage as new diamond grade sign material is great

City

a) Extremely effective during heavy night traffic
b) Residents seem to think the light makes the intersection more visible (2)
c) Find it favorable to install, but expensive
d) Like to see all intersections lighted
e) Advantageous, especially if applied consistently to similar intersections
f) Very important to provide adequate street lighting at isolated rural intersections
g) Benefit during winter snow storms, fog, and overall night identification
h) Lighted rural intersections provide advanced warning of an intersection to motorists
i) Provides better reading of the street name signs
j) Philosophy is to remain a rural community and street lights are perceived to be synomonous with urban development
k) In some cases lighting is valuable, but the only way to justify it is if the data shows a safety benefit.
l) Is there a policy/law now regarding lighting intersections?
m) City policy is that if people want a street light on a rural street, they have to pay for the installation and continuing electricity use
n) City only installs on city property/right of way

Appendix C

Tables Used in NCHRP Report No. 152

Table 5.4

Percent of Daylight Traffic

System-Wide Comparative Analysis

Hour	January	February	March	April	May	June	July	August	September	October	November	December
AM												
MID-01	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.05
01-02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.04	0.04	0.03	0.03
02-03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02
03-04	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
04-05	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03
05-06	0.08	0.08	0.09	0.10	0.11	0.11	0.12	0.13	0.12	0.11	0.10	0.09
06-07	0.23	0.25	0.27	0.29	0.33	0.34	0.37	0.38	0.35	0.33	0.30	0.28
07-08	0.37	0.40	0.43	0.47	0.53	0.55	0.60	0.61	0.57	0.53	0.48	0.46
08-09	0.37	0.40	0.42	0.46	0.52	0.54	0.59	0.61	0.56	0.52	0.47	0.45
09-10	0.33	0.36	0.38	0.42	0.47	0.49	0.54	0.55	0.51	0.47	0.42	0.41
10-11	0.33	0.36	0.38	0.42	0.47	0.49	0.53	0.54	0.50	0.47	0.42	0.40
11-NOON	0.35	0.37	0.40	0.43	0.49	0.51	0.56	0.57	0.53	0.49	0.44	0.42
PM												
NOON-01	0.35	0.38	0.41	0.44	0.50	0.52	0.57	0.58	0.54	0.50	0.45	0.43
01-02	0.38	0.41	0.44	0.48	0.54	0.56	0.61	0.62	0.58	0.53	0.49	0.46
02-03	0.41	0.44	0.47	0.51	0.57	0.60	0.66	0.67	0.62	0.57	0.52	0.50
03-04	0.49	0.53	0.56	0.61	0.69	0.72	0.79	0.80	0.74	0.69	0.63	0.60
04-05	0.53	0.57	0.61	0.66	0.74	0.78	0.85	0.87	0.80	0.74	0.67	0.64
05-06	0.51	0.55	0.58	0.64	0.72	0.75	0.82	0.83	0.77	0.71	0.65	0.62
06-07	0.40	0.43	0.46	0.50	0.56	0.59	0.64	0.65	0.60	0.56	0.51	0.48
07-08	0.29	0.31	0.33	0.36	0.41	0.43	0.47	0.48	0.44	0.41	0.37	0.35
08-09	0.23	0.25	0.27	0.29	0.33	0.34	0.37	0.38	0.35	0.33	0.30	0.28
09-10	0.20	0.22	0.23	0.25	0.29	0.30	0.33	0.33	0.31	0.29	0.26	0.25
10-11	0.15	0.16	0.17	0.19	0.21	0.22	0.24	0.24	0.23	0.21	0.19	0.18
11-MID	0.10	0.11	0.12	0.13	0.15	0.15	0.17	0.17	0.16	0.15	0.13	0.13
Total % of daylight per year	3.55	4.78	5.35	6.70	7.53	8.34	8.96	8.77	7.32	6.21	4.99	4.31

Total % of daylight traffic per year: 76.80

- Indicates nighttime hours

Source: Minnesota ATR and WCCO Weather Internet Site

Table 5.5

Summary of Before versus After Crash Analysis

Before vs. After Crash Analysis

	Before Lighting	After Lighting	Percent Change	Statistically Significant ? (Confidence Interval)
Number of Intersections	12	12		
Number of Day Crashes (%)	41 (46.6%)	47 (62.7%)	13%	
Number of Night Crashes (%)	47 (53.4%)	28 (37.3%)	-40%	
Number of Total Crashes	88	75	-15%	
Day Exposure	23434	23434		
Night Exposure	7079	7079		
Total Exposure	30513	30513		
Average Day Exposure per Intersection (vehicles)	1953	1953		
Average Night Exposure per Intersection (vehicles)	590	590		
Average Total Exposure per Intersection (vehicles)	2543	2543		
Average Day Crashes per Intersection per Year	1.14	1.31	13%	
Average Night Crashes per Intersection per Year	1.31	0.78	-40%	
Average Total Crashes per Intersection per Year	2.44	2.08	-15%	
Day Crash Rate	1.6	1.83	13%	No (90%)
Night Crash Rate	6.06	3.61	-40%	Yes (95%)
Total Crash Rate	2.63	2.24	-15%	Yes (90%)
Night Property Damage Crashes (%)	27 (57%)	19 (68%)	-16%	Yes (90%)
Night Personal Injury plus Fatal Crashes (%)	18 (43%)	9 (32%)	-26%	Yes (90%)
Severity Index	43%	32%	-26%	Yes (90%)
Night Run Off Road Crashes (rate)	12 (1.55)	8 (1.03)	-34%	No (90%)
Night Right Angle Crashes (rate)	9 (1.16)	5 (0.65)	-44%	No (90%)
Night Single Vehicle Crashes (rate)	31 (4.0)	22 (2.84)	-29%	Yes (90%)
Night Multiple Vehicle Crashes (rate)	16 (2.06)	6 (0.77)	-63%	Yes (90%)

Table 5.6

Crash Reduction Benefit-Cost Ratios

Nighttime Crash Reduction	Annual Costs (Amortized First Cost Plus Annual Maintenance and Operations Costs)								
	$100	$250	$500	$750	$1,000	$1,250	$1,500	$1,750	$2,000
10%	120	48	24	16	12	10	8	7	6
15%	129	51	26	17	13	10	9	7	6
20%	137	55	27	18	14	11	9	8	7
25%	146	58	29	19	15	12	10	8	7
30%	155	62	31	21	15	12	10	9	8
35%	163	65	33	22	16	13	11	9	8
40%	172	69	34	23	17	14	11	10	9
45%	181	72	36	24	18	14	12	10	9
50%	190	76	38	25	19	15	13	11	9

Appendix D

Poisson Distribution Confidence Level Curves

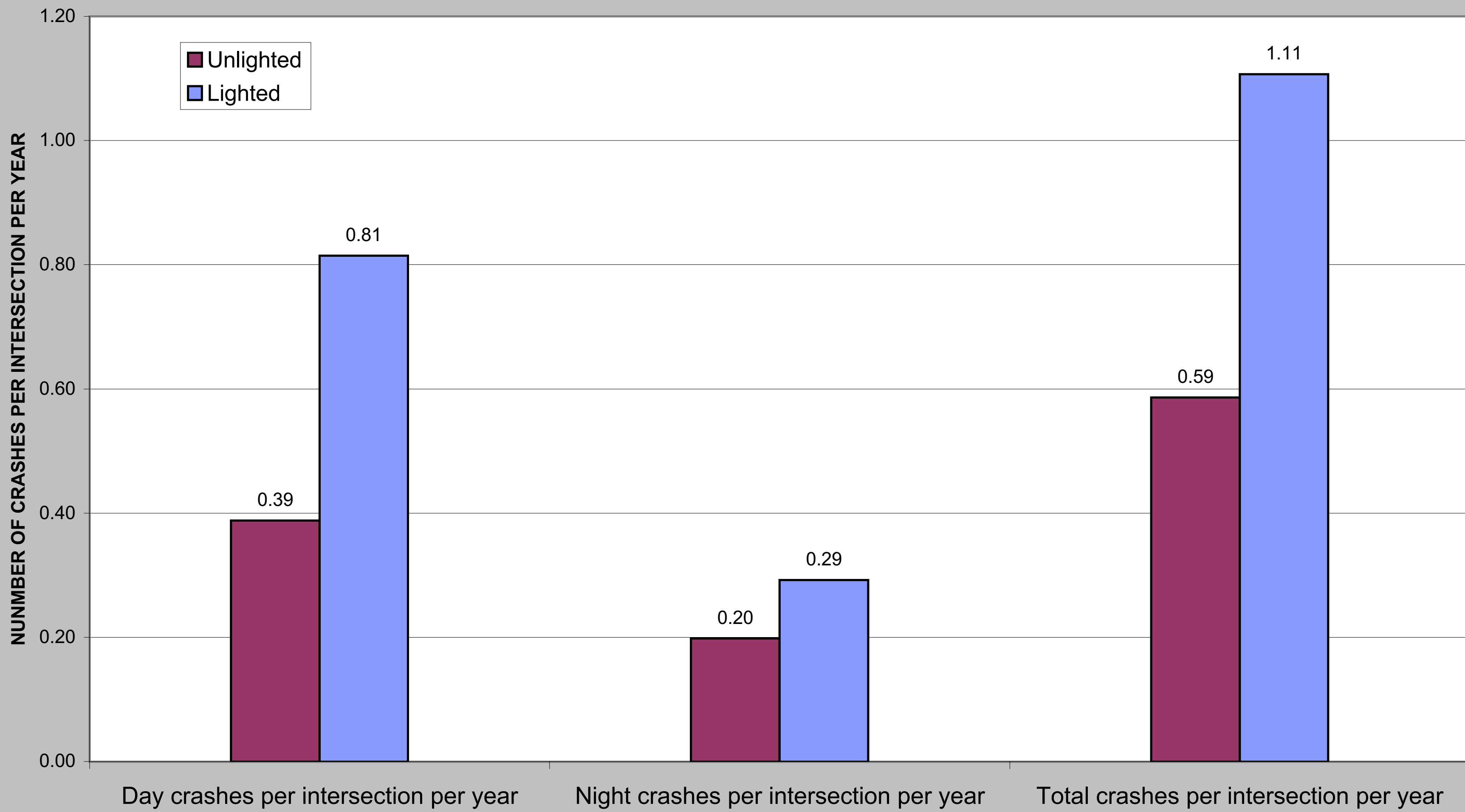


Figure 5.1

Number of Crashes per Intersection per Year

System-Wide Comparative Analysis

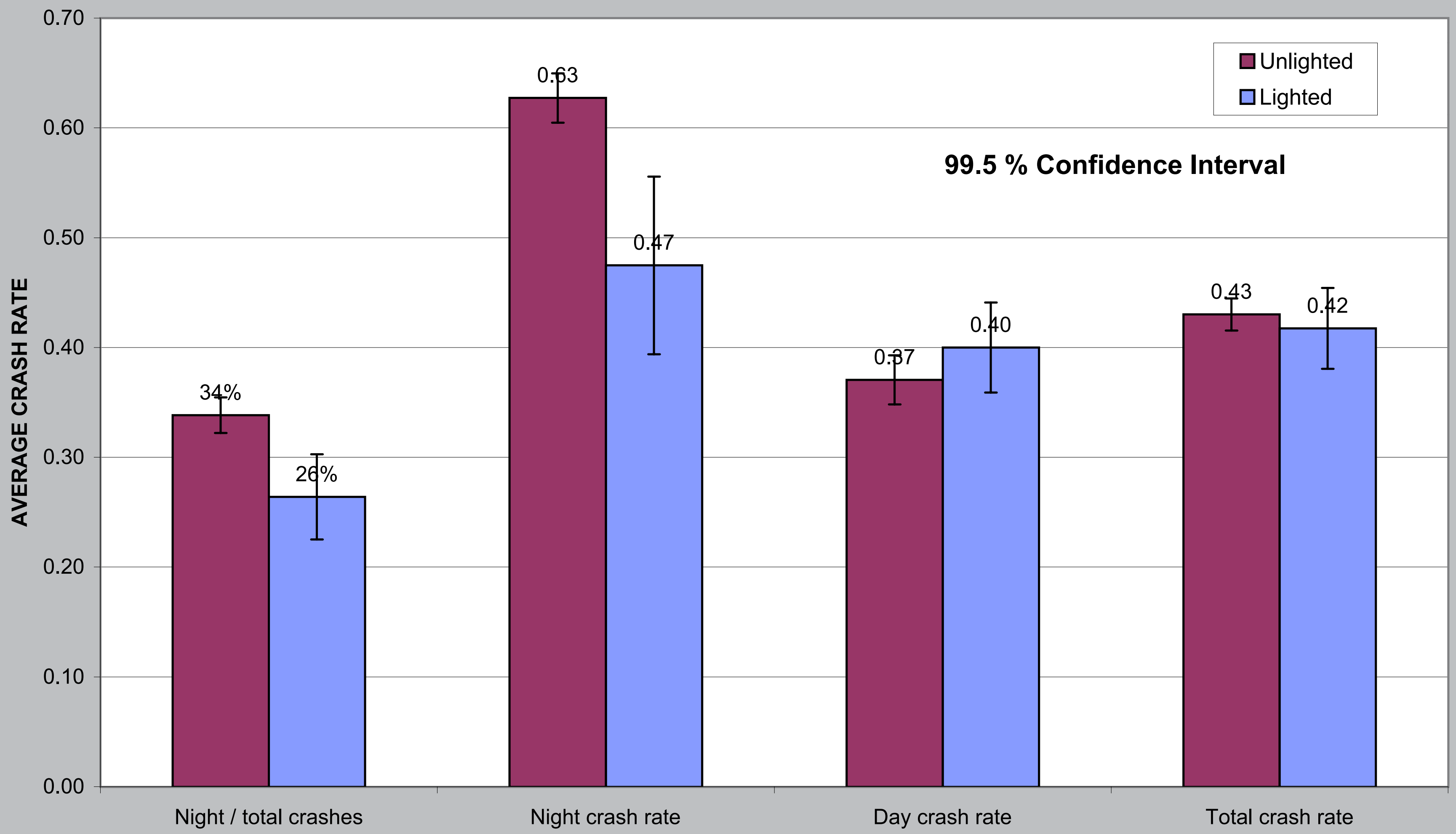


Figure 5.2

Crash Rates

System-Wide Comparative Analysis

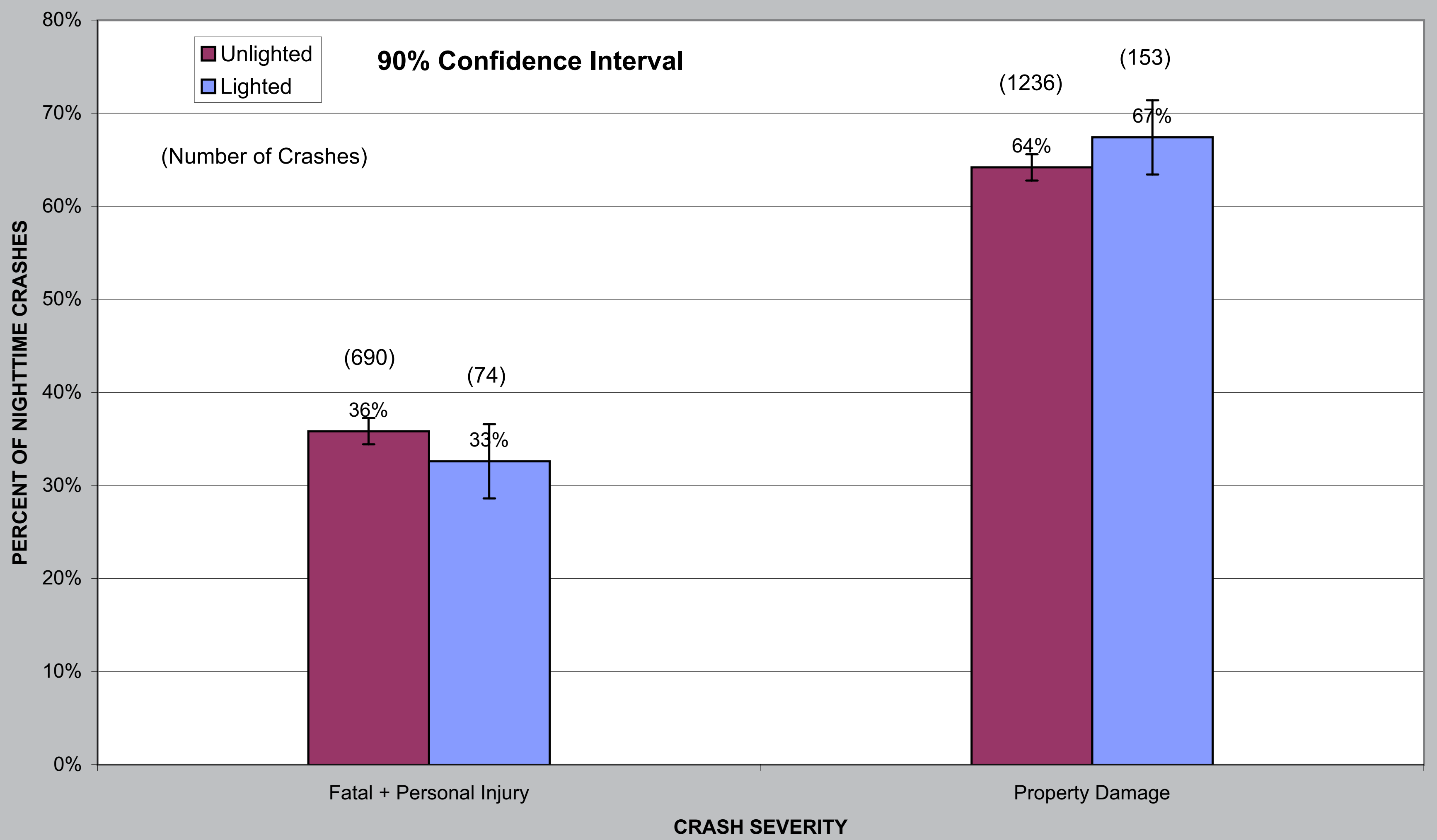


Figure 5.3

Crash Severity - Nighttime

System-Wide Comparative Analysis

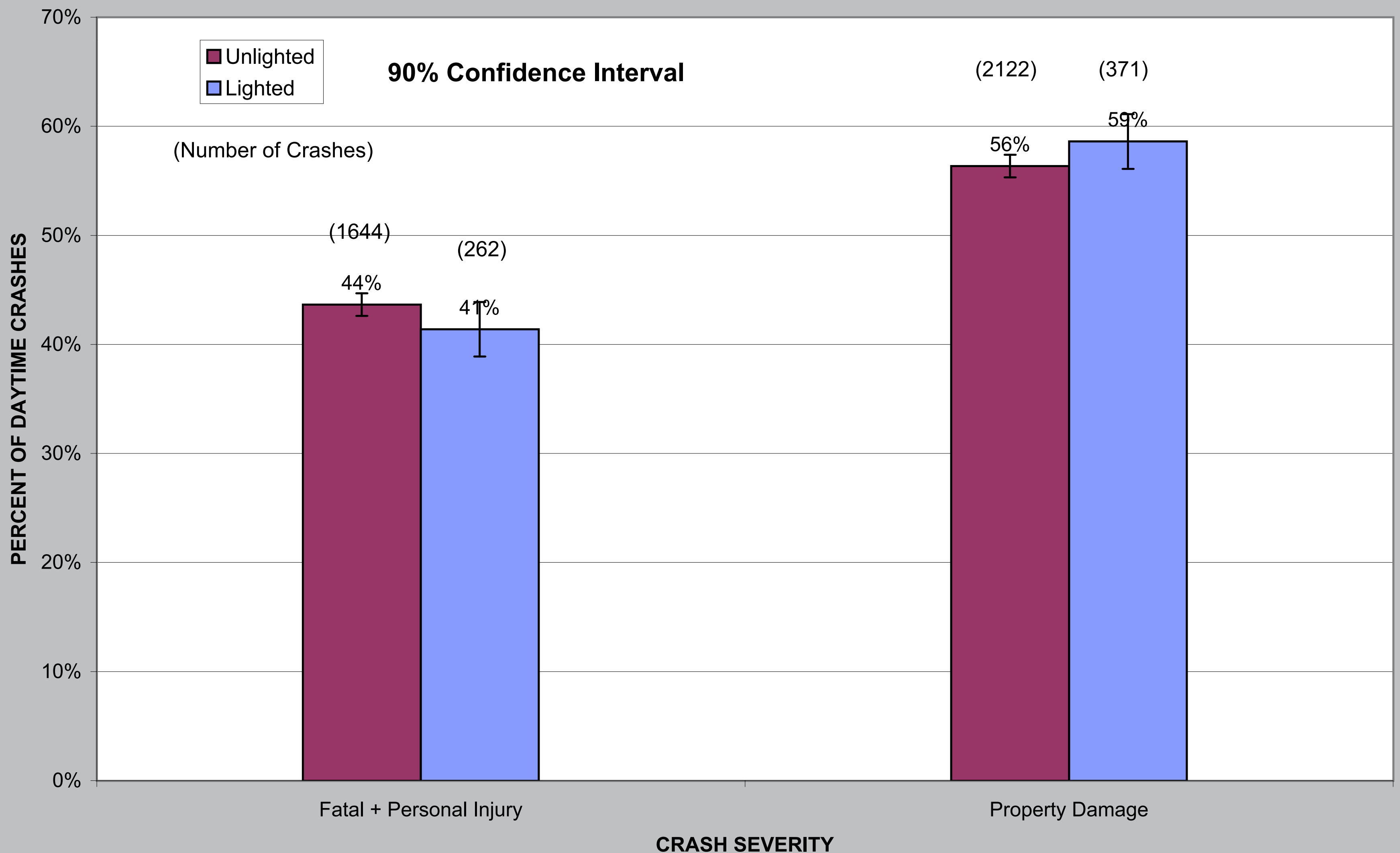


Figure 5.4

Crash Severity - Daytime

System-Wide Comparative Analysis

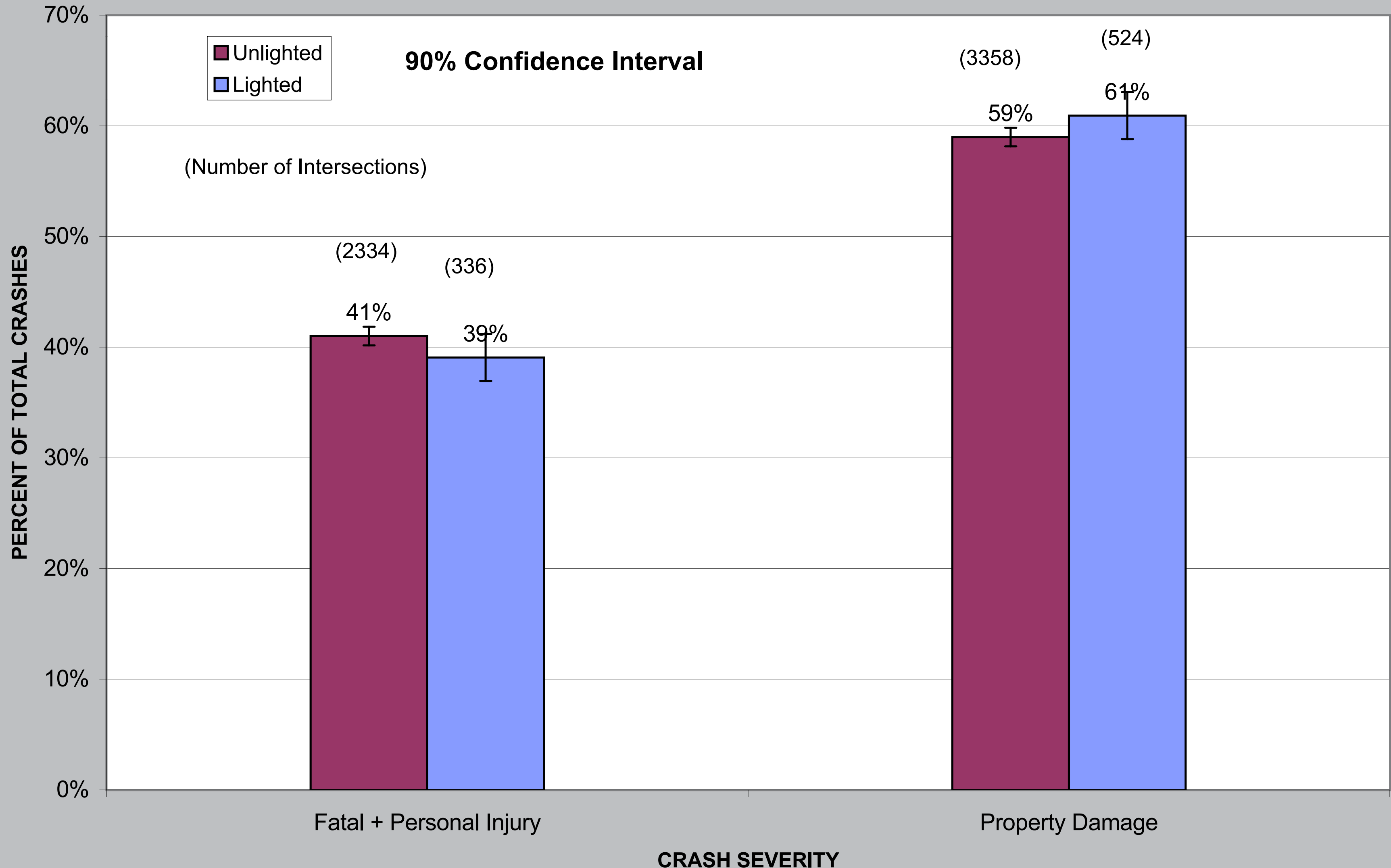


Figure 5.5

Crash Severity - Total

System-Wide Comparative Analysis

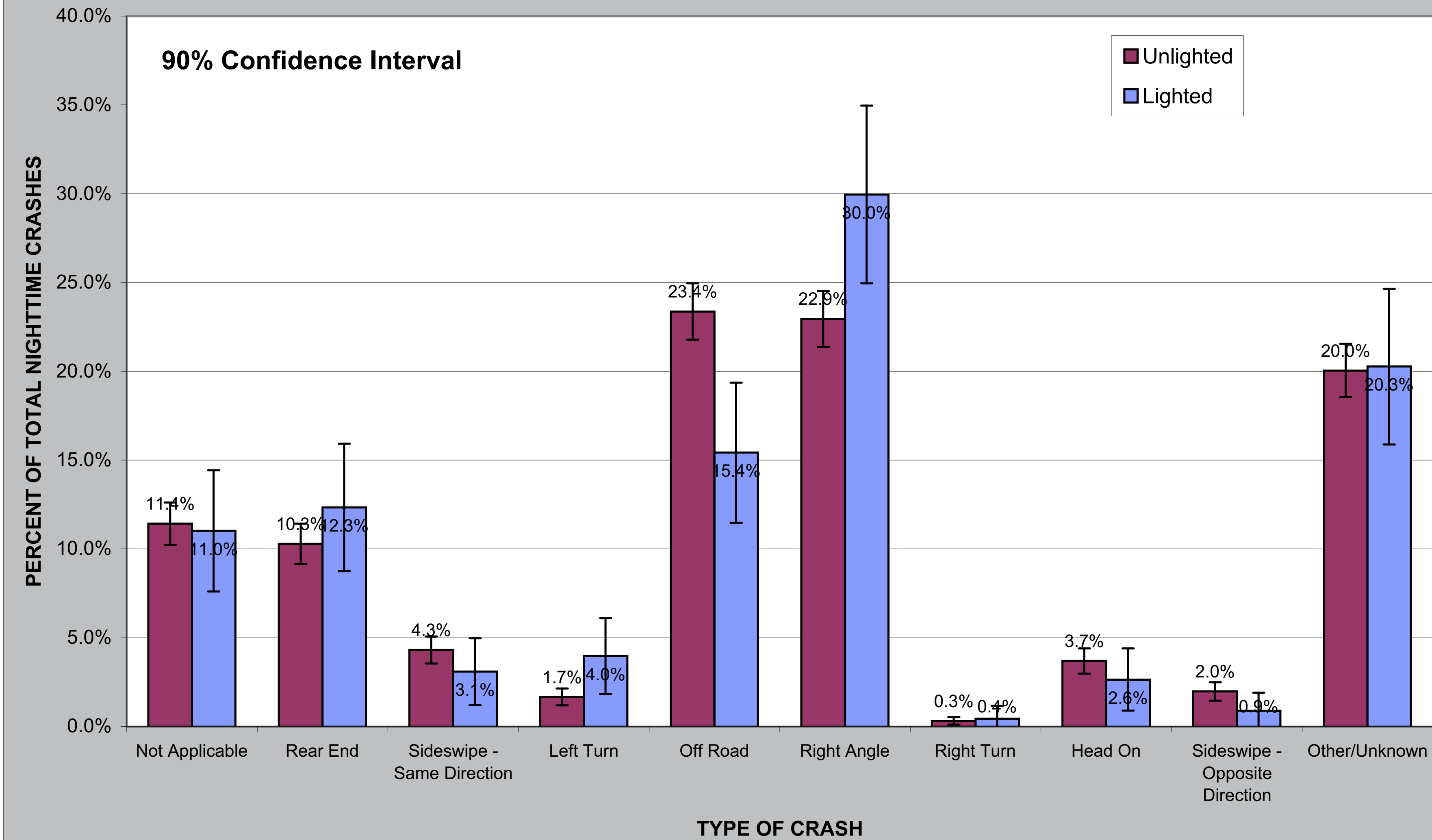


Figure 5.6

Crash Type - Nighttime

System-Wide Comparative Analysis

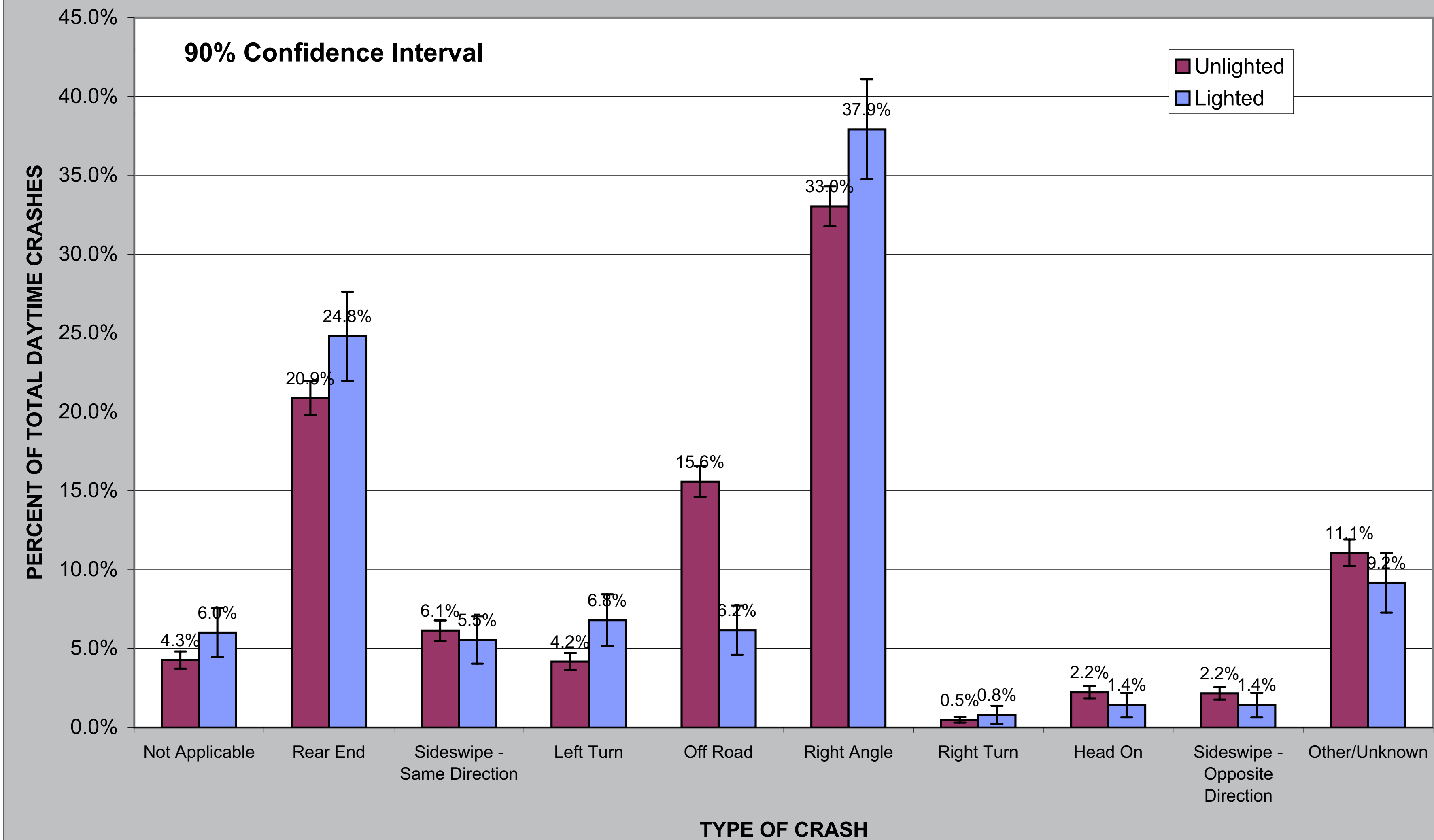


Figure 5.7

Crash Type - Daytime

System-Wide Comparative Analysis

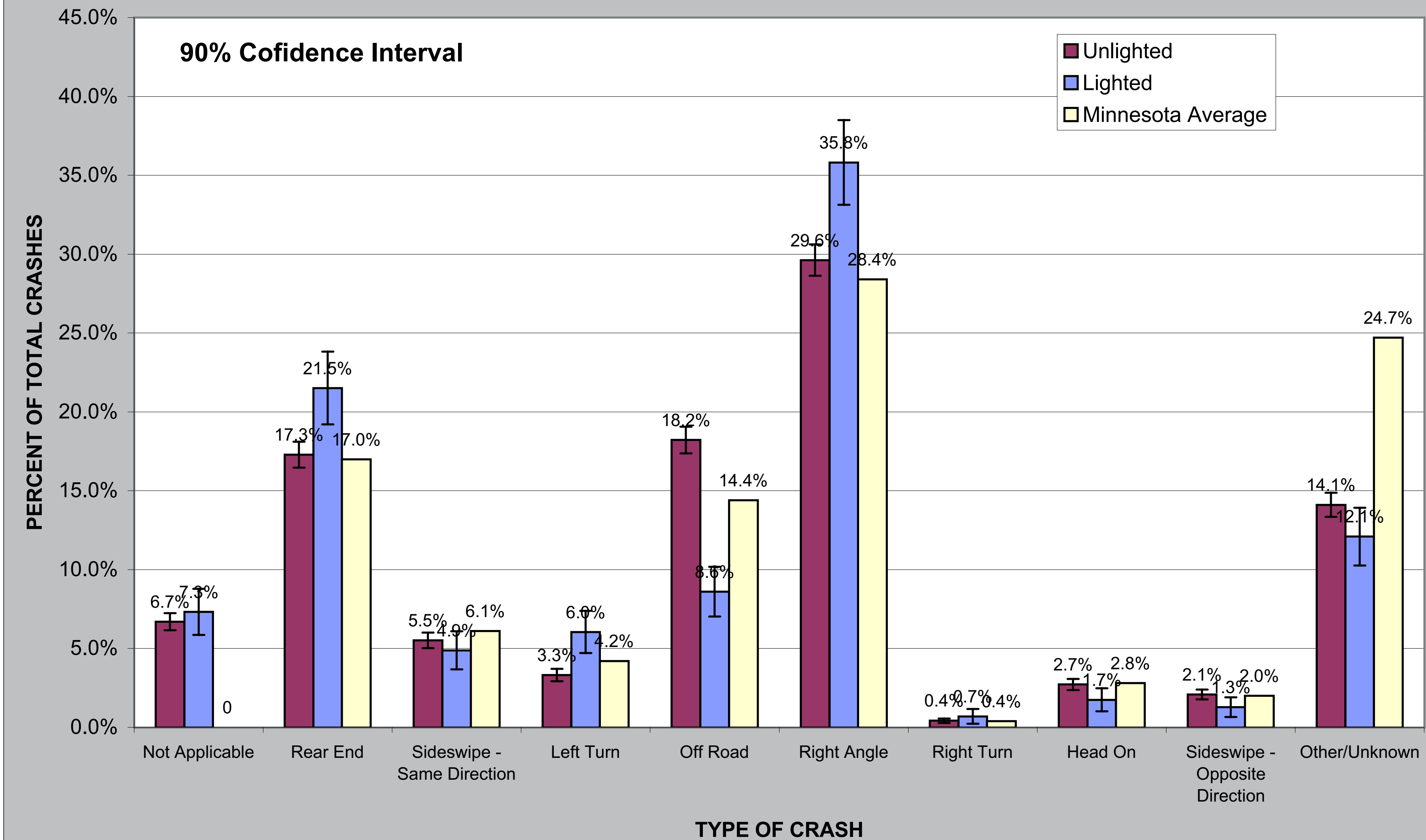


Figure 5.8

Crash Type - Total

System-Wide Comparative Analysis

Appendix E

Benefit – Cost Analysis Example

Benefit – Cost Analysis Calculations and Assumptions

Crash cost values per crash currently used by Mn/DOT:

∉ Property Damage		= $4,000
∉ Personal Injury	A	= $260,000
	B	= $56,000
	C	= $27,000
∉ Fatality		= $3,400,000

∉ Benefit: reduction in nighttime crashes

1. Before lighting:
   - ∉ 1.3 nighttime crashes per intersection per year (taken from "Technical Analysis" section)
   - ∉ 59% Property Damage crashes
   - ∉ 2% Personal Injury A crashes
   - ∉ 11% Personal Injury B crashes
   - ∉ 28% Personal Injury C crashes
   - ∉ 0% Fatal crashes

($4000) * (0.59) * (1.3)	=	$3068
($260,00) * (0.02) * (1.3)	=	$6760
($56,000) * (0.11) * (1.3)	=	$8008
($27,000) * (0.28) * (1.3)	=	$9828
($3,400,000) * (0.0) * (1.3)	=	$0
TOTAL	**=**	***$27,664***

2. After Lighting
   - ∉ 10% decrease in nighttime crashes per intersection per year
   - ∉ 68% Property Damage crashes
   - ∉ 0% Personal Injury A crashes
   - ∉ 7% Personal Injury B crashes
   - ∉ 25% Personal Injury C crashes
   - ∉ 0% Fatal crashes

($4000) * (0.68) * (1.3*(1-0.1))	=	$3182
($260,000) * (0.0) * (1.3*(1-0.1))	=	$0
($56,000) * (0.07) * (1.3*(1-0.1))	=	$4586
($27,000) * (0.25) * (1.3*(1-0.1))	=	$7898
($3,400,000) * (0.0) * (1.3*(1-0.1))	=	$0
TOTAL	**=**	***$15,666***

Total Benefit = ($27,664 - $15,666) = $11,998

- **Cost: Annualized cost of installation, maintenance, and operation**

1. Installation Cost - Annualized
   - Assume life of light pole to be 10 years
   - Assume 5% discount rate over the 10 years
   - For 10 years at 5%, the discount is 0.1295
   - Installation cost ranges were taken from the "Survey of Agencies" section

   Annualized Cost = $3500 * (0.1295) = $450

2. Annual Operation and Maintenance Costs

   Cost ranges were taken from the "Survey of Agencies" section
   Operation & Maintenance Costs = $1050 + $330 = $1380

3. Total Annual Costs

   Annual Installation + Operation + Maintenance = $1830

- **Benefit – Cost Ratio**

Total Benefit / Total Costs = $11,998 / $1830 = 6.6