Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections

Final Report
February 2008

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16. Abstract

Citizens request the installation of roadway lighting in their communities based on several motivations, including the experience or perception that lighting improves traffic safety and reduces crime, while also providing a tangible benefit of taxpayer dollars at work. Roadway authority staff fully appreciate these citizen concerns; however, roadway lighting is expensive to install, supply energy to, and maintain in perpetuity. The installation of roadway lighting is only one of a number of strategies agencies have to address nighttime crash concerns. This research assists local agencies in deciding when, where, and how much rural intersection lighting to provide.

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STRATEGIES TO ADDRESS NIGHTTIME CRASHES AT RURAL, UNSIGNALIZED INTERSECTIONS

Final Report
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EXECUTIVE SUMMARY

Citizens request roadway lighting based on a variety of motivations. These include experienced or perceived safety concerns, a feeling that lighting reduces crime, the desire to receive a tangible benefit from paying taxes, and for a variety of other reasons. Roadway authority staff fully appreciate these citizen concerns; however, roadway lighting is expensive to install, supply energy to, and maintain in perpetuity. Agencies have several mitigation strategies to address nighttime crashes. The installation of roadway lighting is only one of these strategies. This research assists local agencies in deciding when and where to provide rural intersection lighting to address nighttime crashes.

This report summarizes the common types of nighttime crashes at rural Iowa intersections, discusses strategies used by agencies to reduce nighttime crashes, summarizes lighting warrants and practices used by other states, discusses results of a survey of Iowa counties and cities regarding their lighting installation practices, presents a rural Iowa intersection field analysis on the impact lighting and other mitigation measures have on safety, and develops a draft lighting guide to be incorporated into the Statewide Urban Design and Specification (SUDAS) manual.

The types of crashes that occur at rural intersections were evaluated for Iowa and are discussed in the crash characteristics section. Understanding the types of crashes that occur can provide insight to determining which mitigation measures might be most effective. A total of 26% of rural intersections crashes in Iowa occur during dark conditions. The most common causes for single vehicle crashes at rural intersections were run-off-road (27%), animal crashes (17%), and ran stop sign (16%). Common causes for multiple vehicle crashes at rural intersections include running the stop sign (21%), failure to yield right-of-way at stop or yield sign (20%), and other failure to yield right-of-way (10%). The most common type of crash for multiple vehicles was broadside (42%), followed by rear-end (14%). Lighting is most likely to mitigate crashes where the main cause is running the stop sign or other failure to yield right or way and broadside and rear-end crashes.

The next section summarizes the common strategies to reduce nighttime crashes at rural, unsignalized intersections. The use of lighting is often one of the first strategies considered and is popular with the traveling public. However, the cost of hardware to install lighting and the accompanying maintenance and utility charges can be costly for small jurisdictions, such as counties and rural communities. Other strategies, such as use of advance stop line transverse rumble strips, may provide viable solutions. A range of solutions are summarized, including the use of advance signing to warn drivers of an upcoming intersection, use of sign beacons on stop signs or “Stop Ahead” signs, use of reflective material to improve the nighttime visibility of signs, improved signing and marking, use of flashing overhead beacons at intersections, advance stop sign rumble strips, and lighting.

The lighting warrant section summarizes state Department of Transportation lighting warrants for rural roadways as obtained for Iowa and 18 other states. The warrants for both rural intersections and rural highways are presented when these were available.

A survey was developed to question Iowa counties and cities as to their lighting standards and practices. The survey was used to determine current lighting practices in Iowa. Results of the survey are provided. Fourteen cities and twenty-seven counties responded. The section discusses the types of criteria used to determine when lighting is appropriate, the type of lighting used, standards for lighting levels and layout, number of lights, and costs for lighting.

The evaluation section presents the results of a cross-sectional statistical evaluation of 223 rural intersections focused on the safety benefits of lighting and other treatments. Data were collected in the field for each intersection to complete a Bayesian statistical analysis that demonstrates the effectiveness of each strategy on nighttime crash.

The original objective of the study was to determine whether street lighting and other low-cost measures, such as advance stop sign rumble strips, were effective in reducing nighttime crashes. As indicated, a wide range of intersections were included so that different variables could be evaluated.

Another objective of this research was to collect a large sample of rural intersections both with and without lighting. It was hoped that there would be sufficient samples to evaluate type and placement of lighting as a safety benefit. A hierarchical Bayesian model using a Poisson distribution was used to fit various models. The first attempts modeled individual intersection approaches so that type and location of lighting could be included as variables. It was determined after a thorough evaluation of the data and resulting models that the only lighting variable which could be included was presence or absence of lighting rather than the evaluation of type, location, and quality of lighting. This may have been due to sample size, even though 223 intersections were included, or due to the fact that crashes at rural intersections are still fairly rare events, so differences could not be detected.

Models were developed separately for day and nighttime conditions. A number of variables were evaluated for both models, including type of control, presence of overhead beacons, presence of advanced stop line rumble strips, etc. The nighttime model included presence of overhead street lighting. The final daytime model indicated that the significant variables were number of approaches with channelization and whether the intersection was a high crash location (location had four or more daytime crashes in a three-year period). The final nighttime model indicated that the only relevant variables were presence or absence of lighting and whether the location was a high crash location (location had two or more nighttime crashes in a three-year period). The nighttime model results indicated that locations without lighting had twice as many crashes as locations with lighting. Use of lighting at rural intersections is most likely to be effective when there are two or more nighttime crashes in a three-year period. Based upon available data, no significant statistically significant relationship could be established between nighttime crashes and non-lighting low costs measures.

It is not known why the influence of other low-cost measures, such as advance stop line rumble strips or overhead beacons, could not be detected in the models. A number of intersections had a low number of crashes which may have masked the impact. Additionally some treatments are placed at high crash locations and even with a reduction, the location still has a higher than average number of crashes. As result, it is difficult to establish reduction with a cross-sectional model. Even though this study had hoped to address the removal of existing rural intersection lighting, the researchers were not able to discern enough clarity from the statistical evaluation to provide practical guidance.

INTRODUCTION

Nighttime driving can be particularly problematic. In Iowa, approximately 24% of all crashes and 40% of fatal crashes in 2003 occurred under dark conditions. The U.S. DOT and NHTSA report that nationally 45% of fatalities occur under dark conditions versus 27% of total crashes (U.S. DOT 2003). One study indicated that the nighttime fatality rate is three times the daytime rate, while the general nighttime crash rate is approximately 1.6 times the daytime rate (Hasson and Lutkevich 2002; Opiela et al. 2003).

Roadway lighting has been referred to as an effective strategy to reduce nighttime crashes (Hasson and Lutkevich 2002). The public also sees lighting as a positive safety and security measure and often pressures agencies to install lighting at locations perceived as problematic. As a result, agencies often face pressure to routinely install lighting on new facilities and place lighting at problematic locations on existing facilities. At the same time, state and local agencies are facing shrinking resources and increasing demands. Consequently, states and local agencies need better information to make decisions regarding when lighting is an effective option.

The work described in this report was jointly funded by the Iowa DOT Office of Traffic and Safety, Iowa Highway Research Board (IHRB), and MUSCO Lighting. The objective of the research project was to provide agencies in Iowa with information and guidance on the use of lighting so that agencies are able to make cost-effective lighting decisions.

This report is organized in the following manner. First, the scope of the crash problem at rural intersections is evaluated, and then the types of crashes that occur at night are summarized (as the effectiveness of different strategies are dependent on the types of crashes that occur). Next, the report summarizes strategies that have been used to reduce nighttime crashes based on a literature survey. A summary of agency lighting warrants for rural intersections is presented in the following section, followed by survey results of lighting installation guidelines for Iowa counties and cities. The final section discusses results of a 223-intersection, cross-sectional analysis of the effectiveness of different strategies in reducing nighttime crashes.

A separate SUDAS document was also developed that discussed lighting guidance for Iowa.

CRASH CHARACTERISTICS FOR RURAL IOWA INTERSECTIONS

The types of crashes occurring at rural intersections were evaluated to provide insight toward determining the effectiveness of different mitigation measures. The crash analysis period was for 2001 to 2005. All crashes were selected from the Iowa DOT crash database (as it existed Jan 2006) that were coded as Road type 11, 12, 13, 14, 15 (these numbers correspond to an intersection in the crash database). Then rural crashes were extracted for further analysis with "rural" being defined as an area more than 0.5 miles outside the corporate boundaries of any urban area. The final dataset included crashes for rural intersections in Iowa from 2001 to 2005.

The Iowa DOT crash data have a number of data fields that provide information about the crash, driver, and surrounding conditions. The crash analysis relied upon these data fields as discussed in the following sections.

Table 1 shows that the ambient light condition was included for most crashes and that approximately 26% of crashes at rural intersections occur during nighttime conditions and another 4% occur during dawn or dusk. Table 2 indicates how crash severity is also determined by lighting condition. As indicated, 29% of fatal and injury crashes occur during the nighttime.

Table 1. Crashes by lighting condition (2001 to 2005)

Lighting condition	Percent of crashes
Light	68.8%
Dawn/dusk	4.6%
Night	25.6%
Unknown	1.0%

Table 2. Crash severity by lighting condition (2001 to 2005)

	Percent of day crashes	Percent of night crashes
Fatal	2.4%	2.2%
Major Injury	8.7%	7.4%
Minor Injury	18.5%	19.3%
Possible/Unknown	19.4%	16.4%
Property Damage Only	51.0%	54.7%

The major cause for rural intersection nighttime crashes was also evaluated for both single and multiple vehicle accidents. Figure 1 indicates the major cause for single vehicle intersection accidents. As shown, 26.7% were run-off-road crashes, 16.6% were animal crashes, and 15.7% were ran the stop sign. The presence of lighting may help mitigate run-off-road and failure-to-yield crashes. It should be noted that a certain percent of the crashes were indicated as having failed to yield right-of-way even though no other vehicles should have been involved in a single vehicle crash. This may be due to coding errors.

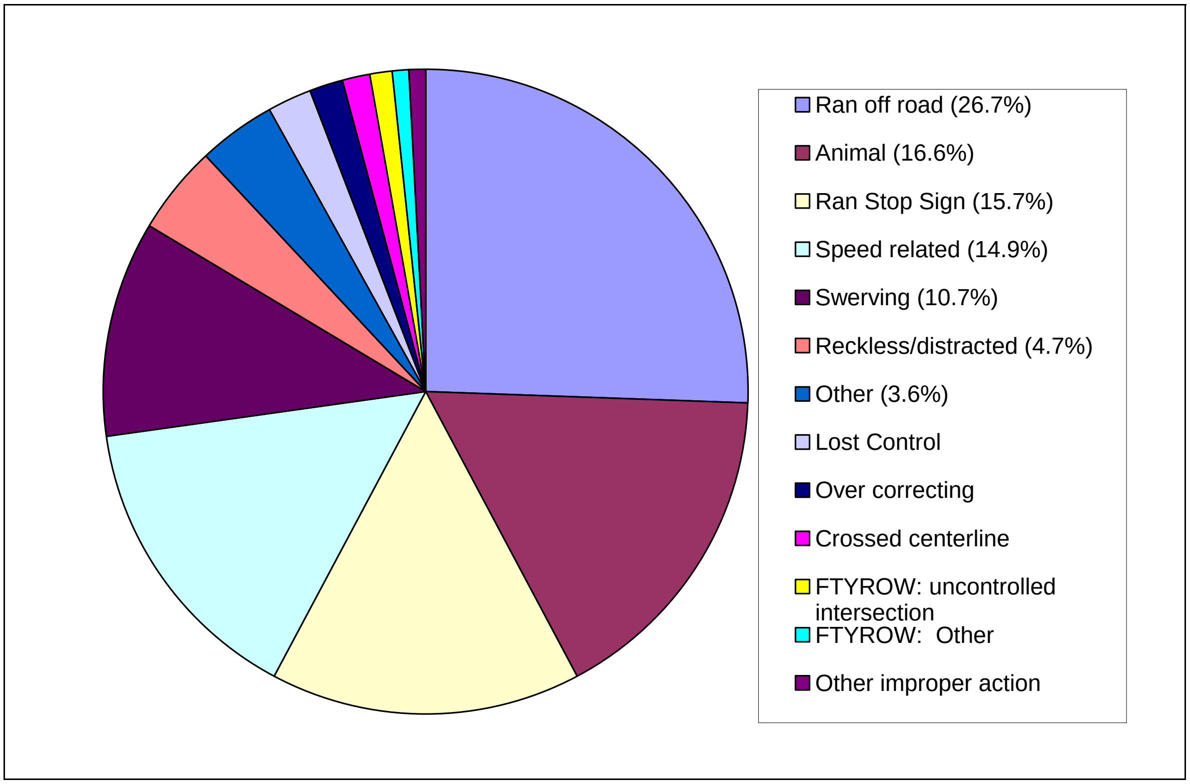

Figure 1. Major Cause for single vehicle rural intersection crashes

Figure 2 identifies the major cause for multiple vehicle rural intersection crashes. As shown, failure to yield right of way or running a stop sign were the major causes for almost 51.2% of multiple vehicle nighttime rural crashes. While it is unknown whether drivers failed to yield the right of way due to inability to see during nighttime crashes, it is likely that providing adequate lighting may mitigate multiple vehicle nighttime crashes.

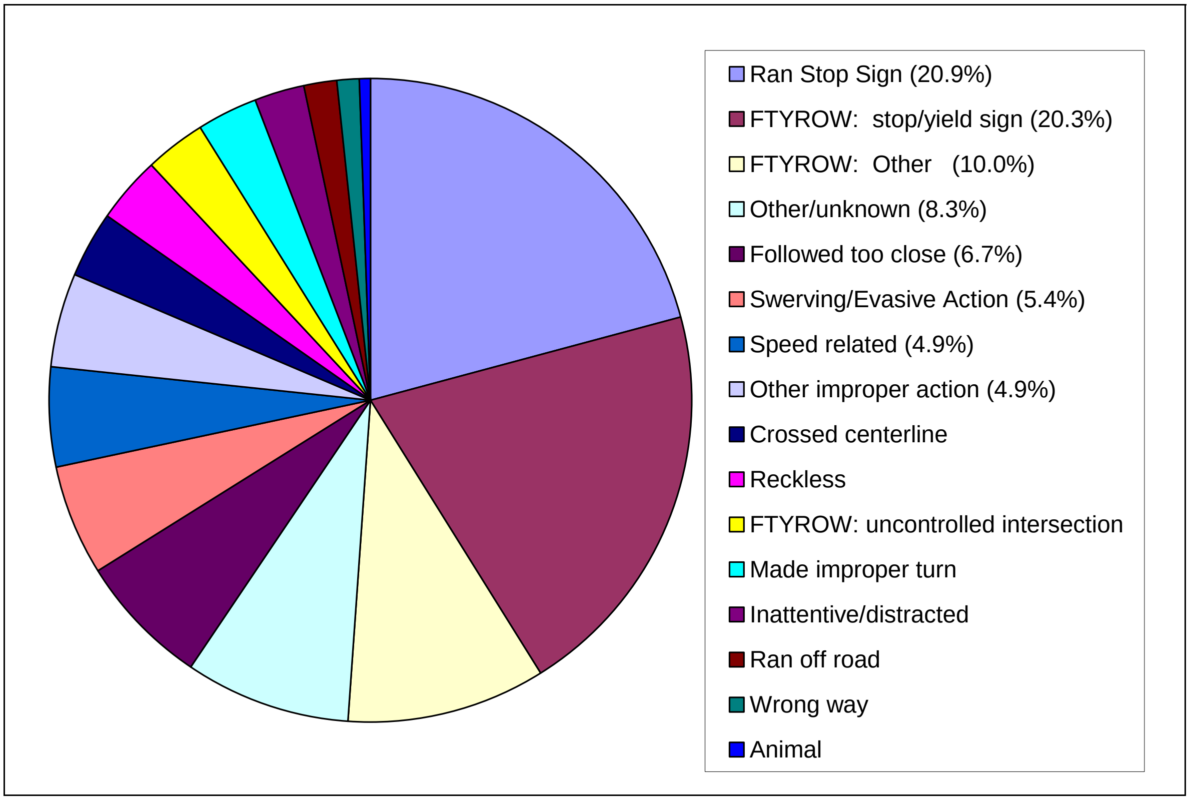

Figure 2. Major cause for multi-vehicle rural intersection crashes

The types of nighttime crashes for multiple vehicles that occur at rural intersections are presented in Table 3. As shown, broadside crashes made up 41.8% of crashes, followed by rear-end crashes (25.3%). Both types of sideswipe crashes made up 16.7% (13.6% same-direction sideswipe, 3.1% opposite-direction sideswipe).

Table 3. Nighttime crashes by type

Type	Percent
Broadside	41.8%
Rear-end	25.3%
Sideswipe, same direction	13.6%
Angle, oncoming left turn	9.6%
Sideswipe, opposite direction	3.1%
Head-on	3.0%
Non-collision	2.3%
Unknown	1.4%

COMMON STRATEGIES TO REDUCE NIGHTTIME CRASHES AT RURAL UNSIGNALIZED INTERSETIONS

A number of strategies are used to address nighttime crashes at rural intersections. The use of lighting is often one of the first strategies considered and is popular with the traveling public. However, the cost of to install lighting and the accompanying maintenance and utility charges can be costly for small jurisdictions, such as counties and rural communities. As a result, other strategies, such as use of advance stop line transverse rumble strips, may provide viable solutions.

Selecting a crash reduction strategy depends on a number of factors, primarily based upon the type and frequency of crashes in contrast to costs and potential to reduce accidents. In some cases, the overuse of certain treatments can create additional problems. For example, if advance stop line rumble strips are widely used in a jurisdiction, drivers may start relying on the tactile clues to alert them of the need to stop along rural highways and may ignore other traffic control when the rumble strips are not used, resulting in failure to stop.

In general, the least aggressive approach should be considered first in addressing crash problems at rural intersections. Pierce County, Washington (Ellison 2006) recommends a progressive approach to address safety issues at rural intersections. This county recommends a series of countermeasures to be used in ascending order of invasiveness, according to the following:

1. Install “STOP AHEAD” signs.
2. Increase the size of “STOP” and “STOP AHEAD” signs.
3. Install transverse rumble strips.
4. Install overhead flashing beacon with illumination.

The Manual on Uniform Traffic Control Devices (MUTCD) and state and local policies and guidelines should always be consulted before treatments are selected. A number of treatment strategies to address crashes at rural intersections are provided in the following sections.

Advance Signing

Advance signing warns drivers of an upcoming intersection, changes in traffic control (after traveling a long distance without traffic control), and can serve to warn drivers when sight distance obstructions exist.

Brewer and Fitzpatrick (2004) evaluated various treatments for rural highways and rural highway intersections. They evaluated three intersections where advance warning signs were used. After installing advance warning signs a reduction was found when comparing the 3-year before and after periods.

Beacons

Beacons are flashing lights which draw attention to a sign (see Figure 3). Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections and found that a flashing beacon mounted on a “STOP AHEAD” sign for a single intersection had a crash reduction from 0.06 to 0.03 crashes/month for the three years before and three years after installation.

Figure 3. Flashing beacons in a variety of settings (Image source for LED Stop Sign: TAPCO, all other images Neal Hawkins)

The Minnesota DOT has replaced four-headed overhead flashing beacons with red flashing beacons mounted on the minor road stop sign and a yellow flashing beacon mounted on the appropriate intersection warning sign for the major approach at approximately 30 intersections (see Figure 4). While results have not been fully evaluated, the Minnesota DOT reports that the “early” after-data show a reduction in crashes at those intersections (Amparano and Morena 2006).

Figure 4. The Minnesota DOT's sign-mounted beacons used to replace overhead flashing beacons (Right image source: Mn/DOT from Amparano and Morena, 2006, Left image source: CTRE)

Stackhouse and Cassidy (1996) compared accident experience at rural intersections for a three-year period before and after installation of various warning beacon configurations. Twelve intersections were included in the study. All had four approaches with stop control on the minor approaches. Four of the twelve intersections had pedestal-mounted flashers installed on both the stop signs and intersection-ahead signs. The authors found a reduction in crash of 40% after the sign mounted flashers were installed.

Reflective Strips on Posts

Reflective material may be used to improve the nighttime visibility of signs. Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections. For instance, they evaluated an intersection where reflective strips on the stop sign were added (see Figure 5). The crash rate three years before use of the reflective strips was 0.06 crashes per month and 0 crashes per month in the three-year period after the improvement.

Figure 5. Reflective strips on stop sign (Image source: Neal Hawkins)

Improved signing and marking

Improved signing and marking may result in better advance warning, or improved driver guidance by use of larger/wider signs and markings and improved retroflectivity. The FHWA is working to establish minimum requirements for pavement markings and has recently published minimum standards for signs. Loss of retroreflectivity is shown in Figure 6.

Figure 6. Illustrates loss of retroreflectivity at night (Image source: Opiela et al. 2003)

The Mississippi DOT developed a program to systematically upgrade the size of regulatory signs (see Figure 7). Larger signs may be especially beneficial for older drivers (Amparano and Morena 2006).

Figure 7. Mississippi DOT upgrades of sign size (Image source: MDOT from Amparano and Morena 2006)

Flashing Beacons at Intersections

A flashing beacon is a flashing light typically suspended above an intersection to warn drivers of an unexpected or hazardous situation. With one-way (T-intersection) or two-way stop control, a flashing red beacon typically faces the stop-controlled approaches, and a flashing yellow beacon faces the non-stop control approaches (see Figure 8). For all-way stop control, flashing red beacons are used for all approaches (see Figure 9).

Figure 8. Use of overhead flashing yellow beacon at stop/through intersections (Image source: Neal Hawkins)

Figure 9. Use of overhead flashing beacons at all-way stop intersections (Image source: Neal Hawkins)

Pant et al. (1992) evaluated the use of intersection control beacons used in conjunction with stop signs at rural, low volume intersections. They conducted a cross-sectional analysis using two-way stop controlled, T, divided, and all-way stop-controlled intersections. Intersections were grouped by type and speed reduction, stop compliance, and accident experience.

For the two-way stop-controlled intersections, four intersections had inadequate sight distance and beacons, four had inadequate sight distance and no beacons, four had adequate sight distance and beacons, and four had adequate sight distance and no beacons. They found that the use of intersection beacons at two-way stop-controlled intersections reduced the 85th percentile speeds in the major direction of traffic, especially when inadequate sight distance was present but did not reduce speeds for the minor approaches.

Pant et al. (1992) also conducted a before and after crash analysis at seven two-way stop-controlled intersections with beacons. They found a 56% reduction in fatal crashes, 3.5% reduction in injury crashes, and a 13.1 increase in property damage-only crashes.

Hall (1991) developed warrants for use of intersection control and hazard warning beacons for New Mexico. They compared accidents before and after installation of beacons at six intersections and found that changes in crashes after beacons were installed were not large enough to be a statistically significant reduction. Hall cited an earlier North Carolina study by Cribbins (1970), who analyzed crash experience at 14 rural intersections where flashing beacons were added. Overall, these intersections had a low number of accidents, but the researchers found a 62% decrease in single-vehicle accidents and a 21% reduction in multiple vehicle accidents.

Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections. They evaluated four intersections where flashing overhead beacons were installed. The crash rate was reduced by 43% (0.49 to 0.28 crashes per month) from the period of three years before to three years after the improvement was installed.

Goldblatt (1977) conducted a study to evaluate the operational effects of continuously- and vehicle-actuated flashing traffic control devices. They study was conducted at the FHWA's Maine facility. Three advance warning device configurations were evaluated at five intersections. The study found that speeds were lower with the use of flashing intersection beacons at stop-controlled approaches, compared to those with stop signs only or vehicle-actuated intersection beacons.

Stackhouse and Cassidy (1996) compared accident experience at rural intersections for three years before and after period-installation of various warning beacon configurations. Twelve intersections were included in the study. All were four-way with stop control on the minor approaches. Eight of the twelve intersections had overhead flashers installed and a 39% reduction in accidents after installation of the overhead flashers was reported.

Stackhouse and Cassidy (1996) also conducted a survey to test driver understanding and response to overhead and sign-mounted beacons. They found that for most drivers both overhead and sign-mounted flashing beacons warned drivers that the intersection was potentially more dangerous. Drivers indicated that they were much more likely to prepare to stop when a red flasher was present than for a yellow flasher. Drivers also indicated that they were more likely to come to a full stop when red overhead flashing beacons were present than for pedestal-mounted red flashers on stop signs. Approximately one-third of drivers stated that under some condition they had been confused by the meaning of flashing lights. About 38% of young drivers and 46% of older drivers believed that if an overhead flashing red light was present for the minor approach, an overhead flashing light was also present for the major approach. This may lead drivers to assume that the major road traffic stops in all cases when a flashing red overhead beacon is present.

Advance Stop Line Rumble Strips

Advance stop line transverse rumble strips are used in rural areas on stop-controlled approaches. The rumble strips are typically set in a series of three sets of transverse grooves that provide a tactile and audible cue to drivers, warning them that they need to stop (Iowa DOT, 2006). Harder et al. (2001) evaluated the effect of in-lane rumble strips on driver response using a driving simulation experiment at thru-stop intersections. The researchers compared different types and patterns of rumble strips and found that the presence of rumble strips affects the point at which drivers begin to brake but has no effect on when drivers begin to slow down or the distance away from the intersection where they actually stop.

The Iowa DOT recommends that rumble strips should not be added to reconstruction or resurfacing projects that do not involve geometric changes or changes in stop conditions unless the Office of Traffic and Safety requests them. According to Iowa DOT guidelines, three sets of rumble strips are typically used. The first set of rumble strips is normally located 200 feet in advance of the “STOP AHEAD” sign, and the last set of rumble strips is located 300 feet in advance of the stop bar with the third located an equal distance between the other two (see Figure 10). The Iowa DOT (2006) also recommends that rumble strips only be placed on approaches with a speed limit of 55 mph or more.

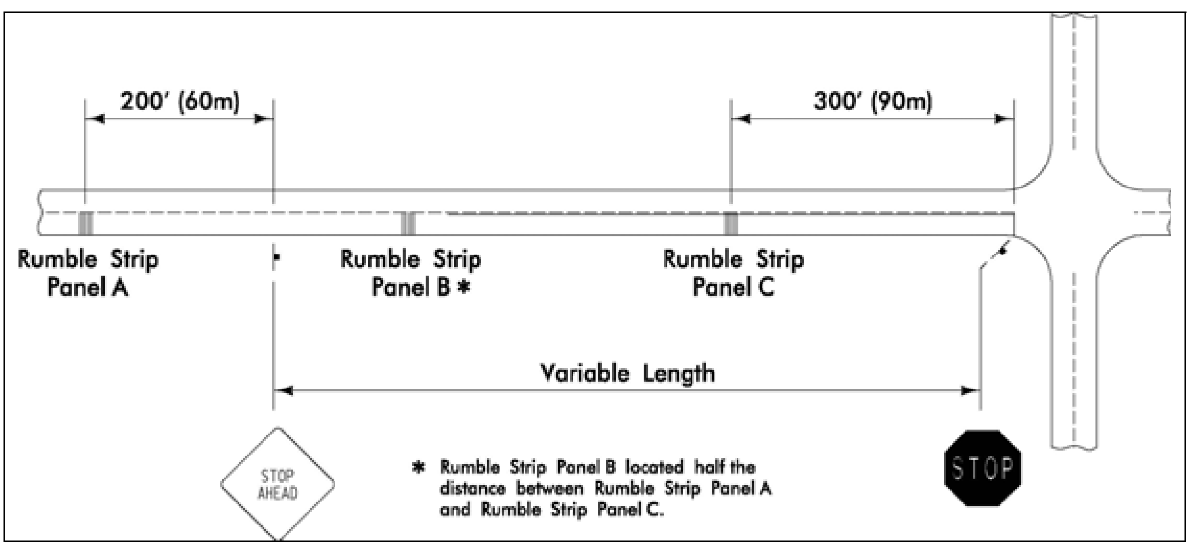

Figure 10. Typical rumble strip panel locations

Harwood (1993) suggests that when rumble strips are used to prompt the driver to engage in a particular action, the rumble strips be placed so that either the upcoming decision point or sign identifying the action to be taken (i.e., Stop Ahead) is clearly visible as the driver passes over the rumble strips. This provides sufficient time for the driver to take the appropriate action. Harwood also suggest that rumble strips in the traveled way, such as stopline rumble strips, are best limited to locations where there is a documented safety problem and where other treatments have not been effective. Based on a summary of 10 studies, Harwood indicated that accident reductions from 14 to 100 percent were observed with use of advance stopline rumble strips. He also cautioned that overuse of rumble strips may lessen their impact.

Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections. They evaluated 2 intersections where approach rumble strips were installed. The crash rate was reduced by 43% (0.34 to 0.19 crashes/month) from the 3-year before to 3-year period after the improvement was installed.

Zaidel et al. (1986) evaluated the use of paint stripes and rumble strips on speed reduction and stop sign compliance at two stop-controlled approaches at a rural intersection. The study intersection had a consistent history of accidents where drivers failed to yield on the minor road. A pattern of geometrically converging paint stripes laid out at a distance of 886 feet was applied to one minor stop-controlled approach, and a similar pattern with continuous transverse rumble strips was applied on the other minor stop-controlled approach. A speed reduction of 3.7 km/h was noted for the paint stripes at 165 meters before the intersection stopline, and a reduction of 31.7 mph was noted at the same distance for the rumble strips. Before application of the treatment, 10% of drivers did not stop at the approach where paint stripes were applied. After the treatment was applied, 8% failed to stop. For the approach where rumble strips were applied, no change was noted in stopping compliance.

Thompson et al. (2006) evaluated change in approach speed for advanced stopline rumble strips at five rural intersections which were considered to be hazardous. Speed was measured at three locations: an upstream location where speeds were not likely to be influenced by the presence of advance stopline rumble strips, the location of a warning “Stop Ahead” sign, and the intersection. Sites were evaluated before and after placement of advance stopline rumble strips. Overall researchers found small but statistically significant changes in traffic speeds after installation of the rumble strips.

Lighting

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

Walker and Roberts (1976) also found reductions in nighttime crash frequency for rural at-grade intersections after installation of lighting. Overall, they indicated a 49% reduction in frequency of night crashes after lighting was installed. The average night crash rate was also reduced from 1.89 to 0.91 crashes per million entering vehicles, a reduction of 52%. These results were statistically significant at the 99% level. More specifically, researchers found no statistical difference of before to after night rates after lighting was installed for unchannelized intersections but there was a highly significant reduction for channelized intersections. No change in crash rate occurred for T or Y intersection when lighting was installed; however, there were significant reductions for 4-leg intersections.

Green, et al. (2003) completed a before-and-after study in Kentucky that analyzed the safety benefits associated with roadway lighting. These researchers indicated that a high percentage of the nighttime crashes on rural roadways had one or more of the following characteristics: occurred on a weekend, involved one vehicle, took place on a curve, or occurred in snow and ice conditions. As part of the research, a procedure was developed to identify locations in Kentucky that have a high number or rate of nighttime crashes. A significant number of the locations were identified as rural; however, urban sites were also included. The researchers conducted analysis of nine intersections before and after the installation of lighting and found that nighttime crashes were reduced by 45%.

Preston and Schoenecker (1999) conducted a before-and-after study to evaluate the impacts of lighting at 12 rural intersections in Minnesota. The report concluded that lighting of the rural intersections resulted in a 25% to 40% reduction in nighttime crash frequency, as well as an 8% to 26% reduction in the nighttime crash severity. The General Accounting office (GAO) lists installation of lighting at rural intersections as a proven strategy based on Preston’s study (GAO 2004).

After the initial study was published, the Minnesota DOT was interested in expanding the study to ensure that the results were statistically significant, since the original study only evaluated 12 intersections. Isebrands, Hallmark, Hans, McDonald, Preston, and Storm (2006) teamed up and expanded the original Minnesota study to evaluate the impact of lighting on nighttime crash experience at rural, unsignalized intersections for the Minnesota Local Road Research Board (LRRB). They conducted both a comparative and before-and-after analysis. The comparative analysis evaluated the ratio of night to total crash ratio at 3,622 rural lighted and unlighted intersections from the Minnesota DOT intersection database (including intersections at U.S. or Minnesota trunk highways). A linear regression model indicated relevant variables affecting the ratio of nighttime to total crashes include presence of street lighting, volume, and number of intersection approaches. The expected ratio of night to total crashes was 7% higher for unlighted intersections than for lighted intersections, and the difference was statistically significant.

The before-and-after study compared the decrease in nighttime crashes after lighting was installed at 33 rural intersections. A Poisson regression model evaluated the change in night crash rate after installation of lighting. Results indicated that the night crash rate was lower after lighting was installed, which was statistically significant. The expected night crash rate before lighting installation was 59% higher than after lighting installation.

Kim et al. (2006) evaluated 165 rural intersections, which included both signalized and unsignalized intersections. Researchers used several models to evaluate the impact of lighting for different crash types. They found a positive relationship between presence of lighting on the major roadway for the models that evaluated all crashes and angle crashes but not for the models that evaluated head-on, rear-end crashes, and sideswipe (same direction) crashes

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

LIGHTING WARRANTS FOR RURAL ROADWAYS

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

A review of light warrants for rural roadways and intersections was undertaken to determine what criteria states were using to determine when street lighting was warranted. The following sections describe lighting warrants for rural intersections from 19 states and warrants for rural roadway lighting for five states.

State Rural Intersection Lighting Warrant Summary

The Iowa DOT provides detailed lighting warrants for full lighting and destination lighting in their *Traffic and Safety Manual* and the *Iowa Administrative Code* (State of Iowa 2004). Warrants include applications for new or reconstructed intersections and existing intersections. The warrants are presented in Table 4 and provide a wide range of measurements for evaluating the need for lighting at rural intersections, including volume, intersection characteristics, intersection sight distance (included in the safety adjustment factor), night to day crash rate ratio, and night crashes.

Table 4. Iowa DOT rural intersection lighting warrants

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

1 Destination lighting is intended only to guide the driver to the intersection and full lighting is designed to increase visibility

2 See Appendix A

Rural intersection lighting warrants were obtained from 18 states in addition to Iowa (see Table 5). Of these states, six use only the guidelines presented in AASHTO’s “An Informational Guide to Roadway Lighting” or NCHRP Report 152. The remaining states use agency-developed criteria to warrant the installation of roadway lighting. Most of these states use nighttime crashes, expressed in terms of frequency or night-to-day crash rate ratio, as a criterion to warrant lighting. The minimum values for nighttime crash frequency range from five in a three-year period for Montana to five in a one-year period in Illinois. (Illinois also uses total crash rate.) The night-to-day crash rate ratio minimum ranges from 1 to 1.5. Two states also utilize these criteria in conjunction with a night-to-day crash rate ratio greater than the statewide average for similar locations as a warrant. Four states require a combination of both nighttime crash frequency and night-to-day crash rate ratio as a warrant. For example, North Carolina requires at least six crashes in a three-year period as well as a night-to-day crash rate ratio greater than 1.5.

Other warrants, not based on crash history, vary from state to state and many times exist in combination with many other warrants, all of which justify the installation of roadway lighting. Some of these warrants that exist in significant numbers among the 13 states are discussed. Poor geometric conditions may justify the installation of roadway lighting in over half of the 13 states. Signalized intersections substantiate lighting in one-third of the thirteen states. Three states justify lighting at intersections with a high potential for crashes on either of the intersecting roads. High pedestrian volume and commercial development areas adjacent to the intersection each serve as one of many warrants for lighting in three states.

Only two states were found to base their lighting warrant on total vehicle volume, and only one state utilized a nighttime volume. In some cases, states use traffic volume in conjunction with other criterion, such as a “T” intersection, channelization, poor geometric conditions, speed of vehicles entering the intersection, or high pedestrian volume.

In general, rural intersection lighting warrants vary greatly among the states. For example, Indiana requires more than seven crashes per year in addition to a night-to-day crash rate ratio of over 0.5. However, this state also allows for rural intersection lighting where a high potential for crashes exists on the intersecting roads, channelized islands, significant commercial or residential development or high truck volumes. Conversely, North Dakota utilizes five different warrants, including two different nighttime crash frequency/rate ratio warrants. Satisfying either of these crash-based warrants may justify the installation of lighting. Additionally, engineering judgment, based on operating conditions, traffic and crash experience, may also justify rural intersection lighting.

Table 5. Warrants for lighting and rural intersections

State	Warrants
California	If one or more of the following conditions exist: • ≥ 190 pedestrians/any single nighttime hour • ≥ 100 vehicles/nighttime hour for one moving lane or ≥ 150 vehicles/nighttime hour for two moving lanes on minor road approach • ≥ 650 entering vehicles/nighttime hours for three approaches or ≥ 800 entering vehicles/nighttime hour for four approaches • ≥ 4 nighttime accidents for any 12-month period • ≥ 6 nighttime accidents for any 6-month period • Traffic signal or flashing beacon if installed • Any two of the following geometric conditions are unsatisfactory: sight distance, horizontal or vertical curvature of the road, channelization
Illinois	If one or more of the following conditions exist: • ≥ 2.4 accidents/MEV in each of three consecutive years • ≥ 2.0 accidents/MEV/yr and ≥ 4 accidents/yr in each of three consecutive years • ≥ 3.0 accidents/MEV/yr and ≥ 7 accidents/yr in each of three consecutive years • Signalized intersection ≥ 5 nighttime crashes in past year and < 2 day-to-night crash ratio (night-to-day > 0.5) • Substantial nighttime pedestrian volume exists • Less than desirable alignment on any of the intersection approaches • Unusual type of intersection, requiring complex turning maneuvers • Commercial development in vicinity causing high nighttime traffic peaks • Distracting illumination from adjacent land development • Recurrent fog or industrial smoke in area
Indiana	If one or more of the following conditions exist: • > 7.0 nighttime accidents/yr caused by lack of lighting and night-to-day ratio > 0.5 • Roads with high potential for accidents (driveways, channelized islands, significant commercial or residential development, high % of trucks & geometric deficiencies)

Table 5. Warrants for lighting and rural intersections (continued)

State	Warrants
Minnesota	If one or more of the following conditions exist: • Geometric conditions of at-grade intersections meet AASHTO guidelines • Traffic signal warrant for minimum vehicular volume met for intersection, or interruption of continuous traffic, or minimum pedestrian warrant is met for any nighttime single hour (6 pm – 6 am) • ≥ 3 nighttime crashes/yr • Lighted intersecting roadway • Illumination in adjacent areas adversely affect drivers' vision • Channelized & 85th percentile approach speeds > 40 mph • School crossing – ≥ 100 pedestrians in any single nighttime hour • Intersection is signalized • Intersection has flashing beacons
Mississippi	AASHTO's "An Informational Guide for Roadway Lighting" or NCHRP Report 152 if a road is not covered by AASHTO
Missouri	If one or more of the following conditions exist: • Intersection is signalized • Divisional Islands are used • > 1.25 night-to-day crash ratio • Poor sight distance exists
Montana	If one or more of the following conditions exist: • Raised channelization at intersection • ≥ 5 accidents in 3-year period due to lack of lighting at intersection • Signalization warranted at intersection • Intersection is unlighted and nearest lighted area is < 300 m away • High conflict area (driveways, commercial/residential area, high truck %) • Complex geometry of roadway • Night-to-day accident ratio > statewide avg. for similar locations
New York	If one of more of the following conditions exist: • For a period of any 4 nighttime hour period: > 400 pedestrians/intersection area AND > 600 entering vehicles AND (85th percentile speed > 40 mph OR intersection is in community w/ pop. < 10,000 & minimum pedestrian & vehicle volume warrant is 70% above requirements) • Where ≥ 1 approach to intersection is lighted under NYSDOT warrant • Above warrants are not met and local government(s) desire installation of street or arterial lighting based on non-user benefits such as aesthetics, civic pride, crime reduction, increased business activity)

Table 5. Warrants for lighting and rural intersections (continued)

State	Warrants
North Carolina	If both of the following conditions exist: • AASHTO warrants based on traffic volume and area classification • Priority Index number assigned to an intersection factoring in nighttime ADT and annual cost of lighting meets the minimum for the state warrant
North Dakota	If one or more of the following conditions exist: • Channelized with raised island or pavement marking • ≥ 4.0 nighttime accidents in 1 year or ≥ 6.0 in 2 years • ≥ 6.0 total accidents in ≤3 years and night-to-day crash rate ratio ≥1.5 • Engineering judgment based on study of operating conditions and traffic /crash experience indicates lighting may result in a significant benefit to the public • Where a local government finds sufficient benefit in form of convenience, safety, policing, community promotions, public relation, or otherwise, and pay 50% installation costs and 100% operation/maintenance costs
Ohio	If one or more of the following conditions exist: • High percentage of night accidents or high night pedestrian traffic volume • Sight distance limitations, complex geometry, high traffic volume, channelization, skewed approaches, unusual traffic patterns, turning roadways, protected turning lanes or driver recognition problems
Oklahoma	AASHTO guidelines in combination with NCHRP Report 152 (see accident data for possible project locations and in some cases “P” political warrant is used)
Oregon	If one or more of the following conditions exist: • ≥ 30% crashes are at night OR ≥ 1.5 night-to-day crash rate ratio (per MEV basis) • Engineering judgment and other factors demonstrate a need for lighting
Pennsylvania	AASHTO’s “An Informational Guide for Roadway Lighting”

Table 5. Warrants for lighting and rural intersections (continued)

State	Warrants	
Rhode Island	*Highway Lighting Management System Plan*	
Texas	**Partial Lighting** If one or more of the following conditions exist: • ADT > 1000 • ≥ 1.25 night-to-day crash rate ratio OR > statewide average for similar unlighted sections, and study indicates lighting may reduce night crash rate	**Complete Lighting** If one or more of the following conditions exist: • ADT > 5,000 • Existing commercial/industrial development with lighting is within immediate vicinity, or crossroad approach legs are lit for 0.5 miles on each side of intersection
Washington	If one or more of the following conditions are met for intersections without channelization: • > 1 night-to-day crash rate ratio or traffic volumes and movement would be improved with installation of left turn channelization • Divided highway intersections • Tee intersections • Railroad crossing • Four-way intersections of 2 lane minor roadway with 4 lane major roadway	
West Virginia	NCHRP 152	

State Rural Non-Intersection Highway Lighting Warrant Summary

Safety was the primary characteristic of the rural highway lighting warrants that were obtained. A summary of warrants for rural highways (non-intersection sections) from five states were obtained and their information summarized in Table 6.

Table 6. Warrants for rural lighting on State/U.S. highways

State	Warrants
Illinois	If one or more of the following conditions exist: • Section of highway with raised median • High conflict locations (vehicle-vehicle interactions): many driveways, significant commercial/residential development, high truck %) • Complex geometry • Night-to-day crash rate ratio > state average for similar locations, and study indicates lighting would reduce night crash rate • Local agency finds sufficient benefit in form of convenience, safety, policing, community promotion, public relations, etc., and pay appreciable percentage of installation, maintenance, and operation costs
New York	If one or more of the following conditions exist: • ≥ 3.0 night-to-day crash rate ratio and total crash rate is at least 2 times > state average, provided 1 nighttime crash per intersection/yr has occurred on the section of road over a 3 year period or an average of 6 or more nighttime accidents/mi/yr • Gap between continuously lighted sections < ½ mile AND % gap length to total length of 2 lighted sections + gap < 25% • Local government(s) desire installation of street or arterial lighting based on non-user benefits such as aesthetics, civic pride, crime reduction and, increased business activity.
North Dakota	If one or more of the following conditions exist: • Reconstruction of existing roadway will require removal of existing lighting system • ≥ 2.0 night-to-day crash rate ratio and study of conditions indicates lighting may result in a significant reduction in night crash rate • Installation of lighting adds to safety and comfort of vehicular driver and pedestrians, and facilitates traffic flow and/or where local governmental agency finds sufficient benefit in form of convenience, safety, policing, community promotion, public relation, or other, and pay 50% installation cost and 100% operation and maintenance costs
Oregon	If both of the following conditions exist: • ≥ 30% of total crashes are at night • Total crash rate > statewide average for similar roadway character
Washington	If all of the following conditions exist, continuous (full) lighting is warranted: • Highway segment is in a commercial area • Nighttime peak hour LOS is D or lower OR > 1 night/day crash rate ratio • Engineering study indicates nighttime driving conditions would be improved with lighting

LIGHTING STANDARDS AND PRACTICES IN IOWA COUNTIES AND CITIES

A survey was developed to question Iowa counties and cities as to their lighting standards and practices. The survey is provided in Appendix B. The survey was used to determine current lighting practices in Iowa.

City Lighting Survey

In fall 2006 the lighting survey was distributed to all cities exceeding 5,000 in population. The 12 cities responding to the survey are noted below along with their year 2000 population. Figure 11 summarizes the survey results.

Burlington (26,839)	Des Moines (198,682)
Carroll (10,098)	Marion (26,294)
Cedar Rapids (120,758)	Mason City (29,172)
Coralville (17,269)	Muscatine (22,697)
Council Bluffs (58,268)	Sioux City (85,013)
Davenport (98,359)	Urbandale (35,904)

All responding agencies, except one, have criteria for the installation of roadway lighting. Half of the cities install lighting at all intersections within the city's jurisdiction. Three cities warrant lighting installation on long mid-blocks, typically longer than 600 feet. Spacing of lights for continuous lighting within a city ranges from 25 to 300 feet in commercial areas, most commonly 200 to 300 feet. A majority of the cities use ornamental lighting for continuous lighting and do not follow the typical standards for point lighting.

Five of the cities have established standards for lighting levels and layout. Three cities use the local utility company's recommendations regarding the illumination level at sites. Three cities have other specific foot-candle and wattage standards based on the functional classification of the street. One city requires a zero candle spillover on property lines. Results are provided in Figure 11.

Ten cities provided an estimate of the number of streetlights within their jurisdiction. The average number of streetlights per agency is 7,000, with five agencies maintaining fewer than 5,000. The City of Des Moines maintains the most streetlights at 24,000. Nine cities provided an annual roadway lighting budget, averaging $750,000. The budget of six cities is less than $500,000, but the budget of the two largest cities, Cedar Rapids and Des Moines, is $1.6 million and $3 million, respectively.

A majority of the cities contracted with local utility companies to install and maintain street lighting. However, it is not uncommon for the city to be responsible for maintaining decorative lighting which was typically found in the downtown areas. Eight of the twelve cities considered installing other guidance features prior to adding or enhancing roadway lighting. These features included additional signing, pavement marking, and decorative lighting not meeting the specifications of the standard fixture type.

Over half of the cities considered energy-efficient lighting alternatives. One city uses LED replacements for the cobra head lights. Nearly all agencies consider high pressure sodium as their source of energy efficiency.

1. Does your agency have criteria for the installation of roadway lighting?
   a) 11 – Y
   b) 1 – N
2. If yes, what criteria are used in determining whether to install roadway lighting? (Answers for each city may be a combination of 2 or 3 of the criteria below.)
   a) 6 - All intersections
   b) 3 – if midblock > 600 ft. long/long blocks
   c) 2 – every 300 ft.
   d) 1 – 25-75 ft. spacing
   e) 1 – 200-300 ft. apart
   f) 1 – end of cul-de-sac
   g) 1 – 200-250 ft apart
   h) 1 – every 600 ft in residential areas, every 300 ft. in commercial areas
   i) 1 – at dead-ends or cul-de-sacs if > 300 ft. from intersection
   j) 1 - SUDAS criteria
3. How do these criteria vary for point and continuous lighting?
   a) 3 accepted styles of lights
   b) High accident ratios, large pedestrian use, terrain obstructions, small/tight curves may require additional street lights
   c) Refer to SUDAS
   d) 1 did not answer
   e) 300-400 ft. apart for continuous, point lighting at intersections
   f) Continuous lighting added with high level of development
   g) Don't differ
   h) Continuous lighting is ornamental and are spaced closer together
   i) Continuous lighting is decorative and are spaced irregularly
   j) Point lighting only
   k) Mid-block lights are required when >= 600 ft. long
4. Does your agency have established standards for lighting levels and layout?
   a) 5 – yes
   b) 7 – no
5. How are illumination levels determined per site?
   a) 4 – Utility Company recommendations
   b) Light meter
   c) Residential – 0.2 foot-candles; Collector – 0.6 foot-candles; Minor arterial – 0.9 foot-candles; Major arterial – 1.2 foot-candles; Downtown – 1.2 foot-candles
   d) Local – 8500 lumens, 100 W; Collector – 14,500 lumens, 150 W; Arterial – 23,000 lumens, 250 W
   e) DOT Standards (1 ft candle/ft^2); Collector – 250-300 W; Local – 100-150 W

Figure 11. Responses for city lighting surveys (12 surveys received)

f) Zero candle spill over on property lines
g) ITE Standards
h) Engineering judgment

6. How many roadway lights are within your jurisdiction?
   a) Average = 7000 lights per city
   b) 5 – under 5000
   c) 5 over 5000
7. Who installs and maintains the lighting system?
   a) 9 – Local Utility Co.
   b) 3 – City decorative lights – city; rest – local utility co.
   c) 1 – residential-local utility co.; continuous-contractor
8. What is your agency's annual roadway lighting budget?
   a) Avg. = $750,000
   b) 6 < $500,000
   c) 3 > $500,000
9. Is consideration given to installing other guidance features prior to adding or enhancing roadway lighting?
   a) 8 – N
   b) 4 – Y
   c) Ex: pavement markings, additional signing, decorative lighting that doesn't follow standard fixture type
10. Does your agency consider energy efficient lighting alternatives?
    a) 7 – Y
    b) 5 – N
11. If yes, please provide a description
    a) 6 - High pressure sodium
    b) Cut-off lenses
    c) Led replacement decorative cobra head lighting

Figure 11. Responses for city lighting surveys (continued)

County Lighting Survey Summary

In fall 2006, a rural roadway lighting survey was distributed to all 99 counties. Twenty-seven counties responded to the survey. A summary by response is provided in Figure 13. Of those counties responding, more than one-third have criteria for the installation of roadway lighting. Roadway classification and traffic volume were identified as the primary factors in warranting the installation of rural lighting. Other factors included crash history (day and/or night) and engineering judgment regarding nighttime visibility. One county indicated that it does not install roadway lighting because the cost has not yet been justified. Figure 12 shows the counties that responded.

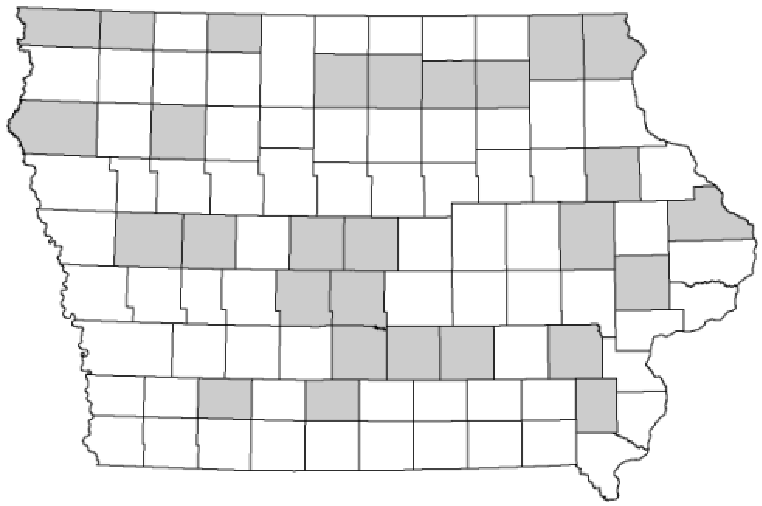

Figure 12. Counties responding to the lighting survey

Of the counties having criteria for roadway lighting, most use point lighting. However, these counties typically do not have established standards for lighting levels and layout. Only three standards were provided by three separate respondents: dual heads, single heads and provision of illumination to all lanes entering the intersection. The determination of illumination levels per site also varied among the respondents.

The number of rural roadway lighting installations within each county varied widely, with the average county reporting 19 installations. Ten of the 24 counties reported that they currently have ten or fewer lights; three counties only reported two installations. Polk County, a predominately urban, high population county, reported the most lighting installations at 85. Most agencies reported that a local utility company installs and maintains the roadway lighting system. Agency roadway lighting budgets ranged from $600 to $100,000, with an average budget near $9800.

Most counties consider the installation of other guidance features prior to adding or enhancing roadway lighting. Seven counties considered energy efficient lighting alternatives, while 13 did not.

1. Does your agency have criteria for the installation of roadway lighting?
    a. No – 15 counties
    b. Yes – 10 counties
    c. Mahaska County uses criteria, but it's unofficial practice.
    d. Boone County does not decide the criteria
2. If yes, what are the criteria used in determining whether to install roadway lighting?
    a. Of the 10 counties that have criteria, these criteria are considered for rural lighting – some may use more than one criterion for warranting lighting
        i. 5 counties used road classification (major county intersects primary state)
        ii. 4 used traffic volume
        iii. 2 installed lights at all paved intersections
        iv. 2 used night accident history, total accident frequency
        v. 1 used darkness (judgment), no lighting at any intersection, "problem intersections"
3. How do these criteria vary for point and continuous lighting?
    a. Of the 10 counties that said yes:
        i. 6 counties have only point lighting
        ii. 2 counties did not answer
        iii. 1 county that did not have criteria for the installation of roadway lighting (answer to 1 = NO) responded with all lighting is point lighting
        iv. 1 county uses 2 destination lights at intersections
        v. 1 county uses destination lights only at all paved intersections
4. Does your agency have established standards for lighting levels and layout?
    a. No – 18 counties
    b. Yes – 3 counties
        i. dual head over lanes for overhead flashing lights
        ii. single overhead lighting
        iii. lights arranged to have each lane into the intersection illuminated
    c. did not answer – 6 counties
5. How are illumination levels determined per site?
    a. Counties determine illumination by the following criterion:
        i. Higher traffic count = better illumination
        ii. Judgment
        iii. One typical street light at a stop sign
        iv. Power Company
        v. 1 light at every intersection
        vi. 250-400 Watt lights
        vii. Us 150 watt sodium vapor light
    b. 4 counties do not determine illumination levels
    c. 15 did not answer

Figure 13. Summary of a rural roadway lighting survey from 27 responding counties

6. How many roadway lights are within your jurisdiction?
    a. 17: $\leq$ 20 lights
    b. 7: >20 lights
    c. 3 did not answer
7. Who installs and maintains the lighting system?
    a. Local utility company – 18
    b. County – 1
    c. Contractor - 3
    d. Mix of the previous three – 3
    e. 2 did not answer
8. What is your agency's annual roadway lighting budget?
    a. 16: $\leq$ \$5000
    b. 6: \$5000 $\geq$ and $\leq$ \$20,000
    c. 2: $\geq$ \$20,000
    d. 3 did not answer
9. Is consideration given to installing other guidance features prior to adding or enhancing roadway lighting?
    a. 14: Yes
    b. 4: No
    c. 2: Depends on the intersection (accident history, etc..)
    d. 1: unknown
    e. 6 did not answer
10. Does your agency consider energy efficient lighting alternatives?
    a. 12: No
    b. 7: Yes
    c. 8 did not answer
11. If yes, provide description.
    a. Of the 7 that consider energy efficient lighting alternatives:
        i. 3: sodium vapor
        ii. 1: switch to non-peak use accounts, upgrade older bulbs
        iii. 1: has not yet, but considering LED's instead of incandescent
        iv. 1: whatever the REC recommends
        v. 1 did not answer
12. Additional Comments
    a. Chickasaw – would consider other energy efficient lighting if it was a cost savings (i.e. solar power) – doesn't currently use energy efficient lighting alternatives
    b. Crawford – only provides lighting to rural intersections on paved routes
    c. Dallas – looks forward to the results of this important survey
    d. Delaware – hasn't justified the cost of intersection lighting yet – would need to cut back on other maintenance items to afford it
    e. Polk – more requests each year as area grows out in fringe area

Figure 13. Summary of a rural roadway lighting survey from 27 responding counties (continued)

EVALUATION OF THE EFFECTIVENESS OF LIGHTING AND OTHER COUNTERMEASURES TO REDUCE CRASHES IN IOWA

The original objective of the study was to determine whether street lighting and other low cost measures, such as advance stop sign rumble strips, were effective in reducing nighttime crashes. As indicated, a wide range of intersections was included so that different variables could be evaluated.

The purpose of street lighting is to supplement vehicle headlights and provide visibility at night. At rural intersections, lighting often plays two roles. First, lighting is used to illuminate areas of the intersection where drivers require additional illumination so that they are able to see other vehicles or pedestrians and avoid a conflict. In order for lighting to accomplish its purpose in this case, lighting needs to be placed so that strategic locations within the intersections are illuminated. This requires proper pole height, wattage, and placement. If the benefit of lighting is to provide proper illumination at appropriate locations, then those intersections with simple destination lighting or those where lighting does not provide illumination at critical locations would have a lower safety benefit than locations with better designed lighting.

Second, in many instances, street lights in rural areas are placed on the nearest utility pole, which is often located far enough away from the roadway that the majority of the lighting falls away from areas where lighting could supplement the driving task. In this case, the light becomes destination lighting, which simply indicates to a driver that an intersection is ahead. If lighting is used to indicate that an intersection is ahead, it would follow that use of a flashing overhead beacon might accomplish the same purpose at a much lower cost.

One of the objectives of this research is to collect a large sample of rural intersections both with and without lighting. The research team intended to evaluate the type and placement of lighting as a safety benefit. As a result, the approximate location and type of light were noted for each approach. In order to accomplish this objective, each approach was initially modeled separately. This allowed the lighting type and location specific to that approach to be included. The presence of stop line rumble strips, traffic control, channelization, and flashing beacon head are also approach-specific.

In order to model approaches individually, crashes were allocated by approach for each intersection. A field in the crash database indicates the initial direction of travel for each vehicle involved in an accident. When a crash did not have a direction indicated in the crash database, the crash narrative was consulted.

Given that before and after crash data are not available, a cross-sectional statistical evaluation was used to evaluate the safety benefits of lighting and other treatments at rural unsignalized intersections.

Data Collection

Data were collected from October 2005 through September 2006. Intersections were selected from around the state of Iowa as shown in Figure 14 (within 33 counties). Intersections had at least three paved approaches (all three approaches at a T intersection or three of four approaches at a standard intersection). Data collectors were instructed to select only rural locations that were at least 0.5 miles from the nearest urban area. They were also instructed to avoid intersections which were unusual. For instance, a rural intersection with a gas station or other commercial area would have been considered unusual, as would an intersection with a severe skew angle on one of the approaches.

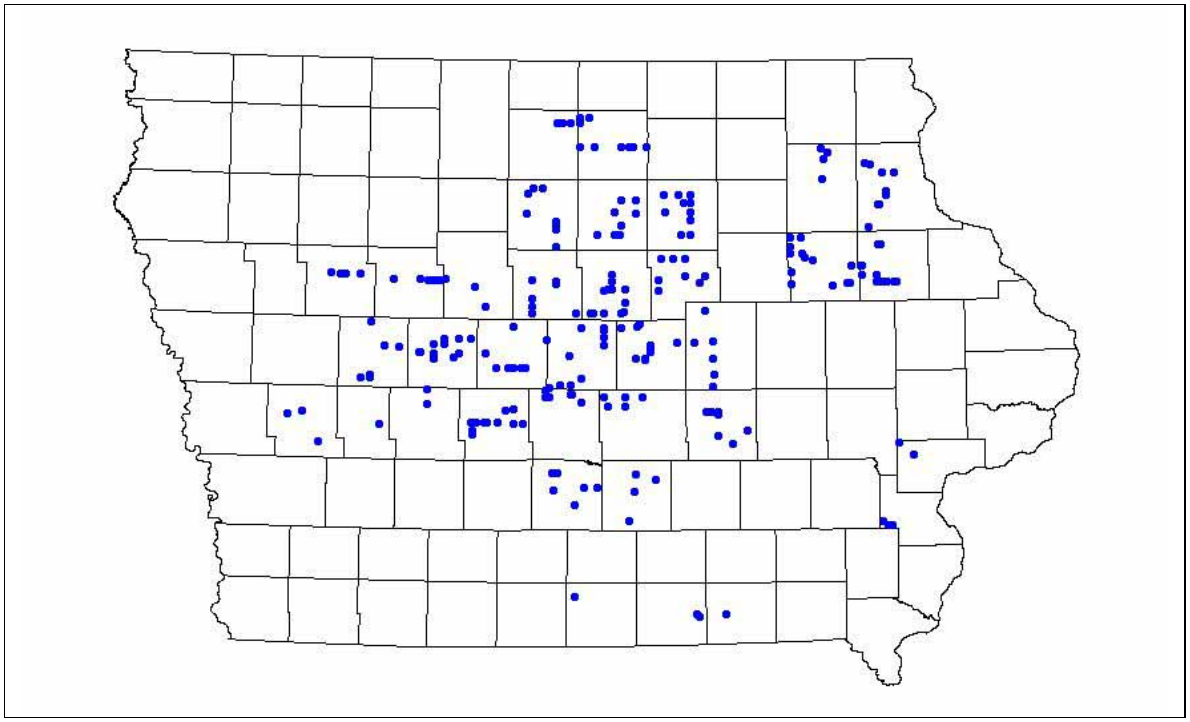

Figure 14. Location of rural intersections in Iowa

The following data elements were collected at each intersection while in the field:

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

2. Information by approach
   a. surface type (asphalt, concrete, gravel)
   b. number of lanes (left, through, right)
   c. traffic control (no control, stop, yield)

d. channelization (painted right-turn island, raised right-turn island)
e. other traffic control (flashing red or yellow beacons, red flags on stop signs)
f. number of rumble strips
g. median type (undivided, grass, painted)

3. Lighting information
   a. location
   b. type of light (cobra head, flood light, other)
   c. location in relationship to the corresponding approach
      - perpendicular to inbound lanes
      - perpendicular to outbound lanes
      - diagonal between approaches
   d. type of pole
      - existing utility (light was placed on existing utility pole without moving the pole to place the light in a particular spot)
      - wood pole placed for light
      - metal pole placed for light

Data were collected for a total of 274 intersections in the 33 counties (see Figure 14) and entered into a database. Each intersection was also located in a Geographic Information System (GIS) database by locating the two intersecting roadways with the 2003 snapshot of the Iowa DOT Geographic Information Management System (GIMS) line work. Average Annual Daily Traffic (AADT) reports were extracted for each roadway and one-half of this was assigned to each approach. Total intersection daily entering volume was calculated by summing the total volume for each approach.

During the data entry process, it was determined that 51 of the intersections could not be included in the final dataset for reasons including; the location could not be located in the GIMS street database; not following the selection criteria regarding a rural setting or having an unusual configuration. Intersections with railroad tracks crossing an approach within less than 50 feet; were also excluded. Several intersections were discarded when it appeared that recent changes to them had occurred.

A total of 223 intersections remained after removing those that were problematic. Of those, 54 were T-intersections, and 169 had four approaches. Total intersection daily entering volume ranged from 305 to 7,625 vehicles per day. Eighty-six had no lighting present, and 137 had at least one street light. All intersections were stop controlled on at least one approach, and 12 were all-way stop controlled. No intersections were controlled with yield signs. Advance stop line rumble strips were present on 139 stop-controlled approaches. In all cases, if rumble strips were present on one paved approach to the intersection, rumble strips were present on all-paved stop-controlled approaches. A series of three rumble strips on the approach preceding the stop sign was the most common configuration. Only five intersections had two sets of rumble strips on the stop-controlled approaches.

The study analysis period was from 2003 to 2005. The crash data used the "2001 2005 Jan 2006" snapshot. For each intersection, crashes within 150 feet of the intersection were selected. Crashes were divided into day and night crashes. Night crashes were determined by time of day. Sunrise and sunset times for each month were determined using the U.S. Naval Observatory website for Ames, Iowa, and crashes which fell during nighttime hours were indicated as night crashes.

Summary of Data

Crash information is provided in Table 7. As indicated, 125 total crashes occurred over the three-year study period at the intersections which had some type of street lighting. Out of the 125 crashes, 88 occurred during the day and 37 at night. The intersections with no lighting experienced a total of 75 crashes with 44 of those occurring during the day and 32 during the night. As shown, the daytime crash rate per intersection was higher at lighted intersections than at unlighted intersections. The nighttime crash rate was lower at lighted intersections than at unlighted intersections.

The ratio of night-to-day crashes was obtained by dividing the total number of night crashes by day crashes, and the ratio of night-to-total crashes was determined by dividing the number of night crashes by total crashes. As shown, the ratio of both night-to-day and night-to-total crashes was lower for lighted intersections than for unlighted intersections (0.39 versus 0.61 and 0.28 versus 0.38, respectively). Using a test of proportionality, the ratio of night-to-day crashes at lighted intersections is lower and statistically different than ratio of night-to-day crashes at unlighted intersections at the 95% level of significance. The ratio of night-to-total crashes at lighted intersections is lower and statistically different at the 10% level of significance than the ratio of night-to-total crashes at unlighted intersections.

Table 7. Crash information for study intersections

Type	Number of Inter-sections	Total	Day Crashes	Night Crashes	Day Crashes/ Inter-section	Night Crashes/ Inter-section	Night to Day Crash Ratio	Night to Total Crash Ratio
Lighted	137	191	137	54	1.00	0.39	0.39	0.28
Unlighted	86	98	61	37	0.71	0.43	0.61	0.38

Analysis

A hierarchical Bayesian model was defined to fit a model using a Poisson distribution. Initially, each approach was modeled separately and the following explanatory variables were considered:

- Pavement type (asphalt, concrete, gravel)
- Traffic control (stop control on minor or all-way {no yield signs were present})

- Other control (presence of flag on stop sign, flashing overhead red beacon, flashing overhead yellow beacon, flashing overhead beacon and flags on stop sign, flashing red beacon on stop sign)
- Median type (undivided, divided, painted)
- Channelization (painted right turn island, raised right turn island, other raised island)
- Number of left-turn lanes
- Number of right-turn lanes
- Type of light (cobra head, dome, flood)
- Pole type (metal, wood, existing utility—this variable was used as a surrogate for placement of the light; a light on an existing utility pole is likely not to place light at the appropriate places at the intersection and in many cases acts as a destination light)
- Location of light (perpendicular to inbound traffic, perpendicular to outbound traffic, diagonal—this was used test whether lighting location was significant)
- Number of rumble strips
- Number of approaches at the intersection (T-intersection or regular 4-approach)

Approach volume was included in the model. The mean of the distribution of crashes at each approach was adjusted using its approach volume; therefore, the mean is the result of the multiplication of approach volume and a parameter λ, where log-lambda represents the linear combination of the explanatory variables. This initial model can be expressed as

$$y_i \sim Poisson(\mu)$$
$$\mu = \lambda * approach\_aadt$$
$$\log(\lambda) = \gamma_1 + \gamma_2 * \mathrm{var}iable2 + \gamma_3 * \mathrm{var}iable3 + \gamma_4 * \mathrm{var}iable4 + \gamma_5 * \mathrm{var}iable5 + ... + \gamma_n * \mathrm{var}iablen$$

The second level of the model is specified by giving the distribution of the hyper parameters γ_k, k = 1,…,8. Thus,

$$\gamma_k \sim N(0{,}1000) \qquad k = 1,...,8$$

Model selection was based in two criteria:

1. Convergence
2. Significance of the explanatory variables

In order to determine if convergence was reached, the potential scale reduction factor (Rhat) was used. At convergence, Rhat = 1.

Significance was determined by looking at the posterior distribution of the γ_k parameters. This works in the same manner that it works with confidence intervals in classic theory. If the number 0 appears in the interval, then the conclusion is that the parameter is not significant. The confidence level was $\alpha = 0.05$.

The dataset was split into two subsets, night and day. The term α_k was used to refer to the hyper parameter when crashes occurred during the day and β_k to refer to the hyper parameter when crashes occurred during the night.

A number of different models were tried that evaluated each approach as an observation. Most of the models either did not converge or there was not sufficient power to distinguish between different models which were evaluated. The inability to develop a meaningful model was due to the fact that most approaches did not have any crashes or, even when crashes were present, the number was low.

It was decided that modeling by approach would not provide useful results, so the data were aggregated for each intersection. Since several variables were specific to an approach, dummy variables were used to reflect whether those variables were present or not at any approach of the intersection. For instance, a variable "*IsRumble*" was used to denote whether one or more approaches at the intersection had rumble strips. A number of variables were also dropped since there were only a few intersections which had the variable in question. For instance, only a couple intersections had flags on the stop sign or a red beacon on the stop sign so this variable was no longer included. The following variables were initially evaluated:

- *Control:* dummy variable which indicates whether the intersection had stop signs on the minor or all-way stops
- *IsBeacon*: dummy variable which indicates the presence of an overhead flashing beacon
- *Channelization*: a dummy variable which indicates presence of channelization
- *NumChannel*: number of approaches with channelization
- *Left_turn*: number of left-turn lanes
- *Right_turn:* number of right-turn lanes
- *Legs4*: a dummy variable which indicates whether the intersection had three or four approaches
- *IsLights*: a dummy variable which indicates whether lighting was present at the intersection
- *NumLights*: indicates total number of lights at the intersections.
- *RumbleStrips*: a dummy variable which indicates whether rumble strips are present on any approach. (In all cases, when one stop-controlled approach at an intersection had rumble strips, all non-gravel approaches with a stop sign at that intersection also had rumble strips)

Two different models were developed to represent daytime and nighttime crashes as described in the following sections. All of the variables listed above were considered. All of the initial models resulted in a very low number of expected crashes, and, consequently, the results were not meaningful. The low number of expected crashes is likely due to the fact that many of the intersections had no crashes. It was decided to consider whether there is an effect of intersections that intrinsically have a higher number of crashes. The top 5% of daytime locations was selected and a dummy variable (*Dayx*) used to indicate whether the location was a high-crash location or not. Intersections that met the definition of being in the top 5% of high-crash locations were those with four or more daytime crashes. A dummy variable (*Nightx*) was used to indicate whether a nighttime location was in the top 5% of nighttime crashes. For the nighttime model, any intersection with two or more crashes over a 3 year period was considered as a high crash location.

Daytime Model

The best daytime model that resulted is described by:

$$y_i \sim Poisson(\mu)$$
$$\mu = \lambda * IEV$$

$$\log(\lambda) = \alpha_1 + \alpha_2 * NumChannel + \alpha_3 * Dayx$$

Where:

IEV = intersection entering volume (equal to ½ times the AADT of each approach link)
μ = expected number of daytime crashes

Table 8 presents the estimates for the daytime model.

Table 8. Estimates for daytime crash model

Variable	Mean	std	2.5%	25%	50%	75%	97.5%	Rhat	n. eff
alpha[1]	-8.1	0.1	-8.2	-8.1	-8.1	-8.0	-7.9	1	1000
alpha[2]	-0.2	0.1	-0.5	-0.3	-0.2	-0.2	0.0	1	1000
alpha[3]	1.4	0.2	1.0	1.2	1.4	1.5	1.6	1	1000
deviance	508.1	2.5	505.3	506.3	507.4	509.1	514.3	1	1000

The final equation is given by:

$$\hat{\mu}_{ij} = \exp(\alpha_1 + \alpha_2 * \text{NumChannel} + \alpha_3 * \text{Daysx}) * IEV$$

The negative coefficient for α_1 suggests that the presence of channelization reduces daytime rural intersection crashes. The presence of an overhead beacon or advance stop-line rumble strips was not shown to have a relationship to daytime crashes, as indicated in the final model.

Nighttime model

The final model for nighttime crashes is defined by the following:

$$y_i \sim Poisson(\mu_i)$$
$$\mu_i = \kappa_i * IEV$$
$$\log(\lambda) = \beta_1 + \beta_2 * IsLight + \beta_3 * Nightx$$

Table 9 presents the estimates for the nighttime model.

In this case, the presence of lighting and whether the location is high crash or not was found to be significant.

Table 9. Estimates for nighttime crash model

Variable	Mean	std	2.5%	25%	50%	75%	97.5%	Rhat	n. eff
beta[1]	-8.8	0.2	-9.2	-8.9	-8.8	-8.7	-8.5	1	1000
beta[2]	-0.7	0.2	-1.1	-0.8	-0.7	-0.5	-0.3	1	1000
beta[3]	2.2	0.2	1.8	2.0	2.2	2.3	2.6	1	1000
deviance	303.9	2.5	301.1	302.2	303.3	305.1	309.7	1	1000

The final nighttime equation is given by:

$$\log(\lambda) = \beta_1 + \beta_2 * IsLight + \beta_3 * Nightx$$

$$\hat{\mu}_i = \exp(\beta_1 + \beta_2 * \text{IsLight} + \beta_3 * \text{Nightx}) * IEV$$

The ratio of the expected mean number of crashes with and without lighting can be calculated by dividing the mean number of nighttime crashes with lighting (holding other variables constant) by the mean number of nighttime crashes with no lighting $e(^{-8.8+0+0}) \div e(^{-8.9-0.7+0}) = 2.01$. Therefore, the expected mean number of nighttime crashes when no lighting is present is 2.01 times higher than when lighting is present at high crash intersections.

It is not known why the influence of other low cost measures, such as advance stop line rumble strips or overhead beacons, could not be detected in the models. A number of intersections had a low number of crashes which may have masked the impact. Additionally some treatments are placed at high crash locations and even with a reduction, the location still has a higher than average number of crashes. As a result, it is difficult to establish a reduction with a cross-sectional model. A before and after analysis was not possible since construction dates and condition of the intersections before lighting could not be established.

In addition to determining which non-lighting measures might be relevant, this study had hoped to address the removal of existing rural intersection lighting, the researchers were not able to discern enough clarity from the statistical evaluation to provide practical guidance.

Practical Application

For a County Engineer to utilize the results of this safety analysis, one simply needs to obtain the actual number of nighttime crashes over a three-year period along with a summary of severity and crash type. This information can be requested (free of charge) through the Iowa Traffic Safety Data Service (ITSDS) at CTRE (http://www.ctre.iastate.edu/itsds/index.htm).

1. Step 1 – Sort the candidate intersections by nighttime crash frequency in descending order.
2. Step 2 – Evaluate crash history by type and focus on areas correctable by lighting (broadside and sideswipe).
3. Step 3 – Identify those intersections having two or more nighttime crashes over the three year period. Based upon the statistical model developed, the addition of lighting at rural intersections provides more benefit when the number of nighttime crashes are two or more over a three year period.

SUMMARY

This report summarizes the common types of nighttime crashes at rural Iowa intersections, discusses strategies used by other agencies to reduce nighttime crashes, summarizes lighting warrants and practices used by other states, discusses the results of a survey of Iowa counties and cities as to their practices in deciding to install lighting, and reports on the results of an analysis to evaluate the effectiveness of lighting.

The report discusses the types of crashes that occur at rural intersections. Understanding the types of crashes that occur can provide insight as to what types of mitigation measures might be effective. A total of 26% of rural intersections crashes in Iowa occur during dark conditions. The most common causes for single vehicle crashes at rural intersection was run-off-road (27%), animal crashes (17%), and ran stop sign (16%). Common causes for multiple vehicle crashes at rural intersections include running the stop sign (21%), failure to yield right-of-way at stop or yield sign (20%), and other failure to yield right-of-way (10%). The most common type of crash for multiple vehicles was broadside (42%) followed by rear-end (14%).

Common strategies to reduce nighttime crashes at rural unsignalized intersections were summarized. These include use of advance signing to warn drivers of an upcoming intersection, use of sign beacons on stop signs or “Stop Ahead” signs, use of reflective material to improve the nighttime visibility of signs, improved signing and marking, use of flashing overhead beacons at intersections, advance stop sign rumble strips, and lighting.

State lighting warrants for rural roadways were obtained for Iowa and 18 other states. The warrants for both rural intersections and rural highways were presented when available. Criteria to determine whether to use lighting and to establish lighting levels and layout were summarized.

Finally a cross-sectional statistical evaluation was used to evaluate the safety benefits of lighting and other treatments, such as advance stop line rumble strips and flashing beacons at rural, unsignalized intersections. A total of 223 rural intersections were used in the analysis. Intersections ranged from having no strategies to having multiple strategies such as lighting and advance stop line rumble strips. Data were collected in the field for each intersection.

The original objective of the study was to determine whether street lighting and other low cost measures, such as advance stop sign rumble strips, were effective in reducing nighttime crashes. As indicated, a wide range of intersections was included so that different variables could be evaluated. One of the objectives of this research was to collect a large sample of rural intersections both with and without lighting. It was hoped that there would be sufficient samples to evaluate type and placement of lighting as a safety benefit. A hierarchical Bayesian model using a Poisson distribution was used to fit various models. The first attempts modeled individual intersection approaches so that type and location of lighting could be included as variables. It was determined after a thorough evaluation of the data and resulting models that the only lighting variable that could be included was presence or absence of lighting, rather than being able to evaluate type, location, and quality of lighting. This may have been due to sample

size, even though 223 intersections were included, or to the fact that crashes at rural intersections are still fairly rare events and differences could not be detected.

Models were developed separately for daytime and nighttime. A number of variables were evaluated for both, including type of control, presence of overhead beacons, presence of advanced stop line rumble strips, etc. The nighttime model included presence of overhead street lighting. The final daytime model only included variables that indicated number of approaches with channelization and whether the intersection was a high crash location (location had 4 or more daytime crashes in a three-year period). The final nighttime model only included variables for presence or absence of lighting and whether the location was a high crash location (location had two or more nighttime crashes in a three-year period). The nighttime model results indicated that locations without lighting had twice as many crashes as locations with lighting.

It is not known why the influence of other low cost measures, such as advance stop line rumble strips or overhead beacons, could not be detected in the models. A number of intersections had a low number of crashes which may have masked the impact. Additionally some treatments are placed at high crash locations and even with a reduction, the location still has a higher than average number of crashes. As result, it is difficult to establish reduction with a cross-sectional model. Even though this study had hoped to address the removal of existing rural intersection lighting, the researchers were not able to discern enough clarity from the statistical evaluation to provide practical guidance.

As part of this project, a supplemental document was developed on lighting design guidelines which will be incorporated into the Statewide Urban Design and Specifications (SUDAS).

In addition to this, Appendix C contains additional information prepared related to improving lighting efficiency and the use of new equipment and methods for roadway illumination.

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APPENDIX A: IOWA DOT INTERSECTION LIGHTING WARRANTS

Iowa Department of Transportation
Office of Traffic & Safety

6B-1

TRAFFIC AND SAFETY MANUAL

Chapter 6 – Lighting
6B – Rural Intersections

Intersection Lighting Warrants

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

Intersection Lighting

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

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

Full Lighting

New or Reconstructed Intersections (Primary to Primary)

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

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

Existing intersection (Primary to Primary)

An intersection is a candidate for intersection lighting if:

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

Primary to Secondary

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

Destination Lighting

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

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

- The intersection is channelized, or

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

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

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

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

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

APPENDIX B: COUNTY AND CITY LIGHTING SURVEY

APPENDIX C: REPORT ON SYNTHESIS OF PRACTICE TO IMPROVE ENERGY EFFICIENCY IN STREET LIGHTING

Synthesis of Practice to Improve Energy Efficiency in Street Lighting

July 2007

Prepared For: **Iowa Energy Center**
Prepared By: Center for Transportation Research and Education at Iowa State University
Neal Hawkins and Shauna Hallmark

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Synthesis of Practice to Improve Energy Efficiency in Street Lighting

Center for Transportation Research and Education
Final: July 31st, 2007

1. BACKGROUND

According to the Illuminating Engineering Society of North America (WSU, 2007) the purpose of roadway lighting is to facilitate safe and efficient use of roadways after dark. The benefits of roadway lighting include:

- Reduction in nighttime accidents
- Facilitate traffic flow
- Promote nighttime business and industry
- Public good
- Public safety

However state and local agencies are facing shrinking resources and street lighting can consume a significant portion of an agency's budget. As an example, the City of Des Moines has approximately 25,000 street lights city-wide and pays $3,110,000 per year in energy and maintenance costs (City of Des Moines, 2007). This equates to roughly $8,500 per evening to provide roadway lighting. With an estimated population of 195,000 residents that's nearly $16 dollars per resident. On a larger scale, Mid American Energy estimates that the Des Moines metropolitan area has approximately 45,000 street lights on public roadways (Mid American Energy, 2007). Using the Des Moines ratio the metro-wide energy cost could exceed $5.5 million each year.

The estimated 68 million streetlights in the US use 300 billion KWh per year of electricity which costs agencies more than $18 billion. Generation of electricity to meet street lighting needs in the US contributes around 150 million tons of carbon dioxide (CO_2) annually (Echelon Corporation, 2007).

The main objective of this research was to identify best practices and leading technologies for energy efficient street lighting and street lighting practices. NYSERDA (2002) defines energy efficient street lighting as lighting that uses a balance of proper energy efficient technologies and design layout to meet performance, aesthetic and energy criteria required by pedestrians, motorists, community residents, municipalities, and utilities.

Efficient and effective use of lighting can provide energy and cost savings. Energy efficiency in lighting can be achieved by better use of existing lighting, control of when and where lights are used and minimizing use when not necessary, and use of technological advancements that are more energy efficient (IDA, 2000). Each is discussed in the following sections. A summary of case studies where communities have implemented innovative practices to reduce energy use in street lighting are also provided.

2. BETTER DESIGN OF EXISTING LIGHTING

In order for lighting to be effective it should provide the amount and type of lighting for the intended purpose. Lighting has two components, quality and quantity, which can affect energy efficiency. Quality affects the requirements for quantity so energy efficiency entails consideration of both. Quantity is the amount of light that reaches the intended surface (Harrington, 1995). Quality defined by Harrington (1995) is “referred to in terms of the color-rendering properties of a lighting system, the absence or presence of veiling reflections, the effectiveness of a luminaire lighting its intended target, and the amount of glare cause by a lighting system within its sphere of influence.”

The International Dark-Sky Association (IDA, 2000) provides several suggestions for better use of existing lighting:

- Lamps that give more lumens per watt are more efficient (lumen is the measure for amount of light and watt is the measure for electrical energy used)
- More light is not always better, over lighting can lead to glare and actually affect visibility
- Lamp and fixture maintenance is also important. Contamination from dust can reduce light output up to 50% in some cases

NYSERDA (2002) suggests several items that contribute to efficient use of existing lighting.

- High lamp efficacy and luminaire efficiency minimized energy
- Long Lamp life affects lamp replacement costs
- High lumen maintenance reduces lamp replacement costs since lamps operate longer before light levels fall below minimum standards
- Proper light distribution places light where desired
- Proper cutoff minimizes light trespass

Proper placement of luminaries and proper distribution of light flux from luminaries can improve light quality, reduce glare and light pollution, as well as reduce energy use. Proper pole height and spacing provides uniform light distribution and minimizes number of poles which results in reduced energy and maintenance costs

2.1 Lamp Technology

Different types of lamps exist and each has different applications and energy efficiencies. The three conventional lamp configurations used in regular street lighting applications include the following (NYSERDA (2002) :

- Mercury vapor was the most commonly used but is being replaced by other lamp technology. It is low-cost but the least efficient lamp type since a 400 W bulb is used which uses more energy than lower wattage bulbs, efficiency is around 40 to 60 lm/W. They also have longer lives, around 16,000 hours) but poor lumen maintenance. The CRI is about 50.

- Metal halide is more efficient (70 to 90 lm/W) than mercury vapor and has good color rendering (CRI 65+) resulting in lower costs. However the lamps are not as long lived as mercury vapor (some are 10,000 or less) and lumen maintenance is less < 60%. Metal halide with cutoff options is more energy efficient and has the highest quality option in terms of light control, light distribution, and color rendering and reduces light trespass than metal halide cobra head. Additionally, pulse-start metal halide are move energy efficient than standard metal halide.
- High pressure sodium (HPS) is the most energy efficient of the conventional technologies (80 to 100 lm/W including ballast power). It is long-lasting (rated around 24,000 hours) and maintains light output over time. Fewer poles are required so energy and maintenance costs are lower. The disadvantage is color rendering (CRI around 22).

It should be noted that, in addition to lamps, the ballasts also require power and reduce the efficacy of the lamp/ballast combination. On another note, the values above should be considered standard in recognition that each technology can have low, standard, and next generation efficiencies.

Different lamp configurations are compared in Table 1.

Table 1: Comparison of Street Lighting Systems (source: NYSERDA, 2002)

Table 1

Economic Analysis Comparing Several Street Lighting Systems

	Mercury Cobrahead	Metal Halide Cobrahead	Metal Halide Cutoff	Metal Halide Post Top	High Pressure Sodium Cutoff
Luminaire name	Cobrahead	Cobrahead	Cutoff	Decorative Post Top	Cutoff
Lamp type	400W MV	250W MH	250W MH	150W MH	250W HPS
Number of luminaires	12	12	12	24	11***
Installed cost	$36672	$36240	$38880	$35904	$35618
Annual energy cost	$2391	$1551	$1551	$1997	$1419
Annual operating cost*	$2536	$1677	$1677	$2509	$1601
Total annualized cost**	$6271	$5368	$5637	$6166	$5229

* Includes energy and maintenance costs

** Includes initial, energy and maintenance annualized over 20 years.

***Assumes a 10% reduction in the number of poles needed because of higher luminous efficacy of high pressure sodium. Color characteristics will be fair.

Lamp efficiency is measured in terms of lumens per watt where a lumen is a unit to measure amount of light and watt is a unit to measure amount of electrical energy used. More lumens per watt is more efficient.

IDA (1992) provided the following chart (Table 2) which shows lighting efficiency by lamp type

Table 2: Lamp Efficiency (Source: IDA, 1992)

Type of Lamp	**Lumens per watt**	**Average Lamp Life (hours)**
Incandescent	8 - 25	1000 - 2000
Mercury Vapor	13 - 48	12000 - 24000+
Metal Halide	60 - 100	10000 - 15000
High Pressure Sodium	45 - 110	12000 - 24000
Fluorescent	60 - 600	10000 - 24000
Low Pressure Sodium	80 - 180	10000 - 18000

Agencies are increasingly moving from mercury vapor to HPS. The City of Indianapolis is replacing 14,000 mercury vapor street lights with high-pressure sodium. They expect to reduce the city's electrical bill by more than $100,000 per year (AES, 2006). The City of Winston-Salem uses high pressure sodium for all new installations. They indicate that the lights are twice as energy efficiently as the mercury vapor and metal halide currently used by the city (WSDOT, 2007).

2.2 Ballasts and Nodes

The type of ballast can affect energy efficiency. Electronic ballasts have several advantages over traditional magnetic ballasts. Electronic ballasts can regulate the current/voltage that is delivered to the lamp which makes lamp ignition more efficient and can reduce the risk of lamp failure by as much as 30% as well as increase average the lamp lifetime by 25%. In general, electronic ballasts use 15% less energy than conventional magnetic ballasts. Additionally, electronic ballasts can also be dimmable so that light levels can be lowered during low use times without completely turning the lights off for security reasons. Dimming schemes can be programmed into the system and remotely controlled.

An electronic outdoor lighting node can be used with electronic ballasts and integrated into a street monitoring system. The node can identify ballast and lamp failures, measure and report energy consumption and lamp burning time, and report other information such as ballast temperature.

3. OPTIMIZE USE OF LIGHITNG

Although lighting may provide significant benefits, it is costly for agencies to maintain. Lighting may be more beneficial at certain times and under certain conditions than others. WSU (2007) suggests reducing the amount of light during hours when traffic volumes are low. Wilken et al (2001) reported that Finland is installing dynamic roadway lighting. Lighting can be adjusted to three levels depending on the amount of traffic and weather conditions. An analysis of lighting costs indicated that electric energy is two-thirds of the total cost of lighting. Wilken et al (2001) also reported that one-third of French towns decrease lighting at night and 8% of networks are dimmed at night. Lighting is decreased from 10 pm to 6 am.

A number of agencies in the US have also experimented with reducing to partial lighting or turning off lighting completely in some areas. The City of Des Moines, Iowa turned some street lighting off due to budget shortfalls in the city budget. However, lighting was later turned back on because of perceived safety concerns.

4. OTHER NON-TECHNOLOGY RELATED

Use better roadway markings and improved signage which may reduce amount of overhead lighting used (WSU, 2007).

5. EMERGING TECHNOLOGIES

A number of emerging technologies promise advances in energy efficiency for street lighting. Manufacturers continue to improve lamps, ballasts, and other lighting components. This section focuses on two specific technologies that hold promise in energy efficiency: LED’s and street light monitoring systems.

5.1 Light Emitting Diode (LED)

5.1.1 The Technology

LEDs are made up of two semiconductors, a P-type material with extra positively charged particles and an N-type material with negatively charged particles, which are bonded to a substrate to make up a “chip”. When voltage is applied, free electrons from the N-type area move to the P-type side and release light. The advantage of LEDs over conventional incandescent lamps is that they don’t have a filament to burn out so they last longer. They are also much more efficient. In the light production process for a conventional incandescent bulb, a significant amount of electricity goes towards generating heat rather than light resulting in wasted energy (Harris, 2007).

For street and parking lot lighting, a number of LED chips are fixed onto a coated printed circuit board enclosed in a durable housing. The LED fixture has no ballast or capacitors like conventional streetlights (Harris, 2007).

LEDs require low direct current voltage and low power to operation resulting in energy savings potential of 50 to 90% compared to conventional street lighting. They are projected to last up to 100,000 hours with less than 40% lumen depreciation after 100,000 hours of operation. Light produced by LEDs provides good color rendering (CRI 85 to 90). Additionally, they are small in size and offer the benefit of greater optical control so that the light can be directed to the locations intended. LED fixture efficiencies are 80 to 90% compared to conventional lights which have fixture efficiencies of 40 to 60%. Higher efficiencies indicate that more light reaches the source and light trespass is minimized. Additionally they do not require strike time and on/off cycling does not affect LED lifetime. They also dim rather than catastrophically fail. They can also be dimmed to provide different amounts of lighting (Tetra Tech, 2003)

One initial drawback to use of LEDs for regular lighting applications is the ability to produce light levels comparable to conventional lamps. In terms of lumens only, LEDs do not compare favorably with conventional street lighting. However, other factors, such as color temperature, color rendering, scoptopic and photopoic light sensitivity also influence how humans view brightness and quality of lighting. As a result, current applications have been for lower classification roadways and parking lots. The second major drawback is cost. Commercially available LED for street and parking lot lighting range from $500 to $995 per fixture. When compared with conventional lighting, such as high pressure sodium at $100 to $250 in 2003, the cost difference is prohibitive (Tetra Tech, 2003).

5.1.2 Manufacturers

Several manufacturers were identified who currently have LED street lighting commercially available.

LEDtronics has a cobra head M-250 and M-400 LED streetlight luminaries which are designed for traditional cobra head housing (see Figure 5-1). Both use 19 Watts and provide 1,200 lumens. The M-400 has 400 LEDs arranged in a light optimizing design. The diodes have a life of over 100,000 hours and can be used along minor roads, pedestrian walkways, and parking lots (LEDtronics, 2007). The M-400 is around $410 for the LED lamp and $725 for the complete assembly (http://news.thomasnet.com/fullstory/30663)

Figure 5-1: Cobra head M-250 and M-400 LED fixture from Ledtronics (image source Ledtronics, 2007)

They also offer a white LED streetlight shoebox fixture (shown in Figure 5-2) which uses 20 Watts of power, mounts on industry standard lamp post, and provides 720 lumens.

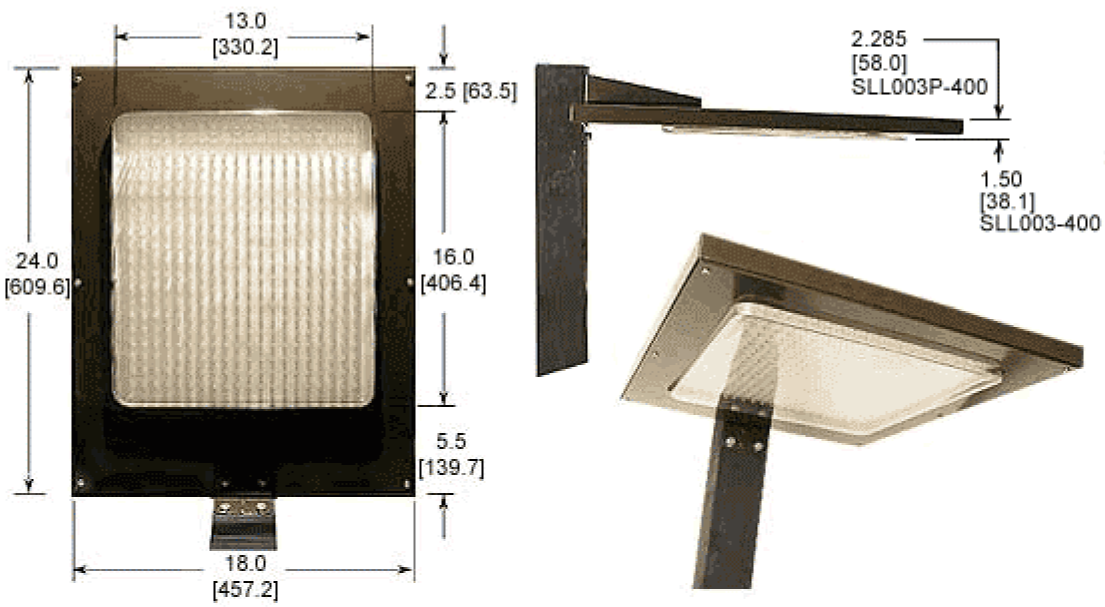

Figure 5-2: White LED Streetlight Shoebox Fixture from Ledtronics (image source Ledtronics, 2007)

LuxBright was also identified as a manufacturer but no internet address could be located for further information.

MoonCell has the Econo_lum LED street light which is an on-grid street luminaire that is suitable for use on secondary roadways, streets and parking lots. The Econo_lum uses 55 Watts and provides 900 lumens (see Figure 5-3). The reduction in glare from high-pressure sodium lights compared to the Econo_lum LED light is shown in Figure 5-4.

Figure 5-3: Econo_Lum Street Luminaries (image source: MoonCell, 2007)

Figure 5-4: Glare from 250W High Pressure Sodium Compared to the Econo_Lum (image source: MoonCell, 2007)

IQLED manufacturers several retrofit cobra head and shoebox streetlights for parking lot lighting, street lighting, ramp lighting, bridge lighting, underpass lighting, and residential lighting. The cobra head LED produces from 3,300 to 6,000 HPS lumens and the shoe box from 94,00 to 13,800 HPS lumens. The company estimates that the LED luminaries have four times the life of conventional luminaries (Osksolar, 2007).

IntenCity Lighting makes an LED to replace a conventional 100 watt high pressure sodium lamp. The system uses white LEDs. The IntenCity luminaire has a sharp cut-off and is International Dark Sky compliant. It produces approximately 1,850 lumens (IntenCity, 2007). The luminaire is shown in Figure 5-5.

Figure 5-5: IntenCity Luminaire (image source: IntenCity, 2007)

Dialight Lumidriver and the University of Manchester have recently teamed up to produce high output LED modules with light outputs that exceed 12,000 lumens. The modules will be designed to integrate thermal management, optical control, and high reliability drive electronics to maximize LED technology for architectural, industrial, and roadway lighting. The focus is high reliability and cost (Dialight_Lumidrives, 2007)

5.1.3 Applications

Several communities are in the process of pilot testing LED street lighting as described in the following cases studies.

Ann Arbor, MI

Ann Arbor began using LEDs to replace traffic signals and pedestrian crossing signals in 2000. Currently, the city is evaluating five different LED street lighting technologies in 21 existing street lights. Nine are cobra head fixtures on a residential street and several are replacement fixtures for globe lights (see Figure 5-6). The LED prototype was developed by Relume Technologies of Oxford, Michigan. The LED bulbs only require 40 watts of power to produce the same amount of emitted light as the standard 100-watt metal halide bulbs. The LED lighting can be directed downwards and can be dimmed. If the technology proves feasible, the city hopes to switch to LED street lighting and cut its $139 million street lighting budget by half (City of Ann Arbor, 2007).

Figure 5-6: Cobra head (left and center) and globe LED lights evaluated in Ann Arbor (Image source: City of Ann Arbor, 2007)

Ede, the Netherlands

Three LED street lights have been installed in the City of Ede, the Netherlands and a fourth is planned (see Figure 5-7). The streetlights were manufactured by Philips Lighting. The Equinox Luminaire combines a mix of 18 white and amber Luxeion/Luxeon III LEDs. The LEDS are expected to last 12 years. The initial cost is estimated at twice that of traditional street lamps but the reduced energy and maintenance costs are expected to be recuperated so that the system pays for itself.

Figure 5-7: Day and Night View of the Philips Equinox Street Lights in Ede (Image source: http://lighting.com/content.cfm?id=1380)

Lincoln, Nebraska

The City of Lincoln, Nebraska is testing an LED street light from Lumecon Co. The Lincoln Electric System will test the LED to evaluate the technology, energy savings, and light pollution reduction. An existing high pressure sodium streetlight is being retrofitted with the LED fixture. The city will use the test to determine whether it is economically feasible to use LED streetlights. They city has 27,550 streetlights and paid $745,000 in 2006 for energy only (maintenance costs add an additional $650,000 annually). They estimate the energy savings around 20% (Lincoln Journal Star, 2007).

Raleigh, NC

The city of Raleigh, NC teamed up with Cree, Inc and tested LED lights in a floor of a downtown parking deck. They estimated that the floor with LED lights used more than 40% less energy than for standard lights on other floors of the parking deck. They also felt the quality of light was better. They plan more testing of LED lighting in applications such as street lights, pedestrian and walkway lights, and architectural lighting. The city estimates that they could save about $80,000 per year in parking deck utility bills using LED. The city also spends more than $4 million to power streetlights and hopes that LED lighting will prove feasible for this application as well (WRAL, 2007). Figure 5-8 illustrates lighting in the parking deck before and after application.

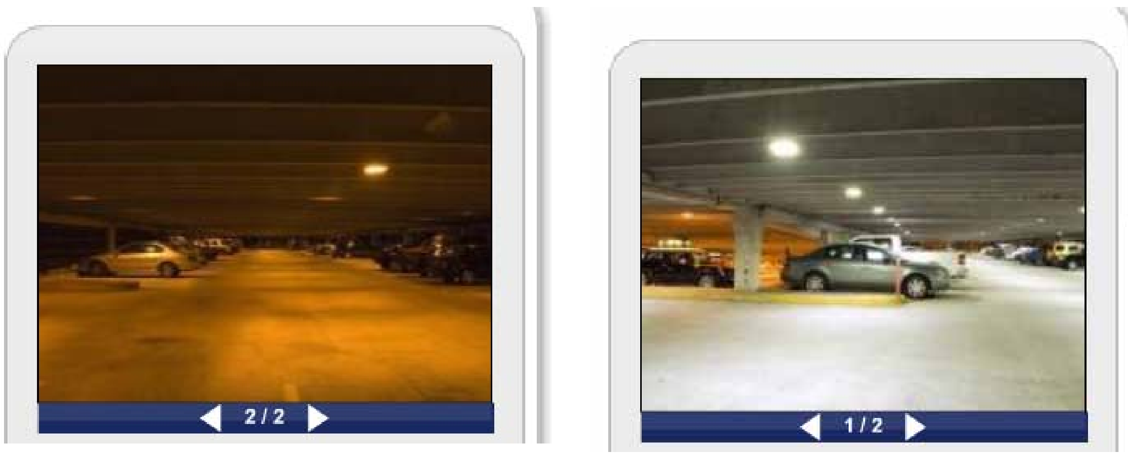

Figure 5-8: Application of LED Lighting in Parking Deck (before LED—left, After LED lighting was installed—right (Image source: WRAL, 2007)

Toronto, Ontario

LED streetlights have been installed in the Exhibition Place in Toronto, Ontario as part of a pilot project to demonstrate the energy and emission reduction potential of LED lighting. The city has approximately 160,000 streetlights and they estimate that if all street lights were converted to LED they would reduce electricity costs by $6 million as well as reducing greenhouse gases by 18,000 tons. The streetlights used in the demonstration contain 117 LEDs which produce the same intensity as a conventional streetlight. Twelve streetlights were installed along a street and four more were placed in a parking lot (see Figure 5-9). Leoteck Electronics produced the streetlights which cost around $1,200 each (Canadian dollars) (LEDS Magazine, 2007).

Figure 5-9: LED Streetlights in Toronto (image source: LEDS Magazine, 2007)

5.2 Street Light Monitoring Systems

Street light monitoring systems can be as simple as ones that use technology to monitor lamp failure and energy use to improve maintenance costs or be sophisticated enough to monitor current conditions and adjust light levels accordingly. Several communities have instituted street light monitoring systems.

Oslo, Norway

The City of Oslo is implementing an intelligent outdoor lighting system using technology from Echelon to remotely control and monitor street lights. The system is expected to reduce energy usage by 50% and minimize maintenance costs. The system will consist of 55,000 intelligent street light ballasts which communicate over existing power lines and interface with a street lighting control center for the city. The system technology can identify lamp failures remotely which reduces the amount of time a streetlight is out and reduces the maintenance costs of having to visually monitor lamp failures. The monitoring center logs and reports energy consumption and running hours. The system also collects data from traffic and weather sensors and calculates the available natural light from the sun and moon using an internal astronomical clock. This information is used by the system to estimate the amount of light needed and to automatically dim some or all streetlights based on local weather, time of year, and traffic density. Controlling light levels also extends the life of the lamp also resulting in reduced maintenance costs (Echelon, 2006a). Figures 5-10 and 5-11 illustrate the system.

Regular streetlights use mechanical ballasts which are either fully off or on and as a result stay at a constant light level through out the night regardless of the need. Intelligent lighting systems can be monitored and controlled from anywhere and adjust light based on current conditions including time of day, traffic flow and density, presence of pedestrians, ambient light, and weather conditions. The ability to reduce light levels reduces both energy use and extends lamp life. The systems use electronic ballasts which can communicate information such as energy use, estimate of remaining bulb life, and bulb failure or damage (Echelon, 2006b).

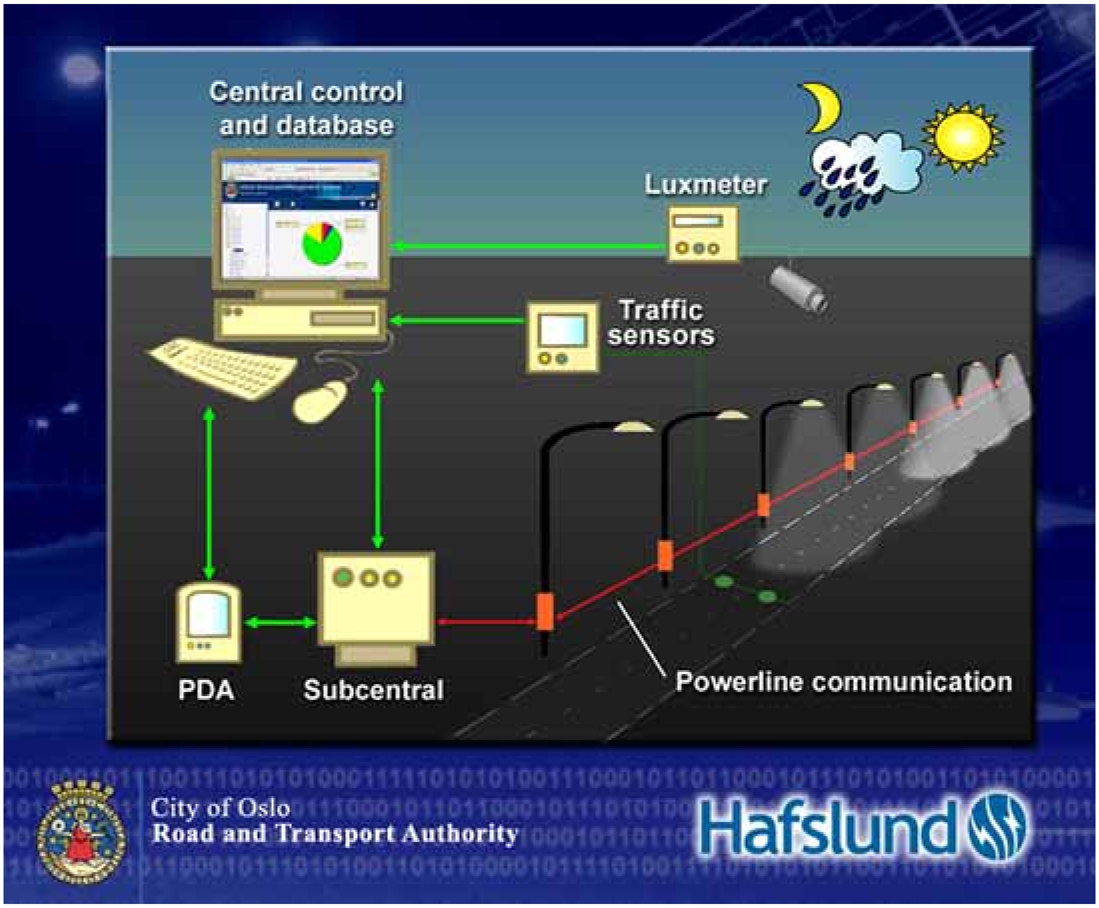

Figure 5-10: Intelligent Street Lighting System (image source: Echelon, 2006a)

Figure 5-11: City of Oslo Streetlight Management System image source: Echelon, 2006a)

The Oslo system is part of the E-Street Initiative, which is part of EU's Intelligent Energy Europe program, an Intelligent Road and Street Lighting Panel made up of companies experienced in intelligent, networked streetlight systems.

<u>Brittany, France</u>

The city of Brittany, France was interested in reducing electricity costs and CO_2 emissions while reducing lamp failures and downtime for security reasons. They employed a streetlight monitoring and management system. An initial evaluation included installing 44 streetlights and one control cabinet with an electronic dimmable ballast and lighting node, which can communicate information back to the network. The supply cabinet has an internet server which functions as the streetlight controller. The system uses an astronomical clock to determine when the lights come on and off and dim the ballast at night when less light is needed. They monitored the system over 12 months and found electricity use reduced by 46%, carbon dioxide emissions were reduced by 70 tons per year, and average lamp downtime was reduced by 90%. The city plans to expand the system to 3,100 more luminaries.

North-German City of Vechta

The North-German city of Vechta along with more than 50 European cities are using a Philips CosmoPolis street lighting system. The system uses 50% less energy than mercury vapor and provides a high quality white light. They technology can also be integrated with lighting controls which can adjust light level at different times. The city upgraded from mercury vapor lamps to the Philips CosmoPolis system and have found an energy savings of 50% per lamp with an estimated reduction of about 100kg per light per year of carbon dioxide (Philips, 2006). The new technology is shown in comparison to the old mercury vapor system in Figure 5-12.

Figure 5-12: Comparison of Mercury Vapor to Philips CosmoPolis Lighting (image source: Philips, 2006)

6. OTHER CASE STUDIES FOR ENERGY EFFICIENT STREET LIGHTING

Several other communities were identified who had incorporated other measures for energy efficient street lighting.

Ames, Iowa

Ames, Iowa has a street lighting improvement program where the city will install a light (called the Hubbel Skycap) on neighborhood streets, alley lights, or security lights at no cost. The skycap redirects light sideward and upward light down to reduce light pollution and to focus light to the source (City of Ames, 2007). The system is shown in Figure 6-1.

Figure 6-1: City of Ames Iowa Lighting Improvement Program (image source: City of Ames, 2007)

Wigan Borough, UK

Wigan Borough in the UK obtains all electricity for street lighting from wind turbines. They also use electronic control gear which is 10% more energy efficient that standard control gear (Wiggan Council, 2007).

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