GEORGIA DOT RESEARCH PROJECT 12-01
FINAL REPORT

EVALUATION OF CURRENT PRACTICE FOR ILLUMINATION AT ROUNDABOUTS: SAFETY AND ILLUMINATION OF ROUNDABOUTS (PHASE I)

Georgia Department of Transportation

OFFICE OF RESEARCH
15 KENNEDY DRIVE
FOREST PARK, GA 30297-2534

TECHNICAL REPORT STANDARD TITLE PAGE

1.Report No.: FHWA-GA-15-12-01	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Evaluation of Current Practice for Illumination at Roundabouts: Safety and Illumination of Roundabouts (Phase I)		5. Report Date: March 2014; Revised July 2015, March 2016 6. Performing Organization Code: Project No. 2006T40
7. Author(s): Michael Rodgers, Ph.D., Michael Hunter, Ph.D., Alexander Samoylov, Ph.D., Franklin Gbologah, Simon Berrebi		8. Performing Organ. Report No.: 1201
9. Performing Organization Name and Address: School of Civil and Environmental Engineering Georgia Institute of Technology 790 Atlantic Drive Atlanta, GA 30332-0355		10. Work Unit No.: 11. Contract or Grant No.: 0010499
12. Sponsoring Agency Name and Address: Georgia Department of Transportation Office of Research 15 Kennedy Drive Forest Park, GA 30297-2534		13. Type of Report and Period Covered: Final, July 2012-Dec 2013 14. Sponsoring Agency Code:
15. Supplementary Notes: Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		
16. Abstract: This report is for the first phase of a two-phase research program to develop recommended practices for GDOT for lighting rural roundabouts. Phase I of the study was designed to improve our understanding of the relationship between roundabout illumination and safety, particularly in rural areas. Such information is essential to developing a sound basis for determining if a rural roundabout should, or should not, be illuminated to the current Illuminating Engineering Society (IES) standard and, if not, whether safety objectives can be met with either unlit roundabouts or roundabouts illuminated at reduced levels. The report provides a summary of relevant literature; international practices for rural roundabout illumination, a safety analysis of nighttime roundabout crashes using data from Minnesota and Georgia and provides preliminary results regarding the cost effectiveness of unlit or partially lit roundabouts as rural safety treatments.		
17. Key Words: Roundabout, Illumination, International Standards, Roadway Safety, Roadway Design		18. Distribution Statement:

19. Security Classification (of this report): Unclassified	20. Security Classification (of this page): Unclassified	21. Number of Pages: 65	22. Price:

Form DOT 1700.7 (8-69)

GDOT Research Project No. RP 12-01

Evaluation of Current Practice for Illumination at Roundabouts

Final Report

SAFETY AND ILLUMINATION OF ROUNDABOUTS-PHASE I

By:

Michael O. Rodgers, Ph.D., Principal Investigator
Michael Hunter, Ph.D., co-Principal Investigator
Alexander Samoylov, Ph.D., co-Principal Investigator
Franklin Gbologah, Graduate Research Assistant
Simon Berrebi, Graduate Research Assistant
School of Civil and Environmental Engineering, Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

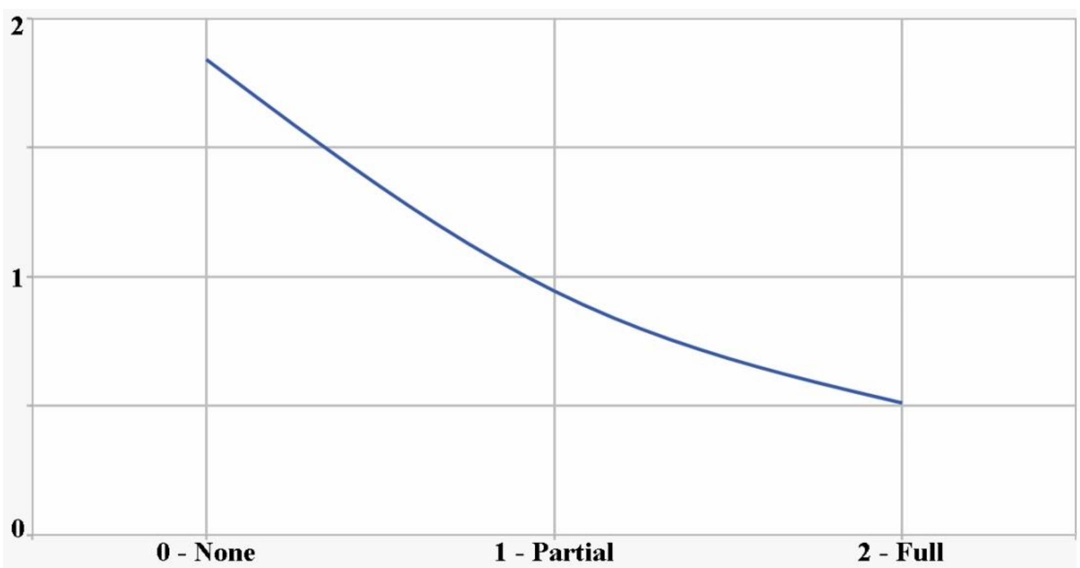
Revised March 2016

Table of Contents

EXECUTIVE SUMMARY

The major goal of Phase I of this project was to determine the feasibility of using a reduced illumination roundabout as a safety treatment for either uncontrolled or stop-controlled rural intersections. Based on the results of this study, the answer would appear to be a qualified "yes". The review of international practices has demonstrated that a majority of countries, including many highly developed ones (e.g. France), have policies to not systematically illuminate rural roundabouts.

Previous studies have suggested that, for unlit stop-controlled rural intersections, installation of standard lighting and conversion to an unlit roundabout have comparable effects on overall intersection crash rates with the roundabout conversion having a greater favorable impact on crash severity. Likewise, the results of the analysis of Minnesota crash data undertaken during this study indicates that partial illumination achieves significant benefits compared to leaving the roundabout unlit. These results are summarized below:



Effect of Different Illumination Levels on Mean Total Nighttime Crash Rates at Roundabouts **(Volume weighted crashes per million vehicles, Minnesota crash data)**

Taken together, it appears that under most conditions, a partially illuminated roundabout will have equal or better safety performance to a comparable fully-illuminated stop-controlled intersection. Likewise, analysis of benefit to cost would indicate that it is difficult to justify the cost of installation of full roundabout illumination for low volume (e.g. ADT<5000) intersections. That being said, the current study suffers from multiple limitations. The most serious of which is the lack of reliable data on intersection illumination in general and for roundabouts in particular.

With the rapid development of roundabouts both in Georgia and across the nation, there is a strong need for continued study on the impact of illumination on intersection safety.

INTRODUCTION

Roundabout intersections can be found in many countries around the world. According to the Insurance Institute for Highway Safety (IIHS), roundabouts are safer than typical 4-leg intersections and typically experience 40% fewer vehicle collisions, 80% fewer injuries and 90% fewer serious injuries and fatalities than their conventional counterparts in both urban and rural settings (1a). Because of their safety and operational benefits, there are ongoing national and international efforts in planning and implementing roundabouts. Internationally, many European nations have roundabouts including the United Kingdom that has an estimated 25,000 roundabouts and France with about 30,000. Currently, at least 21 states in the United States are actively pursuing implementation of roundabouts (3a) with a number of others in various stages of planning.

The wider use of this potentially effective safety measure can be constrained, however, by associated costs. Both current guidance and practice for rural stop-controlled and uncontrolled intersections is to keep the intersections unlit. In contrast, U.S. National guidelines for roundabout design recommend, but do not explicitly require, including provisions for lighting roundabouts in all environments, including rural areas. This recommendation can have significant cost implications, both in terms of construction costs (including the potential costs of bringing power to the intersection) and long term maintenance and operating costs. In rural areas where the costs of providing lighting are proportionately higher, these cost implications can preclude the installation of a roundabout that is otherwise safer than a typical 4-leg intersection.

Overview of Project

The research reported here is for the first phase of a two-phase research program to aid GDOT in developing recommended practices for lighting rural roundabouts. Phase I of the study was designed to improve our understanding of the relationship between roundabout illumination and safety, particularly in rural areas. Such information is essential to developing a sound basis for determining if a rural roundabout should, or should not, be illuminated to the current Illuminating Engineering Society (IES) standard and, if not, whether safety objectives can be met with either unlit roundabouts or roundabouts illuminated at reduced levels. Effectively matching roundabout illumination design to actual safety needs will allow GDOT to maximize its ability to deploy this important operational and safety treatment in rural areas.

Roundabout Lighting

In the United States, the primary technical document related to roundabout illumination is the Illuminating Engineering Society (IES) publication DG-19-08 (2a). According to this guide, illumination of roundabouts serves two primary purposes:

1. "It makes the roundabout visible from the distance, thus improving the roundabout's perception to approaching users.
2. It makes key conflict areas more visible, thus improving users' perception of the layout of the intersection and their perception of one another as they use the roundabout."

However, the IES document provides no specific recommendations as to whether roundabouts should be illuminated. Lighting recommendations for roundabouts in the United States can be found in NCHRP Report 672 *Roundabouts: An Information Guide, second edition* (6a) that has superseded the earlier Federal Highway Administration Publication No. FHWA-RD-00-067 (3a). In short, NCHRP Report 672 recommends illumination for all roundabouts, including those in rural areas, but it is not mandatory and no specific federal guidelines have been issued. Recommended lighting levels range from 8 lux to 34 lux based on type of the intersection (4a) and is based largely on IES DG-19-08 recommendations. NCHRP 672 also recommends transition and perimeter lighting for roundabouts. Only limited guidance is provided for countermeasures if it is not possible to provide lighting.

In Georgia, Section 8.2.4 of Georgia Department of Transportation Design Policy Manual (5a) provides guidance for roundabout design. It states that: "*GDOT adopts the recommended illumination levels in Table 1 of the Illuminating Engineering Society DG-19-08, Design Guide for Roundabout Lighting (IES DG-19-08) (2a) as a standard for the design of lighting systems for roundabouts. If it is not practical to provide the illumination levels defined by this table, then the decision to select a value or retain an existing condition that does not meet these criteria shall require a comprehensive study by the engineer and the prior approval of a Design Variance from the GDOT Chief Engineer.".* This research is designed to: 1) assist in the development of such evaluation studies; 2) provide guidance to the overall design variance process in regard to lighting of rural roundabouts and 3) develop recommendations necessary to update the GDOT policy on illumination of roundabouts especially in regards to conditions were lower illumination levels, or no illumination, may be appropriate.

Project Objectives

This project *Evaluation of Current Practice for the Illumination of Roundabouts: Safety and the Illumination of Roundabouts* was designed to be performed in two phases to meet the six major objectives as shown in the bulleted list below. This report summarizes the findings of Phase I.

- Literature review of US and international research on the linkage between lighting and crash experience at roundabouts and other intersections (Phase I)
- Evaluate lighting guidance for roundabouts throughout North America including documentation of the Illuminating Engineering Society of North America(IESNA) and American Association of State Highway and Transportation Officials (AASHTO) lighting recommendations (Phase I)
- Evaluation of lighting practices at rural roundabouts internationally, including a review of treatments used when lighting is not provided (e.g., signing) (Phase I)
- Survey of North American agencies to determine their current practices and policies (Phase I (the most active agencies); Phase II (comprehensive))
- Provide synthesis of lighting techniques and technologies that may be applicable for rural areas (largely Phase II)
- Provide recommendations for Georgia practice. (Phase I (feasibility for use of reduced lighting); Phase II (recommendations for use of reduced lighting))

This final report consolidates the technical memoranda that address the Phase I objectives and provides recommendations regarding the feasibility of using reduced lighting for roundabouts in Georgia.

PREVIOUS RESEARCH

Illumination and Intersection Safety

In a study of 12 rural Minnesota intersections, Preston and Schoenecker (*1*) used a before-and-after methodology to evaluate the impact of illumination. They reported findings of 40 percent reduction in nighttime crash rates and 20 percent reduction in crash severity. These reductions were statistically significant at 5% and 10% level respectively. Similarly, Green et al. (*2*) investigated the effect of roadway lighting on driver safety using 9 intersections from Kentucky. The study's results showed a 45 percent reduction in nighttime crash frequency after installing lights. Isebrands et al. (*3*) used a Poisson regression model to evaluate the change in expected crash frequencies after installation of lighting at 33 rural intersections in Minnesota. Using a statistical significance threshold of 10%, the results showed a reduction in nighttime crash rate of 37 percent after lighting was installed.

It is often difficult to identify intersection locations with enough samples of before-and-after crash data where illumination was the only safety treatment applied during a study period. In such instances a cross-sectional study comparing intersections with lighting to those without it have been used in most previous studies. In their previously mentioned study, Preston and Schoenecker (*1*) also performed a separate cross-sectional study of over 3400 intersections in Minnesota. The findings from this analysis indicated about 25 percent reduction in nighttime crash rate and 8 percent reduction in injury severity. Bruneau and Morin (*4*) evaluated the safety impact of lighting by comparing 376 unlit and lit rural and near-urban intersections in Quebec, Canada. The lit intersections were made of those with both standard and non-standard lighting. The results which were statistically significant at the 5% level showed that rural intersection lighting can reduce night accident rate by 29 percent for non-standard lighting and by 39 percent for standard lighting. More recently, Hallmark et al. (*5*) as discussed by Isebrands et al. (*3*) conducted a cross-sectional study of 223 rural intersections using a hierarchical Bayesian model with a Poisson distribution. The authors found that the expected mean of nighttime accidents was 2.01 times higher for unlit intersections than for illuminated intersections (i.e. a 50% reduction in crash frequency). In a separate study, Isebrands et al (*6*) evaluated 3622 rural illuminated and unilluminated intersections in Minnesota. The results showed that the expected ratio of nighttime to total crashes was 7 percent higher for unilluminated intersections than for illuminated intersections.

All the above mentioned studies have been undertaken with either before-and-after approach or a cross-sectional approach. However, there are a number of issues with both before-and-after and cross-sectional studies that can affect the validity of their results. First, a before-and-after study can give biased results due to a phenomenon called regression to the mean (*7, 8*). Usually, due to sample size issues, the before and after samples cover just a few years on either side of light installation and the mean of such datasets can be easily affected by temporary events. On the other hand if the duration of the samples covers longer periods, the study can be influence by long-term trends which may no longer be true. Furthermore, as pointed out by Donnell et al. (*9*), a before-and-after study can also be faced with selection bias or endogeneity bias as referred to in other studies (*7*). This bias arises due to the fact that a traffic safety countermeasure such as lighting is normally applied to a site with recent or proportionately higher nighttime number of crashes. However, warrants for lighting are usually applied in conjunction with other operational considerations so these influences may also be impacting the results. The issues of regression to the mean can be successfully addressed by cross-sectional studies. However, a cross-sectional study also faces a selection bias issue and it is difficult to categorically make a case for causation (*9*).

These validity issues have led researchers of other previous studies to adopt other approaches to evaluate the impact of intersection lighting. Elvik (*10*) used a meta-analysis technique to analyze 37 studies from 11 countries. His results showed a 65 percent reduction in nighttime fatal crashes, 30 percent reduction in nighttime injury accidents, and a 15 percent reduction in nighttime property-damage-only accidents. Next, Wanvik (*7*) used the odds ratio estimator effect and the ratio of odds ratio estimator effect to evaluate the safety impact of lighting on nighttime accidents in Holland. His results showed that lighting can reduce the frequency of nighttime crashes by 50 percent on all roads and by 54 percent on rural roads. Also, the results show that adverse weather reduces the benefit of lighting on roads; 26 percent during precipitation with snow and 22 percent when snow or ice covers the surface. He also measured the risk of injury accidents under various conditions relative to the average accident likelihood; on lit rural roads the risk is 17 percent of the average risk while on unlit roads the risk is 145 percent; during rainy conditions the risk on lit roads is 53 percent while on unlit roads it is 192 percent.

Donnell et al. (*9*) developed a comprehensive framework for evaluating the safety impact of intersection lighting using a negative binomial model. Their results indicated a much lower reduction in nighttime crash frequency, 7.6 percent, than what has been reported in previous published studies. However, when the authors analyzed the data without controlling for other safety influencing features a reduction of 28 percent in night crash frequency was observed. This is similar to previous studies and an indication that published benefits in previous studies which did not control for safety contributing features may have been over estimated. Also, Hauer (*11*) and Persaud and Lyon (*12*) advocate the use of the empirical Bayes method as technique to address the issues of selection bias and regression to the mean. Bo et al (*13*) also developed a Full Bayesian Empirical approach that addresses issues of selection bias as well as the empirical Bayes method.

TECHNICAL MEMORANDA

In addition to the literature review outlined above, the phase I project objectives have been addressed through the production of two technical memoranda that are reproduced as appendices to this report. The technical memoranda provide a summary report on the specific analyses or studies carried out in line with the six main project objectives. Each technical memorandum provides a brief description of the objective, methods used, and finding/significance of each analysis.

Each of the technical memoranda provided with this final report is briefly described below.

A Review of International Roundabout Lighting Practices, Policies and Standards

The first memorandum presents a report of a comprehensive evaluation of international roundabout lighting practices in 45 countries. The focus of the evaluation was to identify the available policies and standards operating across the world. In all, 22 European countries, 12 Asian countries, 2 African countries, and 9 from the Americas (outside of the United States) were studied. As mentioned earlier, U.S. practice among the most active state programs (including Georgia), and supported by NCHRP and FHWA recommendations, is to illuminate roundabouts unless a specific decision is made not to do so (i.e. default to illumination). As current Georgia design policy generally requires systematic lighting of all roundabouts even in rural areas where other intersection types such as stop-controlled can be left unlit, the international practices regarding the illumination of roundabouts in rural areas where specifically examined.

Out of the countries examined, in contrast with the US, about 59 percent do not require systematic lighting of roundabouts in rural area. In these areas, the decision to light roundabouts is largely left to the local authorities to decide on a case-by-case basis. The existence of pedestrian facilities or illumination on the approaches tends to increase the likelihood of illumination of the roundabout. Approximately 15 percent of the countries require systematic lighting of roundabouts in rural areas while for the remaining 25 percent it was not possible to make a determination based on the available data. This technical memorandum is provided as Appendix A.

Estimation of the Safety Impact of Illumination at Roundabouts

This memorandum presents the findings of a safety analysis carried out to evaluate the impact of illumination on safety at roundabouts. The findings are based on roadway lighting data and roundabout crash data from Minnesota located in the Highway Safety Information System (HSIS) database. The data covers intersections, including roundabouts, between state routes or between state routes and U.S. highways. The analysis was performed for two types of lighting variables; first is a binary variable representing unlighted and lighted roundabouts, and second is a multi-level illumination level as defined in the HSIS files.

The study examined the variation of the illumination effect on both total nighttime crash rates and different injury severity crash rates. The use of the Minnesota crash data was necessitated in part because Georgia does not have extensive crash data on roundabouts. But even more importantly, the Minnesota HSIS data is the only such database currently available with intersection illumination data. The findings from this analysis identified estimated crash reduction factors for various types of illumination. The Technical Memorandum on the results on the safety analysis is provided as Appendix B.

PROJECT SUMMARY AND RECOMMENDATIONS

The major goal of Phase I of this project was to determine the feasibility of using a reduced illumination roundabout as a safety treatment for either uncontrolled or stop-controlled rural intersections. Based on the results of this study, the answer would appear to be a qualified "yes". The review of international practices has demonstrated that a majority of countries, including many highly developed ones (e.g. France), have policies to not systematically illuminate rural roundabouts.

Previous studies have suggested that, for unlit stop-controlled rural intersections, installation of standard lighting and conversion to an unlit roundabout have comparable effects on overall intersection crash rates with the roundabout conversion having a greater favorable impact on crash severity. Likewise, the results of the analysis of the Minnesota crash data indicates that partial illumination achieves significant benefits compared to leaving the roundabout unlit. Taken together, it appears that under most conditions, a partially illuminated roundabout will have equal or better safety performance to a comparable fully-illuminated stop-controlled intersection. Likewise, analysis of benefit to cost ratios would indicate that it is difficult to justify the cost of installation of full roundabout illumination for low volume (e.g. ADT<5000) intersections.

That being said, the current study suffers from multiple limitations. The most serious of which is the lack of reliable data on intersection illumination in general and for roundabouts in particular. Only a single database has multi-level data on intersection illumination (Minnesota) and these data are limited to only cursory classification. We could identify no source or reliable information of ambient illumination levels in the absence of purpose-built street lighting.

With the rapid development of roundabouts both in Georgia and across the nation, there is a strong need for continued study on the impact of illumination on intersection safety. If we are to develop reliable guidance, it is necessary for a full empirical Bayesian study of the impact of both illumination and roundabouts in rural areas. Since there a plans to convert a number of intersections of various types (uncontrolled, stop or yield controlled and signalized) to roundabouts over the coming years there is a great opportunity for conducting such a study in the near term.

Over the longer term, there is a strong need to improve both asset management and crash reporting systems to facilitate these important safety studies. There is currently no systematic way of identifying if a particular roadway segment in Georgia is illuminated and, if it is, the type and nature of the lighting devices. Georgia, and other states, need to develop and implement more complete and accurate asset management systems and roadway lighting needs to be included in such a system. Ideally this roadway lighting management system would be electronically linked to road segment and intersection inventory and crash data. At a minimum, such a system should be able to identify if the segment is illuminated, how it is illuminated, the installation date, luminaire type, mounting height, and, if available, the illuminance level for intersections. Until such a system can be put in place, in-situ intersections illumination levels needs to be collected at a sample of intersections that can be used to evaluate long term safety impacts.

REFERENCES

1a. Insurance Institute for Highway Safety. *Roundabouts Status Report.* s.l. : IIHS, May 13, 2000, Vol.35, No.5.

2a. Illuminating Engineering Society. *Design Guide for Roundabout Lighting.* IES DG-19-08.

3a. U.S. Department of Transportation, Federal Highway Administration. Roundabouts: An Information Guide. June 2000, FHWA-RD-00-067.

4a. Paul Lutkevich, Parsons Brinckerhoff Quade & Douglas, Inc. An Examination and Recommendation for Current Practices in Roundabout Lighting. July, 2004.

5a. Georgia Department of Transportation. *Design Policy Manual.* Chapter 8. Version 2.0.

6a. Transportation Research Board, National Cooperative Highway Research Program**.** *Roundabouts: An information Guide.* s.l. : Transportation Research Board. NCHRP Report 672, Second Edition.

1. Preston, H. and T. Schoenecker. Safety Impacts of Street Lighting at Isolated Rural Intersections. 1999-17, 1999. Minnesota Department of Transportation

2. Green, W.H., K.R. Agent, M.L. Barret, and J.G. Pigman. Roadway Lighting and Driver Safety. KTC-03-12/SPR247-02-IF, 2003.

3. Isebrands, H., S. Hallmark, W. Li, T. McDonald, R. Storm, and H. Preston, Roadway Lighting Shows Safety Benefits at Rural Intersections. In *Journal of Transportation Engineering*, *No*. *136*(11), 2010, p.p 949-955.

4. Bruneau, J.F. and D. Morin, Standard and Nonstandard Roadway Lighting Compared with Darkness at Rural Intersections. In, 2005, p.p 116-122.

5. Hallmark, S., N. Hawkins, S. Omar, Z. Hans, C. Kinsenbaw, M. Orellano, and H. Isebrands. Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections. 2008. Center for Transportation and Education, Iowa State University

6. Isebrands, H., S. Hallmark, Z. Hans, T. McDonald, H. Preston, and R. Storm. Safety Impacts of Street Lighting at Isolated Rural Intersection - Part 2. MN/RC-2006-35, 2006. M.D.o. Transportation,

7. Per Ole, W., Effects of Road Lighting: An Analysis Based on Dutch Accident Statistics 1987–2006. In *Accident Analysis and Prevention*, *No*. *41*, 2009, p.p 123-128.

8. Retting, R., B. Persaud, P. Garder, and D. Lord, Crash and Injury Reduction Following Installation of Roundabouts in the United States. In *American Journal of Public Health*, *No*. *91*(4), 2001, p.p 628 - 631.

9. Donnell, E.T., R.J. Porter, and V.N. Shankar, A Framework for Estimating the Safety Effects of Roadway Lighting at Intersections. In *SAFETY SCIENCE*, *No*. *48*(10), 2010, p.p 1436-1444.

10. Elvik, R., Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure. In *Transportation Research Record*, *No*. (1485), 1995, p.p 112-123.

11. Hauer, E., *Observational before--after Studies in Road Safety : Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety / by Ezra Hauer*. 1997, Oxford, OX, U.K. ; Tarrytown, N.Y., U.S.A. : Pergamon, 1997. 1st ed.

12. Persaud, B. and C. Lyon, Empirical Bayes before–after Safety Studies: Lessons Learned from Two Decades of Experience and Future Directions. In *Accident Analysis & Prevention*, *No*. *39*(3), 2007, p.p 546-555.

13. Bo, L., P. Bhagwant, L. Craig, and B. Ravi, Validation of a Full Bayes Methodology for Observational before-after Road Safety Studies and Application to Evaluation of Rural Signal Conversions. In *Accident Analysis & Prevention*, *No*. *41*, 2009, p.p 574-580.

14. Lenters, M. Safety Auditing of Roundabouts. *National Roundabout Conference*. 2005. Colorado.

15. Hydén, C. and A. Várhelyi, The Effects on Safety, Time Consumption and Environment of Large Scale Use of Roundabouts in an Urban Area: A Case Study. In *Accident Analysis & Prevention*, *No*. *32*(1), 2000, p.p 11-23.

16. Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter, *Nchrp Web-Only Document 94 - Appendixes to Nchrp 572: Roundabouts in the United States.* 2007b: Transportation Research Board, Washington, DC.

Insert Tab

APPENDIX A: A Review of International Roundabout Lighting Practices, Policies and Standards

GDOT Research Project No. RP 12-01

Evaluation of Current Practice for Illumination at Roundabouts

Technical Memorandum

A Review of International Roundabout Lighting Practices, Policies and Standards

By:

Michael O. Rodgers, Ph.D., Principal Investigator
Michael Hunter, Ph.D., co-Principal Investigator
Alexander Samoylov, Ph.D., co-Principal Investigator
Franklin Gbologah, Graduate Research Assistant
Simon Berrebi, Graduate Research Assistant
School of Civil and Environmental Engineering, Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

Revised March 2016

Table of Contents

INTRODUCTION

Illumination is of great interest to the modern roundabout, perhaps more than any other type of highway intersection because of its unique design features such as raised splitter islands with flared ends at the exit/entry points to the circular path and a raised central island with a radius wide enough to cause the travel path from the approaches to be deflected into a circular path. These features are essential to achieving reduced speeds and eliminating, or significantly reducing, fatal and severe crashes at roundabouts. However, during nighttime driving these features need to be visible otherwise they can become potential sources of hazard for drivers. Also, because of the deflection of the travel path into the circulating roadway, a vehicle's headlight beam is often more tangential to the circular path and does not illuminate objects and/or conflicting movements from the left of driver or the vehicle. This implies that drivers will often be looking into darkness as they navigate the roundabout (*1*). Consequently, the overall safety of a roundabout at night can be enhanced with provision of purpose-built street lighting.

Consequently, the national guidelines (*1*, *2*) for roundabout illumination in the U.S. recommend systematic illumination of roundabouts in both rural and urban areas. However, highway illumination is expensive and in most nations, including the U.S., conventional at-grade rural intersections can be kept unlit. Since widespread roundabout programs by state highway agencies in the U.S. are relatively new there is a knowledge gap in terms of whether rural roundabouts should be treated differently than other conventional at-grade rural intersections. As more states adopt widespread roundabout programs state transportation agencies and local governments would have to decide whether to adopt the recommended systematic illumination, with its implied costs, in all areas or whether to make discriminations based on location. Therefore, a review of the standards and policies for illumination of roundabouts in other nations, especially in nations with comparable transportation systems, would be beneficial to states and local governments who are actively building their roundabout programs.

As part of a research effort sponsored by the Georgia Department of Transportation (GDOT), this report presents the findings of a review of international roundabout lighting practices, policies and standards. The countries evaluated include 22 European Countries, 12 Asian Countries, 2 African Countries, and 9 Countries in the Americas outside of the U.S. The findings presented in this report are first presented for Europe, followed by Asia, Americas, and Africa. The report concludes with a summary of systematic lighting practices at rural roundabouts among the evaluated countries

EUROPE

Most European countries have adopted the European Union standard, European Norm EN 13201 (hereafter called EN), wholly or with some modification as the basis for illuminating their roundabouts. The EN which is composed of four parts has been approved by the European

Committee for Standardization since 2003 (*3*) and it includes both warrants and standard for roadway and intersection illumination.

The first part of the EN, *CEN/TR 13201-1 Road Lighting Part 1: Selection of Lighting Classes (4)* outlines the warrants for illumination. It specifies warranting conditions which are based on vehicle speed, traffic type, traffic volume, and road environment. Table 1 describes these warrants and their lighting situation sets. The EN prescribes appropriate lighting classes for illuminating mainly for situation sets A and B. The prescription of appropriate lighting classes for illuminating for situation sets C, D, and E is generally left to the determination of the various national road agencies. For all the prescribed lighting classes, the EN requires that average luminance should be used as the design criterion for all road segments and average illuminance should only be used in cases where cases where viewing distances are short (such as roundabouts and other conventional intersections) and other factors prevent the use of the luminance criterion *(4)*. Also all uniformity standards are based on the luminance criterion.

Table 1 Grouping of lighting situations (adapted from CEN/TR 13201-1)

Typical speed of main user km/h	User types in the same relevant area			Sets of lighting situations
	Main user	Other allowed user	Excluded user	
> 60	Motorized traffic		Slow moving vehicles, cyclists, and pedestrians	A1
		Slow moving vehicles	Cyclists and pedestrians	A2
		Slow moving vehicles, cyclists, and pedestrians		A3
>30 and ≤ 60	Motorized traffic Slow moving vehicles	Cyclists Pedestrians		B1
	Motorized traffic Slow moving vehicles Cyclists	Pedestrians		B2
>5 and ≤ 30	Cyclists	Pedestrians	Motorized traffic Slow moving vehicles	C1
	Motorized traffic Pedestrians		Slow moving vehicles Cyclists	D1
		Slow moving vehicles Cyclists		D2
	Motorized traffic	Slow moving vehicles Pedestrians		D3
Walking speed	Motorized traffic Slow moving vehicles Cyclists Pedestrians			D4
	Pedestrians		Motorized traffic Slow moving vehicles Cyclists	E1
		Motorized traffic Slow moving vehicles Cyclists		E2

There are three main lighting classes prescribed for roads in the EN; ME/MEW, CE, and S (*3*). Lighting class ME/MEW is for roads with medium to high speed limits (30 km/h and above). The "W" signifies an overwhelmingly wet surface. Lighting class CE is for road within conflict areas such as commercial avenues, complicated cross-roads, roundabouts, conventional intersections, congestion prone places, etc. Lighting class S is for roads mainly used for pedestrians and cyclists.

For each lighting class, EN provides other sub-group classes based on different factors. For example, the ME/MEW class has other sub-groups based on the weather, carriageway separation, intersection density, and traffic volume. Table 2 shows the recommended range of lighting class for situation set A3. For a roundabout with major road falling into situation set A3, Table 2 gives a three sub-group range for the ME/MEW class based on the traffic volume category of the major road. Therefore, additional factors are provided to select the correct sub-group class from the range. Table 3 presents the recommended selection from the range. The applicable ambient luminance and other factors from Table 3 determines the correct sub-group (←, **0**, →) from the range.

Table 2 Recommended Range of Lighting Classes for Situation Set A3 (Source: CEN/TR 13201-1)

Main weather type	Separation of carriageways	Intersection density	Traffic flow vehicles											
			< 7 000			≥ 7 000 and ‹ 15 000			≥ 15 000 and < 25 000			≥ 25 000		
		Intersctions/km	←	0	→	←	0	→	←	0	→	←	0	→
Dry	Yes	< 3	ME5	ME5	ME4a	ME5	ME5	ME4a	ME5	ME4a	ME3b	ME4a	ME3b	ME3b
		≥ 3	ME5	ME4a	ME3b	ME5	ME4a	ME3b	ME4a	ME3b	ME2	ME3b	ME2	ME2
	No	< 3	ME5	ME4a	ME3b	ME5	ME4a	ME3b	ME4a	ME3b	ME2	ME3b	ME2	ME2
		≥ 3	ME4a	ME3b	ME3b	ME4a	ME3b	ME 2	ME3b	ME2	ME2	ME3b	ME2	ME1
Wet			Choice as above, but select MEW classes											

Table 3 Recommended Selection from Range (Source: CEN/TR 13201-1

Conflict area	Complexity of visual field	Parked vehicles	Difficulty of navigational task	Ambient luminance		
				Low	Medium	High
No	Normal	Not present	Normal	←	←	0
			Higher than normal	0	0	→
		Present	Normal	←	0	→
			Higher than normal	0	→	→
	High	Not present	Normal	←	0	0
			Higher than normal	0	→	→
		Present	Normal	0	0	→
			Higher than normal	→	→	→
Yes				→[a]		

[a] For conflict areas, luminance is the recommended design criterion. However, where viewing distances are short and other factors prevent the use of luminance criteria, illuminance may be used. Comparable CE classes to recommended ME classes can be found in Table 3.

Once the sub-group lighting class is determined, it can be compared with the CE lighting class which is applicable for roundabouts, intersections, and other conflict areas. Table 4 shows the chart for matching lighting classes of comparable lighting level.

Table 4 Lighting classes of comparable lighting level (Source: CEN/TR 13201-1)

	ME 1	ME 2	ME 3	ME 4	ME 5	ME 6		
	MEW 1	MEW 2	MEW 3	MEW 4	MEW 5			
CE 0	CE 1	CE 2	CE 3	CE 4	CE 5			
			S 1	S 2	S 3	S 4	S 5	S 6

[1)] For ME / MEW classes: CIE road surface reflectance of CIE publication 66:1984, Table C.2.

The actual illuminance level for the appropriate CE class can be found in the second part of the EN, *EN 13201-2 Road Lighting Part 2: Performance requirements (5)*. Table 5 presents horizontal illuminance levels of the CE series of lighting classes.

Table 5 Performance requirements for CE series of lighting classes (Source: EN 13201-2)

Class	Horizontal illuminance (Lux)	
	E [minimum maintained]	U_o [minimum]
CE0	50	0.4
CE1	30	0.4
CE2	20	0.4
CE3	15	0.4
CE4	10	0.4
CE5	7.5	0.4

Austria

In Austria all road sections, including roundabouts in urban areas must have street lighting. However, in rural areas there is generally no lighting except at dangerous sections which must be determined on a case-by-case basis by the highway safety engineer (*6*). Therefore, there is no systematic policy to illuminate roundabouts. Lighting that is provided at roundabouts must meet the standards set in parts 2, 3, and 4 of the EN (*6*).

Belgium

Road authorities in Belgium use part 1 of the EN as the main warrant for roundabout illumination. This is supplemented by an additional warrant *prNBN L 18-004:2010: Public lighting – Selection of lighting Classes (7)*. This supplemental warrant provides complementary parameters in assigning road segments to the lighting classes in the EN. It also prohibits a difference of more than two equivalent lighting classes on adjacent road sections (*8*). For such cases the higher illumination level must be used. For lighting standards, Belgium road authorities use parts 2, 3, and 4 of the EN (*8*). Table 6 shows the lighting performance standards used in Belgium. All publicly owned roundabouts (Giratories) are illuminated under the CE1 lighting class with a minimum average illumination of 30 lux (*7, 8*). Therefore, roundabouts will be systematically illuminated.

Table 6 Belgium Lighting Parameters (Source: prNBN L 18-004:2010 (F))

Catégorie	Fonction	Sous-catégorie	Classe CEN équivalente	L moy [cd/m²]	U_l	U_0	TI max [%] (2)	SR	E_h moy [lux]	U_0 (E)	E_h min [lux]
Réseau à grand gabarit I, II, III	Autoroute et liaisons interrégionales Collectrice régionale	Zone de conflits (rings, accès,…)	(1)	1,5	0,60	0,40	15	-	-	-	-
		Sections courantes	ME3b	1,0	0,60	0,40	15	0,50	-	-	-
		Giratoires	CE1	-	-	-	-	-	30	0,40	-
		Carrefours	CE2	-	-	-	-	-	20	0,40	-
Réseau interurbain I, II, III	Liaison et collectrice au niveau local et sublocal	Voiries	ME3b	1,0	0,60	0,40	15	0,50	-	-	-
		Giratoires	CE1	-	-	-	-	-	30	0,40	-
		Carrefours voie secondaire	CE3	-	-	-	-	-	15	0,40	-

Bulgaria

Bulgarian road authorities use part 1 of the EN as warrant for roundabout illumination. They also comply with parts 2, 3, and 4 of the EN for lighting performance standards. The EN replaced the Bulgarian standard *BSS 5504/1982* in 2005. There is no policy to systematically illuminate rural roadways (including roundabouts). The decision to illuminate is made by local governments or municipalities and the Executive Road Agency considering local situations and availability of funds (*9*).

Czech Republic

In the Czech Republic, a translated and slightly modified version of the EN is used. The Czech standard is also in four parts and it offers further guidance on the selection of lighting classes. It also offers significant variation in parameter values for different periods of the night to account for ambient luminance and traffic flow. Nominal lighting levels can be reduced up to 50 percent or up to 25 percent in case of extreme variation in traffic flow (*9*). A change in ambient luminance can also allow a reduction in nominal lighting values. However, for road segments or conflict areas with high nighttime crime risk or nighttime accident frequency the reduction in nominal lighting level is not recommended (*9*, *10*). Also, there is no systematic requirement to illuminate rural roads – including roundabouts – road authorities decide whether or not to illuminate on a case-by-case basis. The general practice is to only illuminate if at least one adjacent road is illuminated (*9, 10*)

Denmark

Danish road authorities use all the four parts of the EN. Part 1 is the warrant for illumination and Parts 2, 3, or 4 apply to performance values and measurements (*11*). However, the local Danish recommendation which was published in 1999, *Vejbelysningsregler (Illumination levels on State Routes)* is also still in force (*9, 11*). Generally, all roundabouts in urban areas must be illuminated but those in rural areas must be decided by the different road authorities (*6*). Therefore, Denmark does not systematically illuminate roundabouts.

Estonia

The Estonian road authorities use the EN part 1 to warrant the illumination of roundabouts. Also, they comply with the prescriptions of EN parts 2, 3 and 4 for the lighting levels for various lighting classes. In Estonia, illumination is provided on rural roundabouts that have at least one illuminated adjacent roadway section or have pedestrian crossings (*6*). In urban areas all roadways, including roundabouts must have lighting provided (*6*).

Finland

In Finland the National Code of Practice for Road Lighting, *TIEH 21003-v-06*, serves as both a warrant and a standard for roadway illumination. The warrant component is based on the part 1 of the EN but makes further distinction between types of road sections and accounts for weather conditions. The standard component is also based on the EN parts 2, 3, and 4. The standard also recommends and provides performance requirements for adaptive lighting when feasible *(8)*. The Finnish National Road Administration has the responsibility for planning and designing, the installation and maintenance of public road lighting. According to the National Road Lighting Policy, roundabouts must generally be illuminated (*6*).

France

The current French policy on illumination of highway intersections is contained in *The Design of Interurban Intersections on Major Roads (12)* which was published by the Service for Roads and Highway Technical Studies (SETRA) in 1998. For specific reference to roundabouts the earlier publication; *Technical Guide: Roundabout Illumination (Guide Technique: Eclairage des Carrefours à Sens Girratoires) (13)* is the principal document unless there is contrary recommendation in the current policy mentioned prior. In cases where none of these documents can be referenced, the EN is applied in full. Generally, roundabout intersections in rural areas are not illuminated (similarly to other at-grade intersections) in France. However, an exception is made when there are illuminated areas in the immediate vicinity, one of the adjacent legs is illuminated, or there is a pedestrian crossing on the roundabout.

Germany

Germany uses a translated version of the EN as the warrant and standard for roundabout illumination. The German standard also includes provisions for the dimming of lights in cases of reduced traffic. Normally roads in urban areas are lit if the area is built-up or the road leads to a built up area. In rural areas, the application of road lighting is not frequent. The decision to light a location is done on a case-by-case basis. (*6*). Therefore, there is no systematic requirement for rural roundabout illumination in Germany.

Greece

Road authorities in Greece use part 1 of the EN as the warrant to illuminate roundabouts. Also, there is compliance with parts 2, 3 and 4 of the EN for performance requirements on lighting classes. Generally, roundabouts on the national road network must be illuminated if it is at a main junction or on a road section connecting urban areas. For roundabouts that are off the national network, the local authorities must decide whether or not to illuminate (*6*). Therefore, Greece also does not have a systematic requirement for lighting roundabouts in rural areas.

Holland

Dutch road agencies use the *Handboek Openbare Verlichting-2007* (Public Lighting Handbook) (*14*) as warrant for illumination of roundabouts and they use *Nederlandse Praktijk Richtlijn* (Practical Dutch Guidelines) (*15*) as their standard. These documents are translated and slightly revised versions of the EN. However, the documents do not differ from the EN with regards to roundabout illumination. The standard emphasizes energy saving, minimizing life-cycle costs (LCC), and the use of adaptive lighting (*9*). In Holland, regions are responsible for defining their own policy and local road authorities decide whether or not to illuminate rural roundabouts. The policies differ across the country (*9*).

Iceland

Even though Iceland is not part of the European Union, the Icelandic road authorities have adopted all four parts of the EN as the warrant and standard for illumination of roundabouts. The Icelandic policy for roundabout is to systematically illuminate in both urban and rural conditions (*6*).

Ireland

The Irish road authorities use the British Standard BS 5489-1:2003 (*16*) as the warrant roundabout illumination (*9*). However, for lighting standard they use parts 2, 3, and 4 and the EN. In Ireland, rural roundabouts are systematically lit (*6*).

Italy

Italy uses a translated and slightly modified version of the EN Part 1, UNI 11248 *Illuminazione Stradale – 2012 (Roadway Illumination) (17),* as the warrant for roundabout illumination. This document does not differ from the EN with regards to roundabout illumination. The parts 2, 3, and 4 of the EN are used as standard for illumination (*6, 17*). In 2006 the Ministry of Infrastructure and Transportation outlined the policy for roundabout illumination. Rural roundabouts with split-level maneuvers or grades must be illuminated. If a roundabout belongs to neither of these two categories then it is the responsibility of the local road authorities to decide whether or not to illuminate.

Luxembourg

In Luxembourg the "service électromécanique" uses part 1 to 4 of the EN as the warrant and standard for roundabout illumination. The EN was transposed into law in 2005 (*6*).

Norway

The Norwegian Public Roads Administration publishes its own warrant and standard. The standard is based on parts 2, 3, and 4 of the EN (*9*). The warrant is based on traffic volume and the presence of physical separation of carriageway (i.e. divided highway or barrier separation). Table 7 presents the recommended lighting class for various traffic volumes on both separated and non-separated carriageways (*18*). Norway actively supports the use of adaptive lighting systems where it will be effective even if costly (*9*).

Table 7 Recommended Roadway Lighting Classes in Norway (Source: (*8*))

ADT	<1500	1500 – 4000	4000 – 8000	8000 – 12000	>12000
Separated carriageways		MEW3	MEW3	MEW3	MEW3
Non-separated carriageways	MEW4	MEW3	MEW2	MEW2	MEW2

The lighting performance measures for the Norwegian Standard (8) are shown in Table 8.

Table 8 Recommended Lighting Levels for Respective Lighting Classes in Norway

Average luminance (cd/m^2)		2	1.5	1	0.75	0.5			
Class	CE0	MEW1 CE1	MEW2 CE2	MEW3 CE3 S1	MEW4 CE4 S2	MEW5 CE5 S3	S4	S5	S6
Average illuminance (lux)	50	30	20	15	10	7.5	5	3	2

Poland

Poland has had virtually no road illumination standard since it went from a centrally commanded to a liberal market economy (*9*). For now, policy and guidelines are given by the Polish Committee of Illumination and the Association of Polish Electricians on a case-by-case basis. A polish version of the EN is being drafted *(8)*.

Slovenia

The Slovene road authorities use the part 1 of the EN as warrant for roundabout illumination. Parts 2, 3 and 4 of the EN is used as standard for lighting performance requirements (*9*).
The decision to illuminate rural roundabouts is left to the discretion of municipalities (*9, 19*). Slovenia has developed a strong practice of adaptive illumination for roundabouts that dims lighting level at low traffic times of the night (*19, 20*).

Spain

In Spain, the Royal Decree 1890/2008 *Instrucciones técnicas complementarias EA-01 a 07(Complementary Technical Instructions)* is used as both a warrant and a standard for roundabout illumination. The document states that illumination of a roundabout must be at least 50% more than the highest lighting level of its adjacent legs. Also, if a roundabout is to be illuminated, its minimum average luminance level must be 40 lux. Furthermore, the roundabout must maintain its luminance level for 200m in every direction (*21*).

Sweden

The document VGU (VV Publication 2004:80) (*22*) acts as both a warrant and a standard for roadway illumination in Sweden (*9*). It gives recommendations for the choosing of lighting classes and assigns the corresponding illumination levels. The document provides for the adaptive lighting of roadway sections, this is done extensively in Sweden. The standard component is based on the EN (*9*). The federal and local authorities have the responsibility to decide whether to illuminate public and local roads respectively (*9*).

Switzerland

The Swiss Standard for lighting public roads is based on the EN. However, the Swiss Association of Lighting has published additional recommendations to the standard (*6*). There is no central control over rural roundabout (including other roadways) illumination. The application of the standard is the responsibility of the Cantons, Cities, and Municipalities. However, most roundabouts in urban areas are well lit.

United Kingdom

In England, the British Standard BS 5489-1:2003 (*16*) is used as a warrant to determine the lighting class of road sections *(12)*. This is done according to the recommendations in Figure 1. The warrant states that if none of the adjacent legs to a roundabout are lit but a decision is made to illuminate it, the CE lighting class should be chosen as the equivalent to the prevailing ME/MEW class corresponding to the traffic demands and general environment of the roundabout. Once the lighting class has been determined, parts 2, 3, and 4 of the EN are used to assign the appropriate minimum average illuminance level and overall uniformity (*23*) There is no mandatory requirement to provide lighting (*6*), however; the vast majority of British rural roundabouts are illuminated (*23*).

Hierarchy description	Type of road/general description	Detailed description	Traffic flow (ADT)	Lighting class
Motorway[a]	Limited access	Routes for fast moving long distance traffic. Fully grade-separated and restrictions on use.		
		Main carriageway in complex interchange areas	⩽40 000 >40 000	ME1 ME1
		Main carriageway with interchanges <3 km	⩽40 000 >40 000	ME2 ME1
		Main carriageway with interchanges ⩾3 km	⩽40 000 >40 000	ME2 ME2
		Emergency lanes	—	ME4a
Strategic route[b]	Trunk and some principal "A" roads between primary destinations	Routes for fast moving long distance traffic with little frontage access or pedestrian traffic. Speed limits are usually in excess of 40 mph and there are few junctions. Pedestrian crossings are either segregated or controlled and parked vehicles are usually prohibited.		
		Single carriageways	<15 000 >15 000	ME3a ME2
		Dual carriageways	<15 000 >15 000	ME3a ME2
Main distributor[b]	Major urban network and inter-primary links Short- to medium-distance traffic	Routes between strategic routes and linking urban centres to the strategic network with limited frontage access. In urban areas speed limits are usually 40 mph or less, parking is restricted at peak times and there are positive measures for pedestrian safety reasons.		
		Single carriageways	⩽15 000 >15 000	ME3a ME2
		Dual carriageways	⩽15 000 >15 000	ME3a ME2
Secondary distributor	Classified road (B and C class) and unclassified urban bus route, carrying local traffic with frontage access and frequent junctions	Rural areas (Zone E1/2[c]) These roads link the larger villages and HGV generators to the strategic and main distributor network.	⩽7 000 >7 000, ⩽15 000 >15 000	ME4a ME3b ME3a
		Urban areas (Zone E3[c]) These roads have 30 mph speed limits and very high levels of pedestrian activity with some crossing facilities including zebra crossings. On-street parking is generally unrestricted except for safety reasons.	⩽7 000 >7 000, ⩽15 000 >15 000	ME3c ME3b ME2
Link road	Road linking between the main and secondary distribution network with frontage access and frequent junctions	Rural areas (Zone E1/2[c]) These roads link the smaller villages to the distributor network. They are of varying width and not always capable of carrying two-way traffic.	Any	ME5
		Urban areas (Zone E3[c]) These are residential or industrial inter-connecting roads with 30 mph speed limits, random pedestrian movements and uncontrolled parking.	Any Any (with high pedestrian or cyclist traffic)	ME4b or S2 S1

NOTE 1 See Table B.3 for conflict areas.

Figure 1: UK Recommended Lighting Classes for Motorways and Traffic Routes

ASIA

Unlike Europe there is currently no uniform roadway illumination warrant or standard across Asia. Existing practice is uncoordinated among countries. However, the Association of South East Asian Nations is discussing the possibility of a uniform warrant and standard. Several Asian countries have adopted illumination practices modeled on the EN, the British Standard 5489, or the AASHTO Design Manual. Others have also developed their own illumination standards. Regarding roundabout illumination, Australia and New Zealand are currently the only Asian nations that have a common document.

Australia

There is no unified warrant for roadway illumination across Australia. Each territory is responsible for defining its own warrant. The *AS/NZS1158.1.1: 2005 (Lighting for Roads and Public Spaces)* is a joint New Zealand-Australia standard (*24*) which provides clear guidelines on roundabout illumination. It includes minimum lighting level requirement and geometric design guidance for each lighting class. Roundabouts fall into category V lighting (motorized traffic and road safety) or category P (pedestrian movement and personal security). In South New Wales there is systematic illumination of roundabouts.

Hong Kong

In Hong Kong, the Public Lighting Design Manual-2006 is used to warrant roundabout illumination (*25*). The document references the British Standard 5489 (*16*). The warrant selects lighting classes according to functional class, traffic density, traffic complexity, traffic segregation, pedestrian volume, and ambient brightness (*25*). The standard includes the provision that maintained average illuminance on the road surface of a roundabout shall be higher than on the approach roads. Additionally, the document provides for the use of high mast lighting at roundabouts where "higher than normal level of illuminance is considered desirable or the large number of conventional lighting columns would confuse the motorists with patterns of lanterns at different levels and impair the aesthetics." In Hong Kong, roundabouts can be illuminated as class CE2 or CE3 depending on traffic flow as shown in Table 9.

Table 9 Hong Kong Lighting Levels for Conflict Areas (Source: (*25*))

<table>
<tr><th>Lighting Class</th><th>Area of Consideration</th><th>Traffic Flow</th><th>Minimum Average Illuminance</th><th>Minimum Illuminance</th></tr>
<tr><td>CE0</td><td>Toll Plaza</td><td>High</td><td>50 lux</td><td>20 lux</td></tr>
<tr><td>CE1</td><td rowspan="2">Mixed Vehicle and Pedestrian e.g. Carpark, Bus Terminus, Taxi/Maxicab Station; and Road Junction, Roundabout</td><td>High</td><td>30 lux</td><td>10 lux</td></tr>
<tr><td>CE2</td><td>Medium</td><td>20 lux</td><td>7.5 lux</td></tr>
<tr><td>CE2</td><td>Pedestrian and Cycle Underpass</td><td>Low or Medium</td><td>20 lux</td><td>7.5 lux</td></tr>
<tr><td>CE3</td><td>Road Junction, Roundabout</td><td>Low</td><td>15 lux</td><td>5 lux</td></tr>
<tr><td>CE4</td><td>Cul-de-sac, Small Parking Lot Access road junction</td><td>Low</td><td>10 lux</td><td>2.5 lux</td></tr>
</table>

India

The standard for roadway lighting in India is the *IS1944-1970 (26)*. The lighting level and class assigned to roadways is primarily based on traffic. Roundabouts must meet general illumination criteria for junctions and must have minimum lighting levels of 50 lux and distance between lighting poles must be less than 70% of adjacent roads. For small roundabouts with central island less than 18 meters, the code allows the location of a single luminaire pole in the center of island (*26*).

Israel

In 2010, Israel adopted the EN. Part 1 of the EN is used as the warrant for roundabout illumination while parts 2, 3, and 4 are applied as the lighting standard to determine the levels for various lighting classes. Also, the decision of whether or not to illuminate a roundabout is done on a case-by-case basis.

Kazakhstan

CH PK B.2.5-18-2003 (Instructions for designing outdoor electric lighting for cities, towns and villages) is both the warrant and the standard. It does not provide information specifically on roundabouts, but it gives guidelines regarding junctions. In general, if there is a pedestrian crossing at a roundabout, illumination is obligatory (*27*).

Korea

The Installation and Maintenance Guidelines for Roadway Safety Facilities (*28*) is used as both a warrant and a standard for roadway illumination in Korea . The Korean Roundabout Design Manual (*29*) stipulates that in unusual circumstances such as the presences of pedestrians, lighting should follow the basic concept of the Installation and Maintenance Guidelines for Roadway Safety Facilities. Otherwise, lighting can be modified according to local conditions.

Malaysia

There is no warrant for roadway illumination in Malaysia. The Jaban Kerja Raya (National Road Authority) decides whether to illuminate a roundabout on a case-by-case basis. The *Guide to the Design of At-Grade Intersections* (*30*) recommends that channelized intersections should have lighting provided even if it is not warranted and if lighting is not available, the islands should be equipped with pavement reflectors. Roundabouts are channelized intersections so they should be illuminated.

New Zealand

In New Zealand there is no uniform illumination warrant for roundabouts. Road authorities in each region independently decide whether or not to illuminate. Also, similar to the Australian standard they must also decide whether a roundabout is category V lighting (motorized traffic and road safety) or category P (pedestrian movement and personal security).The joint New Zealand-Australian standard (*24*) provides clear guidelines on roundabout illumination including required lighting level tables and geometric design guidance per lighting class.

Philippines

The Philippine road authorities addressed the need for safe and efficient lighting systems for the first time in the Roadway Lighting Guidelines-2008 (*31*). The Philippine road lighting policies are still at an experimental stage. The document does not specifically mention the roundabout but provides directives for at-grade junction illumination.

Russia

The Russian Agency of Technical Regulation and Meteorology adopted the EN in 2005 *(46)*. Part 1 of the EN is used to pick lighting classes at roundabouts. Illumination requirements of the roadway classes are then prescribed with parts 2, 3 and 4.

Turkey

The Turkish road lighting standard is based on the CIE Publication No: 12-1977 (Recommendations for the Lighting of Roads for Motorized Traffic). Supplemental guidelines are provided in the *Yol Tasarımının Esasları ve Uygulamaları* (*32*) which is modeled after the AASHTO Standard (*33*).

AMERICAS

Countries in the Americas have their own individual policies on how to illuminate roundabouts. Most of these policies are modeled after the International Committee for Illumination guideline CIE 115:2010 (*34*).

Argentina

In Argentina, municipalities have the responsibility for deciding whether or not to illuminate the roundabouts within their jurisdiction. When a decision is made to illuminate a roundabout, there are three Argentine standards that can be used jointly to determine the required illumination (*35*). The *AADL J IRAM-2022 Street lighting 21 (Classification of roads and recommended levels)* is used to determine the lighting class. This same document is then used to find the appropriate illumination level. *AADL J IRAM-2020 Street lighting 23 (Design features)* provides geometric guidelines for roadway illumination and *AADL J IRAM-2021 Street lighting 67 (Testing requirements)* gives a procedure to test whether road portions satisfy safety lighting requirements. All three standards are based on the CIE 115:2010 (*34*)

Brazil

Under Brazilian legislation, public lighting is the responsibility of municipalities (*36*). They decide whether or not to illuminate roundabouts. The most recent Brazilian Standard, *NBR 5101 (Road Lighting Procedure),* was published in 2012 and it serves as both a warrant and a standard for roadway illumination (*37*) The Brazilian Standard is based on the CIE 115:2010 (*34*).

Canada

In Canada, each province produces its own policies. In Quebec and Ontario, illumination is recommended for almost all roundabouts (*38, 39*). Less densely populated provinces, where power supply is not readily available on rural roadways have less strict policies. However, all roundabouts under provincial jurisdiction must comply with the warrants listed in the "Ministry Policy for Roundabout Illumination" (*38*). This document provides a standard for the required illumination levels and the geometric design and it is based on the Illumination Engineering Society of North America (IESNA) Design Guide for Roundabout Lighting (DG-19) (*1*). In general all roundabouts under provincial jurisdiction are to be lighted. The Canadian *Guide for the Design of Roadway Lighting* can also serve as a standard because it incorporates the recommendations of the IESNA standard. The required illumination levels are determined according to the type of crossroads and the pedestrian area classification. The recommended lighting levels in Lux as well as the Uniformity ratios for various types of crossroads are presented in Figure 2.

Illumination for Roundabouts

Functional Classification		Maintained Average Horizontal Illuminance in Lux on the Pavement based on Pedestrian Area Classification			Uniformity E avg. / E min
		High	Medium	Low	
At least one of the approach or intersecting roadways is continuously lighted	Major/Major	34.0	26.0	18.0	3:1
	Major/Collector	29.0	22.0	15.0	3:1
	Major/Local	26.0	20.0	13.0	3:1
	Collector/Collector	24.0	18.0	12.0	4:1
	Collector/Local	21.0	16.0	10.0	4:1
	Local/Local	18.0	14.0	8.0	6:1
None of the approach or intersecting roadways is continuously lighted	Major/Major	18.0	14.0	8.0	6:1
	Major/Collector	18.0	14.0	8.0	6:1
	Major/Local	18.0	14.0	8.0	6:1
	Collector/Collector	18.0	14.0	8.0	6:1
	Collector/Local	18.0	14.0	8.0	6:1
	Local/Local	18.0	14.0	8.0	6:1

Figure 2 Canadian Lighting Levels at Roundabouts

Chile

The *Reglamento de Alumbrado Pùblico de Vìas de Tràfico vehicular* serves as both a warrant and a standard (*40*). The warrant stipulates that conflict areas including roundabout must always be illuminated. A roundabout must at least be illuminated to the highest lighting level of its legs. If none of the legs (*41*, *42*) are illuminated, the roundabout must be lit to the highest prescribed level of illumination of the adjacent intersection legs. The guidelines are aligned with the CIE 115: 2010 (*34*) requirements.

Columbia

In Columbia, both the warrant and standard for roundabout illumination is contained in the *Reglamento Técnico de Iluminaciòn y Alumbrado Pùblico (43, 44)*. Unlike the Chilean standard, Columbia's standard does not recommend illumination for roundabouts when none of the legs is illuminated. The standard explains how to calculate minimum light levels but does not give geometric requirements. The guidelines are aligned with the CIE 115:2010 (*34*) requirements.

Mexico

There is no uniform illumination warrant and standard in use across Mexico. Individual states decide whether or not to illuminate roundabouts. Some states have well documented roadway illumination policies. Chihuahua for example establishes clear policies in *Decreto* No. 850/95 XVIII (*45*). Generally, it is recommended that at the least, roundabouts should be illuminated to the minimum level of the legs.

Nicaragua

The geometric design guide, *Guia de Diseno Geometrico*, also serves as the Nicaraguan standard. It includes a section on roundabouts and requires that all roundabouts in Nicaragua must be illuminated. However, because rural roundabouts may be located far from energy sources, this is not always the case in practice.

Peru

The decision of whether or not to illuminate a rural roundabout is made at the administrative divisions. *N° 013-2003-EM/DM. - Norma Técnica de Alumbrado de Vías Públicas (technical standard for public road lighting)* (*46*) is used as the warrant and it defines the applicable lighting classes. This document must be used in conjunction with the standard - CIE 115:2010 (*34*). Additionally, the warrant requires that a roundabout must at least be illuminated to the minimum illumination level of its legs.

Venezuela

The central government is responsible for the illumination of roundabouts. The *Resumen NVF 3290: 2008* establishes technical guidelines for roadways including transition zones (*47*).

AFRICA

Africa does not have a uniform roadway illumination warrant and standard. Most countries also do not have an official illumination warrant and/or standard.

Ghana

In Ghana, the Metropolitan, Municipal, and District Assemblies (MMDAs) are responsible for the development, installation, ownership and maintenance of streetlights within their jurisdictions (*48*). Ghana does not have a national road lighting standard.

South Africa

In South Africa, the modern roundabouts are called traffic circles and they are not as widespread as mini-roundabouts. The current warrant and standard document is made up of two parts; *SANS 10098-1 Public Lighting - Part 1: The Lighting of Public Thoroughfares for Lighting Public Roads and SANS 10098-2 Public Lighting – Part 2: The Lighting of Certain Specific Areas of Streets and Highways.* It is unclear whether these documents address roundabouts specifically.

SUMMARY OF SYSTEMATIC RURAL ROUNDABOUT LIGHTING PRACTICES

Table 10 presents a summary of systematic rural roundabout lighting practices among the surveyed countries. The results in these table show that 59 percent of all the countries scanned do not have a systematic policy to light rural roundabouts. These include countries with comparable transportation systems such as Germany, France, Holland, Canada, and New Zealand. The results further show that while warrants exist in these countries, there is underlying trend to leave the ultimate decision to light a roundabout to local authorities. Also, the results highlight some key factors which affect the illumination of rural roundabouts in these countries. These key factors include:

- The presence of pedestrian volumes at the roundabout.
- The presence of illumination in the immediate vicinity of the roundabout
- At least one approach street is illuminated
- The availability of power

Next, while a few countries, 16 percent of surveyed countries, do attempt to illuminate all roundabouts it is more common to find a requirement to light all urban roundabouts. Also, it was not possible to determine the nature of rural roundabout illumination requirement at about 25 percent of the countries surveyed. The survey results also show that adaptive lighting practices are not common with respect to roundabout illumination among the scanned countries. Figure 3 presents a map of all the surveyed countries.

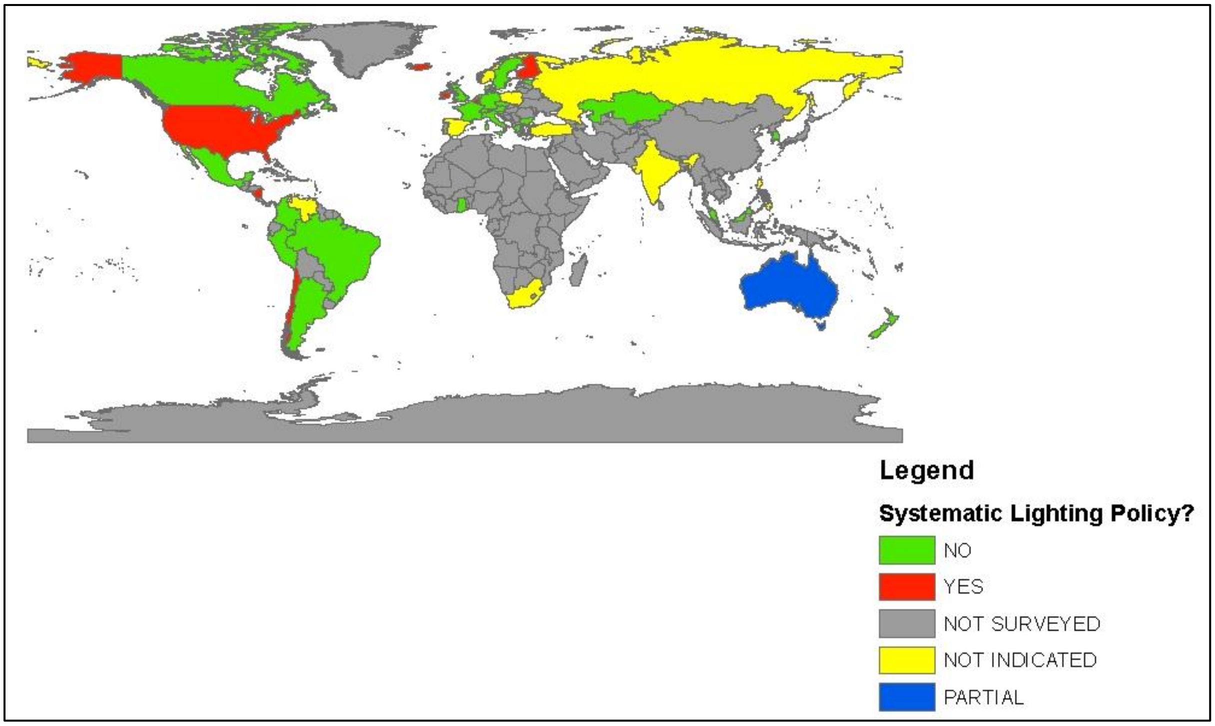


Figure 3 Map of Surveyed Countries

Table 10 Summary of Systematic Lighting Practices at Rural Roundabouts

Country	Warrant & Standard	Roundabout Lighting in Rural Areas		Illuminance Range (Lux)	Known to Use Adaptive Lighting
		Systematic?	Comment		
Austria	EN	No		7.5 - 50	
Belgium	EN with supplements to warrants	Yes		30	
Bulgaria	EN	No		7.5 - 50	
Czech	EN with modifications	No	Illuminate if an adjacent leg is illuminated.	7.5 - 50	Yes, but not applicable in high crime areas
Denmark	EN in collaboration with original Danish recommendations	No		7.5 - 50[1]	
Estonia	EN	No	Except if adjacent legs are illuminated or pedestrian crossing is present	7.5 - 50	
Finland	EN with modifications	Yes		7.5 - 50	Yes
France		No	Except if adjacent legs are illuminated or pedestrian crossing is present		
Germany	EN (Translated version)	No		7.5 - 50	Yes
Greece	EN	No	Unless those on national network	7.5 - 50	
Holland	EN with modifications (Translated)	No		7.5 - 50	Yes
Iceland	EN	Yes		7.5 - 50	
Ireland	BS for warrant, EN for standard	Yes		7.5 - 50	
Italy	EN with modification (Translated)	No	Unless it is grade separated or has split level maneuvers	7.5 - 50	

Table 10 Summary of Systematic Lighting Practices for at Rural Roundabouts – cont'd

Country	Warrant & Standard	Roundabout Lighting in Rural Areas		Illuminance Range (Lux)	Known to Use Adaptive Lighting
		Systematic?	Comments		
Luxembourg	EN	Not Indicated		7.5 - 50	
Norway	EN with modification	Not Indicated		7.5 - 50	Yes
Poland	None[2]	Not Indicated			
Slovenia	EN	No		7.5 - 50	Yes
Spain	Unique	Not Indicated		40+	
Sweden	EN	No		7.5 -40	Yes
Switzerland	EN with additional recommendations	No			
United Kingdom	BS for warrant, EN for standard	No	Can be lighted if one adjacent leg is illuminated	7.5 - 50	
Australia	No uniform warrant, standard is *AS/NZS1158*	Only in territory		?	
Hong Kong	Warrant based on BS, Standard based on EN	Not Indicated		15 - 20	
India	Unique	Not indicated		50	
Israel	EN	No		7.5 - 50	
Kazakhstan	Unique	No	Unless pedestrian crossing is present	?	
Korea	Unique	No	Unless pedestrian crossing is present	?	
Malaysia	Unique	Yes	All channelized intersections must be lighted	?	
New Zealand	No uniform warrant, standard is *AS/NZS1158*	No		?	
Philippines	Unique	Not Indicated		?	
Russia	EN	Not Indicated		7.5 - 50	

Table 10 Summary of Systematic Lighting Practices for at Rural Roundabouts – cont'd

Country	Warrant & Standard	Roundabout Lighting in Rural Areas		Illuminance Range (Lux)	Known to Use Adaptive Lighting
		Systematic?	Comments		
Turkey	Based on CIE 12-1977 and AASHTO	Not Indicated		?	
Argentina	No uniform warrant, Standard based on CIE 115:2010	No		?	
Brazil	Based on CIE 115:2010	No		?	
Canada	Unique warrant, standard based on IESNA DG-19	No	Unless in Quebec and Ontario or under provincial jurisdiction	8 - 34	
Chile	Based on CIE 115:2010	Yes		?	
Columbia	Based on CIE 115:2010	No		?	
Mexico	No uniform warrant or standard across Mexico	No	Unless one of the legs is illuminated in Chihuahua State	?	
Nicaragua	Unique warrant and standard[3]	Yes	But most are not because of distance to power sources	?	
Peru	Unique warrant used in collaboration with CIE 115:2010	No		?	
Venezuela	Unique warrant and standard[3]	Not Indicated		?	
Ghana	No known warrant or standard	No		?	
South Africa	Unique	Not Indicated		?	

1. Based on the EN. The local Danish recommendation was not available for comparison with the EN in terms of illumination levels.
2. A version based on the EN is being drafted.
3. It was not possible to determine if it is based on any of the major lighting standards; IESNA, EN, BS

REFERENCES

1. Illuminating Engineering Society, Design Guide for Roundabout Lighting, IES DG-19-08. Illuminating Engineering Society of North America, New York
2. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnsonm, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R.B. Crown, B. Guichet, and A. O'Brin. Roundabouts: An Informational Guide, 2nd Ed. NCHRP 672, 2010. Transportation Research Board
3. Modus. *Intensification of Public Lighting Systesm*. MODUS Magazine. Accessed 12/1/2013
4. European Committee for Standardization, Cen/Tr 13201-1 Road Lighting - Part 1: Selection of Road Lighting Classes, European Committee for Standardization, Brussels
5. European Committee for Standardization, En 12201-2 Road Lighting - Part 2: Performance Requirements, European Committee for Standardization, Brussels
6. CEDR's TG Road Safety. Road Lighting & Safety. *Conference of European Directors of Roads*. 2009. France.
7. Institut belge de l'éclairage – Belgisch instituut voor verlichting. Eclairage Public – Sélection Des Classes D 'Éclairage Prnbn L 18-004:2010 (F). 2010. Belgium
8. Lorphevre, R., *Interview: Belgium Roundabout Illumination Policies*, S. Berrebi, Editor. 2012.
9. E-Street Initiative. *Work Package 4.2 - National Guidelines 4.7.2008*. Accessed
10. Kotek, L., *Czech Republic Roundabout Illumination Policy and Standards - Phone Interview*, S. Berrebi, Editor. 2012.
11. Dannish Ministry of Transport. Meddelelse Elmateriel Nr. 11/05. 2005. Denmark
12. SETRA - Service d'Etudes Techniques des Routes et Autoroutes. The Design of Interurban Intersections on Major Roads: At-Grade Intersections. 1998. Bagneuz, Cedex
13. Centre d'Études des Transports Urbains. Guide Technique - Eclairage Des Carrefours À Sens Giratoires. 1991. France
14. Dijkstra, G. and S. Roosenboom. Handboek Openbare Verlichting Gemeente Almere. 2009. The Netherlands
15. Dutch Lighting Committee, Npr 13201-1:2002 Nl : Public Lighting - Part 1: Quality Criteria, The Netherlands
16. British Standards, Bs 5489-1:2003 Part 1: Lighting of Roads and Public Amentity Areas, British Standard, United Kingdom
17. Soardo, P., *Uni 11248 Illuminazione Stradale – Sicurezza, Risparmio Energetico, Compatibilita Ambientale Ruolo E Responsabilita Del Progettista*. 2013: Italy.
18. Norwegian Public Roads Administration. Road Traffic Safety Equipment : Technical Requirements. 2011. Norway
19. Bizjak, M., *Phone Interview - Slovenia Roundabout Lighting Policies and Standards*, S. Berrebi, Editor. 2012.
20. Black Sea Regional Energy Centre. Intelligent Road Street Lighting in Europe. 2006. Sofia
21. Ministerio de Fomento, *Normative Téchnica 13 – Illuminaciòn*. 2012.

22. Vagverket, J., B. Skagersjo, and S. Kommunforbundet. Vagar Och Gators Utformning, Vgu 2004:80. 2004:80, 2004. Stockholm
23. Parry, N., *Phone Interview - British Roundabout Lighting Policies and Standards*, S. Berrebi, Editor. 2012.
24. Joint Technical Committee. As/Nzs 1158.1.1:2005. 2005.
25. Lighting Division. Public Lighting Design Manual. 2006. Hong Kong
26. Bureau of India Standards, Is 1944 - 1 and 2 Code of Practice for Lighting of Public Thoroughfare. Part 1 and 2 for Main and Secondary Roads (Group a and B) [Etd 24: Illumination Engineering and Luminaries], Bureau of India Standards, New Delhi
27. *Электронное Объявление Об Осуществлении Государственных Закупок Товаров Нормативно-Технической Литературы Способом Запроса Ценовых Предложений, Сн Рк В.2.5-18*. 2001.
28. Ministry of Land Transport and Maritime Affairs. 도로안전시설 설치 및 관리 지침 - 조명시설 편. 2012. Korea
29. Ministry of Land Transport and Maritime Affairs, *Korean Design Guide for Roundabouts*. 2010, Ministry of Land Transport and Maritime Affairs: Korea.
30. Jalan, C., I.B.U. Pejabat, and J.S. Salahuddin. A Guide to the Design of at-Grade - Arahan Teknik 11/87. 2009.
31. Department of Energy. Roadway Lighting Guidelines. 2008.
32. Turkish General Directorate of Highways, *Yol Tasarımının Esasları Ve Uygulamaları*. 2005.
33. AASHTO, *Roadway Lighting Design Guide*, A.R.L.D. Guide, Editor. 2005.
34. International Commission on Illumination, Cie 115:2010 Lighting of Roads for Motor and Pedestrian Traffic 2nd Edition, CIE Central Bureau, Austria
35. Asociacion Argentina de Luminoteca, *Politicas Publicas Municipales En Alumbrado Urbano*. 2001.
36. Rosito, L. *Desenvolvimento De Illuminacao Publica No Brasil: Capitulo Ii: Vias Publicas*. 6. Accessed
37. Brazillian Standards, Nbr 5101:2012 Public Road Lighting - Procedure,
38. Ontario Ministry of Transportation. Ministry Policy for Roundabout Lighting. 2012.
39. Ministère des Transports du Québec. Quebec - the Roundabout. *2004 Annual Conference of the Transportation Association of Canada*. 2002. Québec.
40. Empresa de Energia del Pacifico, *Manual De Normas Tecnicas De Alumbrado Publico*. 2000.
41. Republica De Chile Ministerio De Economía, F.Y.R., *Reglamento De Alumbrado Público De Vías De Tráfico Vehicular*. 2008.
42. Ministro de Obras Publicas, Manual De Carreteras, Volumen 6, Securidad Vial. In, 2012.
43. Ministerio de Minas y Energia, *Reglamento Técnico De Iluminaciòn Y Alumbrado Pùblico – Anexo General. Retilap* 2012.
44. Ministerio de Transportes y Comunicacion, *Manual De Diseño Geométrico De Carreteras*. 2001.
45. Secretaria de Servicios Juridico Legislativos, Decreto No. 850/95 Xviii P.E - Código Municipal Para El Estado De Chihuahua,
46. Ministerio de Energia y Minas, N° 013-2003-Em/Dm. - Norma Técnica De Alumbrado De Vías Públicas,
47. Comite de electricidad. Resumen Nvf 3290:2008 - Alumbrado Publico Diseno. 2008.

48. Ghana Energy Commission, *Street Lighting Current Practice in Ghana*. 2011.

Insert Tab

APPENDIX B: Estimation of the Safety Impact of Illumination at Roundabouts

GDOT Research Project No. RP 12-01

Evaluation of Current Practice for Illumination at Roundabouts

Technical Memorandum

Estimation of the Safety Impact of Illumination at Roundabouts

By:

Michael O. Rodgers, Ph.D., Principal Investigator
Michael Hunter, Ph.D., co-Principal Investigator
Alexander Samoylov, Ph.D., co-Principal Investigator
Franklin Gbologah, Graduate Research Assistant
Simon Berrebi, Graduate Research Assistant
School of Civil and Environmental Engineering, Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

Revised March 2016

Table of Contents

INTRODUCTION

This report presents the methodology and results of analysis performed on intersection crash and illumination data to estimate the relationship between roundabout safety and illumination levels. A discussion on prerequisite data, available data sources, and inherent data issues is followed by a description of the analysis methodology and discussion of the results before finally summarizing the key findings on how intersection safety is affected by illumination.

DATA REQUIREMENTS AND AVAILABILITY

Minimum Data Requirements

A successful evaluation of the effect of illumination on roundabout safety requires the simultaneous availability of several types of data; crash data, roadway characteristics, intersection characteristics (including intersection type and presence/absence of purpose-built lighting and illumination levels), and traffic data. Additionally, historical sunrise and sunset data is also required to establish times for civil twilight.

The crash data must provide case-by-case information on accidents within the study period. At a minimum it must include information such as:

- Date of accident
- Accident or case ID
- Time of accident
- Location of accident (roadway and milepost or latitude/longitude, rural/urban designation, road segment or intersection)
- Crash severity (fatal, serious, injury, possible injury, and PDO).

The roadway data must also include, at the least, information that allows the identification of different homogenous segments. For example, county route name, number of lanes, width of lanes, posted speed limits, beginning milepost, and ending milepost. It must also distinguish between one-way and two-way segments for accurate computation of intersection entering volumes.

Also, there must be information on the intersections of interest within the study area. Essentially, information must be available on

- Intersection type
- Traffic control mechanism
- Illumination levels
- Location (rural/urban designation, route and milepost).

Next, there must be reliable traffic volume data on the annual average daily traffic (AADT) for every intersection leg for all the years in the analysis period. Last, historical sunrise and sunset data with adjustments for daylight savings would be needed to distinguish nighttime crashes from daytime crashes.

Data Sources

Georgia Data

Most roundabouts in Georgia are fairly new with the majority of them being constructed from 2005 onwards. Therefore, in this study we investigated the availability of the minimum data requirements in Georgia from 2005 to 2012. The available data sources were the Georgia crash database for accident information and Georgia Department of Transportation (GDOT) RCLINK database for roadway information. The investigation revealed that the required crash data elements were available, although potential issues exist with the location data in the crash database likely requiring significant manual efforts to retrieve the data. The required roadway data and traffic data were more limited. The roadway characteristics were generally available from the RCLINK database but all of the necessary elements were not available. Specifically, the RCLINK database lacked any specific information regarding intersection illumination. In addition, there were some inconsistencies in the availability of other information over the eight year period. These limitations precluded the conduction of the study using only Georgia data and other data sources were necessary to supplement these data.

Minnesota Data from the Highway Safety Information System

The Highway Safety Information System (HSIS) was the primary tool used to identify data sources to supplement the available Georgia data. The HSIS provides access to relatively high quality data from selected states that have been selected based on the (a) range of data variables collected, (b) the quality of the data, (c) the quantity of the data, and (d) the ability to merge electronically coded data from different files (*1*). It includes the potential crash, roadway, intersection, and traffic data required for this study. The HSIS includes data from 7 states; California (CA), Illinois (IL), Maine (ME), Minnesota (MN), North Carolina (NC), Ohio (OH), and Washington (WS).

Two out of the crash databases from the 7 states includes information or a variable that can be used to identify roundabouts. These two states are Minnesota and North Carolina.

Like Georgia, most jurisdictions do not archive information regarding intersection illumination. In addition, relatively few jurisdictions have had a significant number of roundabouts for a relatively long period. An extensive search of HSIS based on the data requirements for this study identified two candidate states– California and Minnesota – for further analysis.

The intersection data from California includes a binary variable for lighting presence (YES or NO) while the data from Minnesota includes multiple illumination levels; None, Point, Partial, Full, and Continuous. The Minnesota data was selected for this study because the availability of multiple illumination levels offers more analysis options.

The study uses MN HSIS data from 2003 to 2010. The crash data contains about 78000 records per year (state network only). The crash data does not include (a) crashes for which the investigating officer was not specified in the original police reports, (b) crashes which could not be linked to the roadway file by HSIS staff, and (c) crashes where the estimated damage was less than $1000 (*1*).

Each annual intersection data file contains data on about 33000 intersection legs and 8000 intersections and interchanges. These are intersections on major roadways maintained by the eight Minnesota DOT districts. The data covers all interchanges and intersections of U.S. Highways, intersections of U.S. Highways and State Routes, and intersections of State Routes. In addition, there are variations in the number of intersections and interchanges in the annual files due to changes in route designations between state and local governments.

Each annual roadway data file contains records covering about 12,000 miles of trunk roads, 33,000 miles of state roads, and 90,000 miles of non-state and local roads. Also, each annual MN HSIS traffic data file contains estimated AADTs for all roadway sections across the state. However, for some road segments which are intersection legs the AADTs are not current, that is, they do not match the data year. These intersections legs are usually on “intersections within an interchange”, e.g., intersections at ramp terminals or exit ramps.

Significantly, the MN data from the HSIS has been designed to facilitate easy matching of crash data, traffic data, roadway data, and intersection data. Each record contains three general variables that can be used for this purpose. The variables are the route system (RTE_SYS), route number (RTE_NBR), and the milepost (*1*).

Issues with the Minnesota Data

The Minnesota HSIS data is currently the best data available to evaluate the impact of illumination on roundabout safety. However, it has a number of inherent issues that presently limit the level of sophistication for the safety analysis.

First, it is currently not possible to separate the MN HSIS data into a “before” sample and an “after” sample because there is no information on the dates the lights were installed. This makes it impossible to apply an approach such as the Empirical Bayes Method.

Second, the HSIS data is limited to only intersections on state and/or U.S. routes (*1*). However, many roundabouts in Minnesota are not on these routes. This limits the sample size of available roundabouts and makes it difficult to create and test subgroups of the data such as crash severity types, rural/urban locations, AADT categories, and geometric attributes. Also, jurisdictional changes in the assignment of routes between the state and local governments can affect the availability of intersections in the annual data files.

METHODOLOGY

Treatment of MN HSIS Intersection File

The MN annual intersection files contain data for both intersections and interchanges. However, for the purposes of this study interchanges are not needed so all such records were filtered out to create new annual intersection files containing records of only intersection legs. These new files were subsequently indexed with intersection IDs for easy identification all individual intersection legs. Each set of intersection legs were identified and matched to the roadway data using its RTE_SYS, RTE_NBR, milepost, and INT_DESC (a variable that lists the intersecting roads) variables and the RTE_SYS, RTE_NBR, beginning milepost (BEG_MP), and ending milepost (END_MP) of the roadway data. These matched records were appended to the database along with the designated one-way and two-way directions of their corresponding roadway segments.

As previously mentioned some of the AADTs for intersection legs are not current, i.e., they do not match the data year. These traffic volumes were updated in step-wise manner using yearly population growth rates for Minnesota. Each, yearly population growth rate was computed by comparing the current year's population to that of the previous year. The population data used covers 1990 to 2012. There were some instances where the AADT year preceded 1990. In such cases the AADTs years were assumed to be 1990. Table 1 presents the estimated Minnesota population growth rates used to adjust the AADTs. The maximum AADT adjustment performed was 21 percent to adjust an AADT from 1990 to 2010.

The last step in this initial analysis of the intersection data involved recoding the intersection illumination levels. Each annual file has eight original illumination codes; None, Point Lighting, Partial, Partial (Energy Conservation Program), Full, Full (Energy Conservation Program), Continuous, and Continuous (Energy Conservation Program). Our analysis on the identified roundabout intersections showed that there were very few "Point Lighting" intersections and so we merged them into the "None" group. Also, an energy conservation program will have an effect on power consumption and not illumination level

Therefore, we combined illumination levels in energy conservation program with their non-program alternatives to create just four illumination levels; None, Partial, Full, and Continuous. Partial illumination focuses on lighting just the roundabout intersection, e.g., illuminating just the roundabout circle. Full illumination includes illumination of the roundabout circle as well as the transition zone on the intersection legs. Continuous illumination is usually done as part of a corridor level illumination project and this is usually in urban areas. Figure 1 and Figure 2 shows sketches of Partial and Full illumination respectively.

Table 1 Minnesota Population and Population Growth Rates from 1990 to 2010

Year	Population Size	Estimated Growth Rate (%)
1990	4,375,099	
1991	4,416,292	0.94
1992	4,469,450	1.20
1993	4,515,118	1.02
1994	4,570,355	1.22
1995	4,626,514	1.23
1996	4,682,748	1.23
1997	4,735,830	1.13
1998	4,782,264	0.98
1999	4,838,398	1.17
2000	4,919,479	1.68
2001	4,977,976	1.19
2002	5,033,661	1.12
2003	5,088,006	1.08
2004	5,145,106	1.12
2005	5,205,091	1.17
2006	5,231,106	0.50
2007	5,263,493	0.62
2008	5,287,976	0.47
2009	5,300,942	0.25
2010	5,303,925	0.06

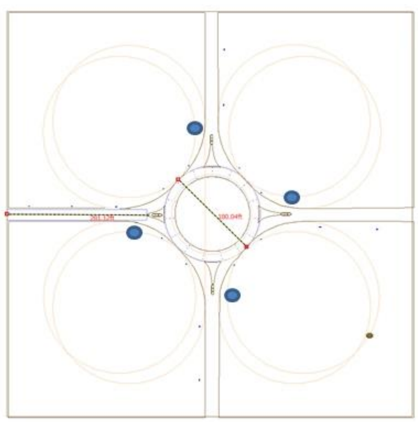


Figure 1 Partial Illumination

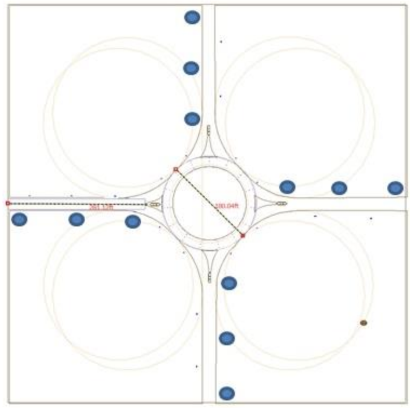


Figure 2 Full Illumination

Identification of MN HSIS Roundabouts

The MN HSIS intersection files do not provide a direct identification of roundabouts but the crash files provide an indirect identification through the LOC_TYPE variable. However, there are many crash locations which share the same RTE_SYS, RTE_NBR, and milepost as some coded roundabout locations but cross-referencing analysis with Google Earth showed that most of these are not actually roundabout locations.

Therefore, a separate roundabout inventory of Minnesota was developed based on information received from MNDOT and the Kittleson Roundabout Database (*2*). This inventory was further cross-referenced with Google Earth. This inventory identified 125 existing roundabouts with verified crossroad names and year of construction. The roundabout inventory was then cross-referenced against the annual HSIS intersection files using the INT_DESC to create a new annual file of identified roundabout intersections for merging with the crash files.

Treatment of the MN HSIS Crash File

To prepare the crash files for analysis, the first step in the process was to append a new time of day variable (Day or Night) based on the accident date, accident time, and historical sunrise and sunset times that were adjusted for daylight savings time. Next, each annual accident file was matched to the corresponding annual intersection file and the intersection IDs were appended to the crash records where possible. The accidents were assigned to intersections by a Minimum Distance Algorithm using a buffer of 325 ft. The algorithm uses RTE_SYS, RTE_NBR, and milepost (+/- 325 ft.) of the intersections to compare the RTE_SYS, RTE_NBR, and milepost of the accidents and assigns the accident to the intersection that is closest to the accident location.

Subsequently, scripts were run to create new recoded columns or appended columns based on data from the intersection file. Some of these data columns included rural/urban code based on the original crash location population grouping (population density based) and a binary lighting presence code based on the previously recoded illumination levels in the intersection file.

Intersection Entering Volume Computation

The designated one-way and two-way codes that were previously appended to the intersection legs include five codes;

- Code D – divided roadway
- Code O – one-way couplet
- Code U – undivided two way road
- Code X – one-way street towards decreasing reference posts
- Code Z – one-way street towards increasing reference posts

In computing the intersection entering volumes all AADTs on legs with a direction code of D or U were evenly split among the legs. Also, AADTs on legs for which no direction code could be found in the roadway data were divided into two, i.e., it was assumed that the legs were two-way roads. After traffic assignment, the AADTs for all the legs were summed up to compute the entering AADT. Annual entering volumes were calculated by multiplying these entering AADTs by 365. Also, an analysis of eight randomly selected continuous traffic counting stations in Minnesota showed that the about 24 percent of AADTs occurred at nighttime. This figure is in line with an earlier study (*3*) that also found that the proportion of rural Minnesota intersection AADT occurring at night was about 23 percent. Therefore, 24 percent of the annual entering volumes were used in computing the nighttime crash rates.

Analysis File

A final analysis file was created for evaluating the relationship between illumination and safety. This file combines the crash data for the identified roundabouts for the analysis period (2003 – 2010) into a single file and groups crash data at the individual intersection level. Analysis variables include: intersection ID, intersection type, traffic control, rural/urban code, crash year, illumination level, lighting presence (binary), annual traffic, total number of crashes, total daytime crashes, total nighttime crashes, total number of crashes by severity (fatal, serious, injury, possible injury, and PDO) for both nighttime and daytime, total crash rate, total nighttime and daytime crash rates, and total crash rates for each accident severity type for both nighttime and daytime. The crash rates (number of crashes per million entering vehicles) were computed as shown in Equation 1. Figure 3 presents a schematic diagram of the analysis methodology

$$crash\ rate = \frac{1{,}000{,}000 * total\ number\ of\ crashes\ within\ analysis\ period}{sum\ of\ annual\ nighttime\ entering\ vehicles} \qquad (\mathbf{1})$$

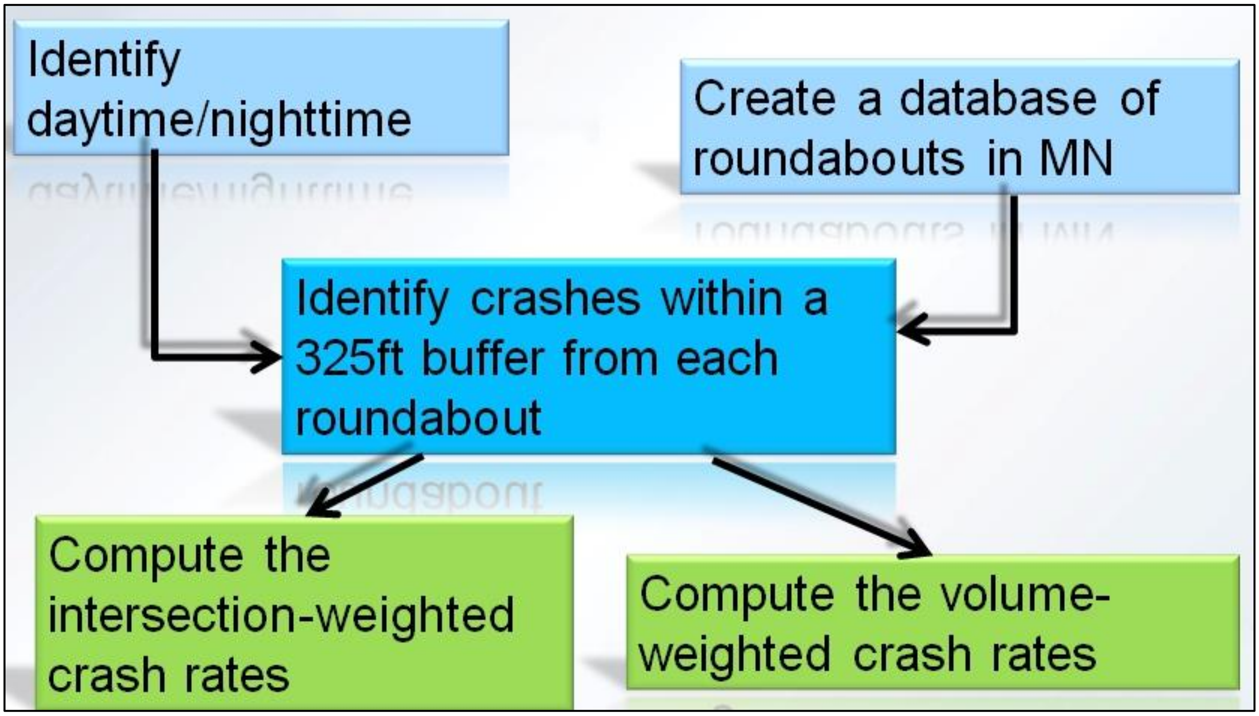


Figure 3 Schematic Diagram of the Analysis Methodoloy

RESULTS AND DISCUSSIONS

The results presented in this section are based on only crashes which were successfully matched to roundabout intersections. As stated previously, a few caveats must be recalled when considering these results. First, the utilized HSIS Minnesota crash data covers only US and state road intersections. As many roundabouts exist off the state network the observed crash rates may not represent the true mean crash rates for all Minnesota roundabouts, which may be higher or lower than the stated average. It is also unknown if any sampling bias exists in the lighting policy, e.g., lighting was placed on roundabouts with a higher likelihood of incidents. Similarly, it is not known if any underlying design or operation differences exist between lit and unlit roundabouts. Finally, in what should be considered a positive constraint, incidents at roundabouts are a rare event. The rarity of these events results in small sample sizes and thus increases the uncertainly in any statistical analysis.

Given these constraints this analysis was undertaken under the tentative assumption that the relationship developed for this subset of roundabouts and the larger population should be reasonably constant. Unfortunately, there is no independent way of verifying this assumption. However, it is expected that these results will provide meaningful initial insights in to the potential impact of lighting on safety until future efforts can address the underlying data accuracy and availability issues.

The analysis results presented was performed using two methods; intersection weighting and traffic volume weighting. By intersection weighting, crash rates were computed annually for each roundabout and then averaged to derive crash rates for specific analysis subgroups. In volume weighting, the crashes and traffic volumes for specific analysis subgroups were summed before computing the group crash rate.

Descriptive Analysis of Minnesota Data

Table 2 presents a breakdown of crashes from the identified roundabouts. It can be seen that about 36 percent of all crashes within the study period occurred at night. Also, the minimum number of identified roundabouts within any year is three while the maximum is thirteen. Next due to the sample size of the identified roundabouts it was not possible to split the data into rural and urban areas and perform separate analysis. Figure 4 shows another analysis of the data in terms of observed crashes per roundabout per year.

Table 2 Breakdown of Crashes from Identified Roundabouts in the MN HSIS Data

Year	No. of Identified Roundabouts	Total crashes	Day crashes	Night crashes
2003	2	7	5	2
2004	2	12	9	3
2005	2	7	4	3
2006	3	3	1	2
2007	3	8	5	3
2008	7	24	11	13
2009	11	29	21	8
2010	13	44	30	14

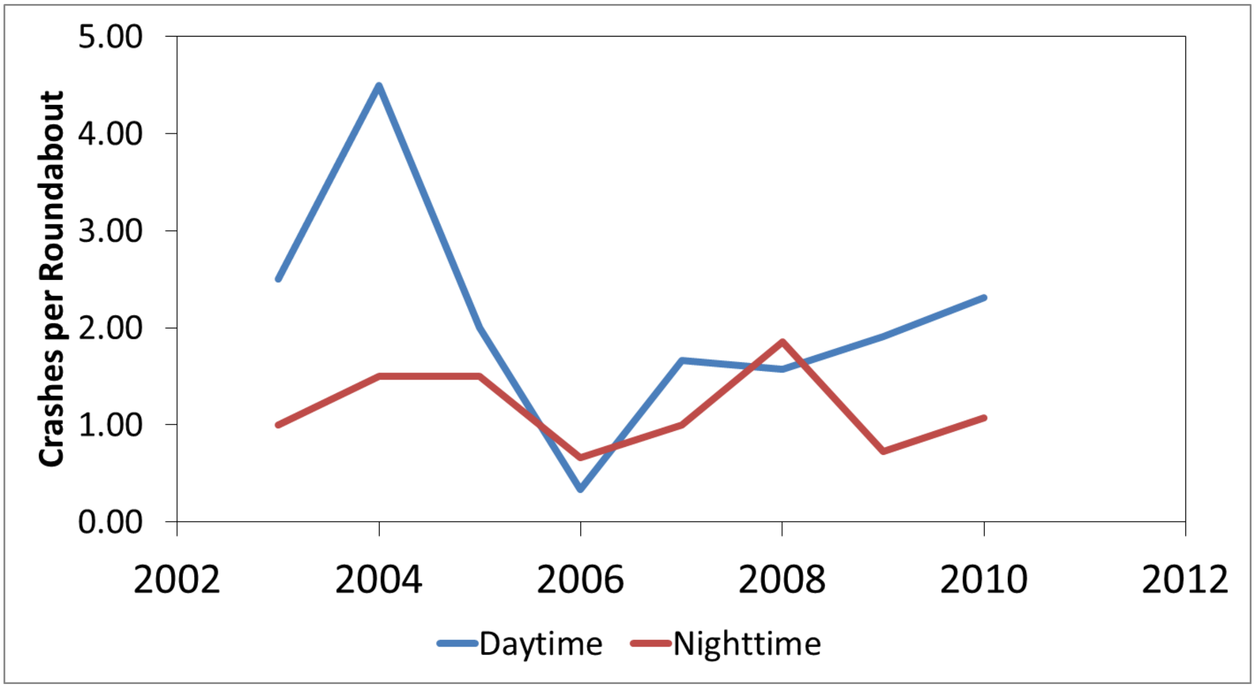


Figure 4 Observed Crashes per Roundabout per Year

Effect of Illumination on Crash Rates

This section of the report presents the results of analysis to identify the impact of illumination on roundabout safety. First, the analysis was performed with just a binary lighting presence variable (lit or unlit). This variable has been the principal variable for past research work. Subsequently, the analysis was performed with the four identified illumination levels (None, Partial, Full, Continuous) in the Minnesota data described previously. The results presented here are based on only nighttime crashes.

Effect on Observed Crash Rates at Lit and Unlit Roundabouts

Table 3 and Table 4 present the results of the lighting presence analysis for intersection weighting and volume weighting respectively. From the results it is seen that roundabouts with lighting experienced a mean crash rate that is about 59 - 65 percent lower than roundabouts that were unlit. Furthermore, the crash rate at unlit roundabouts is at least two and a half times as high as the crash rate at lighted roundabouts.

Table 3 Observed Effect of Lighting Presence at Lit and Unlit Roundabouts
(Intersection weighted crashes per million entering vehicles)

	Lit	Unlit
Mean Nighttime Crash Rates	0.75	1.85
Ratio of Mean Nighttime Crash Rates (Unlit/Lit)	2.5	
% Change in Mean Nighttime Crash Rates from Unlit to Lit	-59	

Table 4 Observed Effect of Lighting Presence at Lit and Unlit Roundabouts
(Volume weighted crashes per million entering vehicles)

	Lit	Unlit
Mean Nighttime Crash Rates	0.72	2.04
Ratio of Mean Nighttime Crash Rates (Unlit/Lit)	2.8	
% Change in Mean Nighttime Crash Rates from Unlit to Lit	-65	

Next, the effect of illumination on roundabout safety was analyzed for total nighttime crash rates for multi-level illumination categories. Table 5 and Figure 5 show the results for the intersection weighted analysis while Table 6 and Figure 6 show the results for the volume weighted analysis.

Table 5 Effect of Different Illumination Levels on Observed Total Nighttime Crash Rates at Roundabouts (Intersection weighted crashes per million entering vehicles)

	None	**Partial**	**Full**
Mean	1.84	0.94	0.52
Standard Deviation	1.51	1.01	0.74
85th Percentile	4.02	2.47	1.58
50th Percentile	1.28	0.84	0.24
25th Percentile	0.82	0.05	0
15th Percentile	0.80	0	0
% Total Change (mean) Compared to "None"		-49	-72
% Incremental Change (mean)		-49	-45

Table 6 Effect of Different Illumination Levels on Observed Total Nighttime Crash Rates at Roundabouts (Volume weighted crashes per million entering vehicles)

	None	**Partial**	**Full**
Mean	2.04	0.79	0.54
% Total Change (mean) Compared to "None"		-61	-74
% Incremental Change (mean)		-61	-32

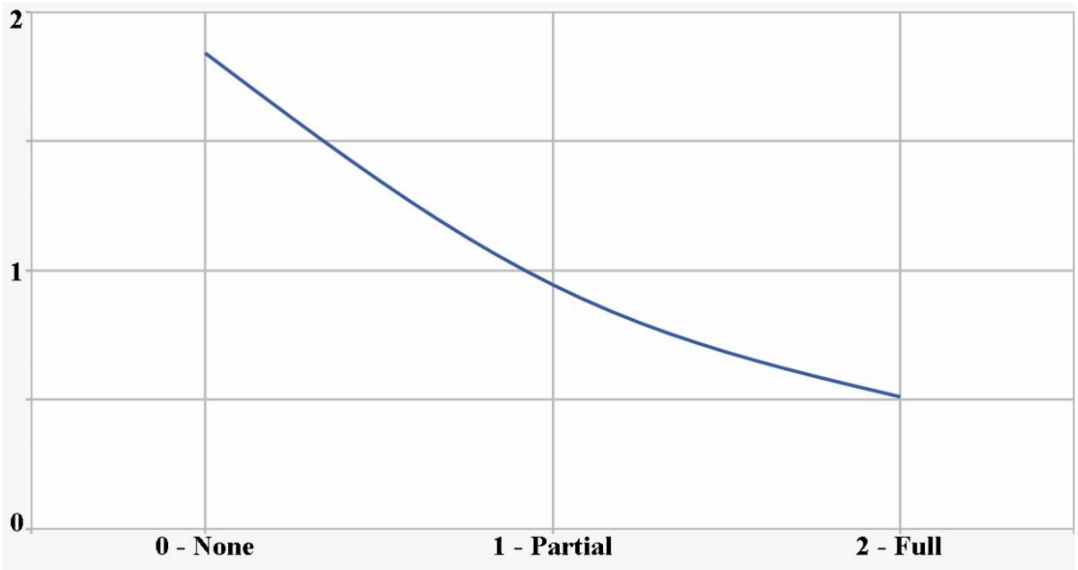


Figure 5 Effect of Different Illumination Levels on Mean Total Nighttime Crash Rates at Roundabouts (Intersection weighted crashes per million vehicles)

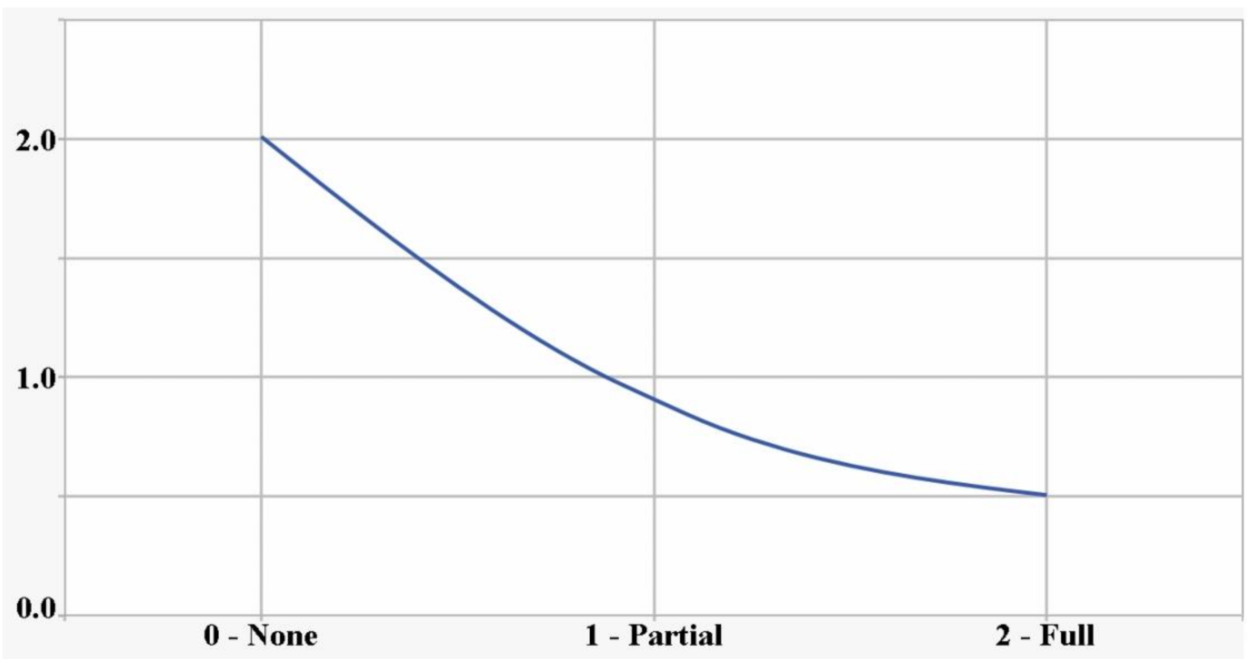


Figure 6 Effect of Different Illumination Levels on Mean Total Nighttime Crash Rates at Roundabouts (Volume weighted crashes per million vehicles)

It can be inferred from the above results on the impact of different illumination levels on roundabout safety that roundabouts with partial illumination experienced about 49 - 61 percent reduction in nighttime crash rates compared to roundabouts without illumination. Also, providing full illumination at roundabouts can reduce nighttime crash rates by about 73 percent compared to unlit roundabouts. In addition, converting a roundabout with partial illumination to one with full illumination can provide incremental nighttime crash rate reductions ranging from 32 percent to about 45 percent.

Significantly, about 68 - 83 percent of the benefits that can be gained from full illumination could be achieved with only partial illumination. This finding appears to contrast the logic of increasing the minimum recommended transition zone length from 260ft (*4*) to 400ft (*5*).

Effect on Observed Crash Severity Rates

The effect of illumination on roundabout safety was further analyzed for different types of crash severities. The crash severities analyzed are fatal crashes, serious crashes, injury crashes, and property-damage-only (PDO) crashes. Due to the small sample size of roundabouts and related crashes we combined possible injury and injury crashes into one severity group. The results from this analysis are presented in Table 7 and Table 8 for the intersection weighted and volume weighted analysis respectively. These results indicate that roundabouts with lighting had about 58 - 68 percent lower rate for injury crashes, and about 57 - 62 percent lower rate in PDO crash rates. Also, the results indicate that roundabouts with lighting can eliminate or significantly reduce the occurrence of fatal and severe crashes. However, it should be noted that the analysis data included only one roundabout fatal crash.

Table 7 Effect of Illumination on Observed Nighttime Crash Severity Rates for Lit and Unlit Roundabouts (Intersection weighted crashes per million entering vehicles)

	Fatal		Serious		Injury		PDO	
	Lit	Unlit	Lit	Unlit	Lit	Unlit	Lit	Unlit
Mean	0	0.08	0	0	0.15	0.35	0.60	1.41
Std. Dev.	0	0.17	0	0	0.23	0.27	0.66	1.32
Quantiles85	0	0.34	0	0	0.51	0.64	1.52	3.35
Quantiles50	0	0	0	0	0	0.38	0.48	0.93
Quantiles25	0	0	0	0	0	0.08	0	0.52
Quantiles15	0	0	0	0	0	0	0	0.43
% change (mean)	N/A		N/A		-59		-57	

Table 8 Effect of Illumination on Observed Total Nighttime Crash Severity Rates for Lit and Unlit Roundabouts (Volume weighted crashes per million entering vehicles)

	Fatal		Serious		Injury		PDO	
	Lit	Unlit	Lit	Unlit	Lit	Unlit	Lit	Unlit
Mean	0	0.09	0	0	0.14	0.44	0.58	1.51
% change (mean)	N/A		N/A		-68		-62	

Verification of Findings

There are other safety influencing variables which could not be accounted for in this analysis due to the limited data available. Figure 7 shows that even at daytime there is a benefit to have installed illumination at roundabouts. However, the benefit for nighttime is greater and this is shown by the steeper gradient of the nighttime crash rate vs illumination level curve. This observed daytime benefit of installed illumination may be due to other safety measures because the warrant for street lighting is hardly applied in isolation. Some of these measures could be better signage and markings. Other possible explanations may be visual cues from seeing light poles ahead which may alert drivers about the intersection ahead resulting in better driver behavior.

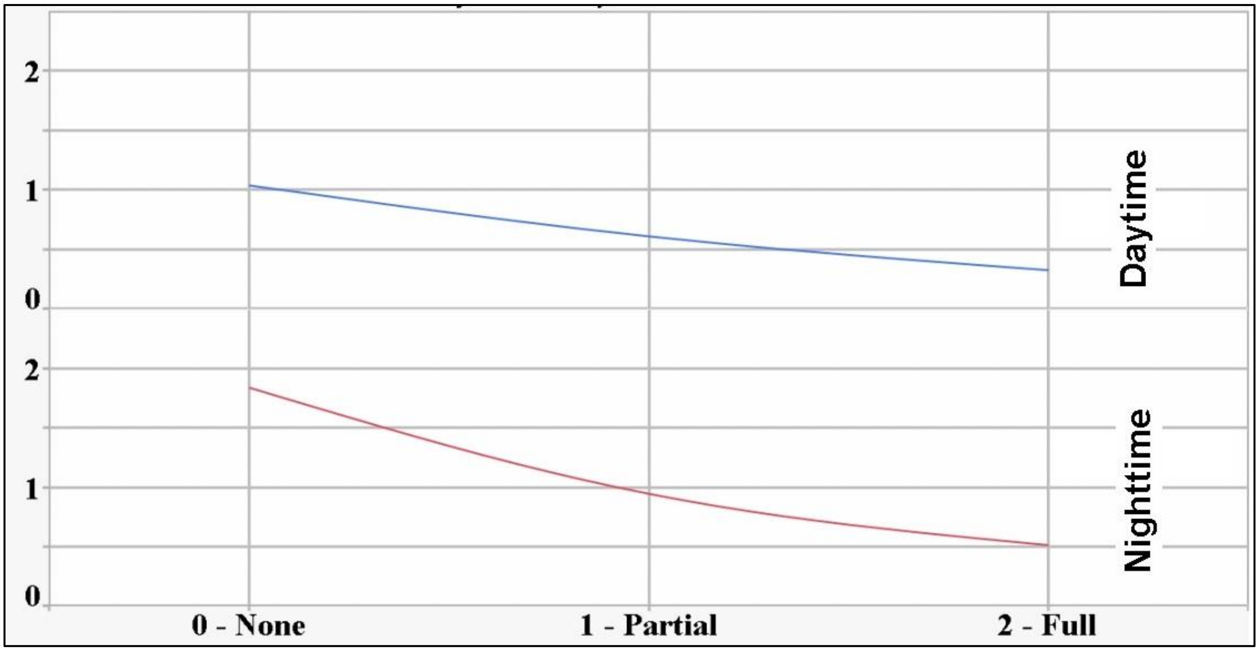


Figure 7 Comparison of Total Nighttime Crash Rates and Total Daytime Crash Rates at Roundabouts (Intersection weighted crashes per million entering vehicles)

Despite the data limitations, it is possible to gauge the impact of these unaccounted safety influencing variables by comparing the crash rate ratios at lit and unlit for both daytime and nighttime using the same sample of roundabouts. Table 9 presents the calculated crash rates and crash rate ratios at lit and unlit roundabouts for both nighttime and daytime.

There are many safety influencing variables, such as intersection geometry, which could not be accounted for in this analysis mainly because of data limitations. However, it is important to analyze the results in a way that minimizes the influence of such unaccounted for variables so there will be higher confidence in the attributing the results to the effect of illumination.

To do this, the ratio of nighttime crash rates at lighted roundabouts to nighttime crash rates at unlit roundabouts was compared to the ratio daytime crash rate at roundabouts with installed lighting to daytime crash rate at roundabouts with no installed lighting. These ratios can be calculated from the data shown in Table 9 which presents the calculated crash rates at lit (or roundabouts with installed lighting) and unlit (or roundabouts without installed lighting) roundabouts.

Table 9 Estimated Crash Rates at Lit and Unlit Roundabouts **(crashes per million entering vehicles)**

	Intersection Weighted			Volume Weighted		
	Lit	Unlit	Ratio	Lit	Unlit	Ratio
Mean Nighttime Crash Rates	0.75	1.85	0.40	0.72	2.04	0.35
Mean Daytime Crash Rates	0.48	1.04	0.46	0.46	0.98	0.47

It can be inferred from the crash rates in Table 9 that during the daytime the average crash rate at roundabouts with installed lighting is about 47 percent of the average crash rate at roundabouts without installed lighting. However, during the nighttime the average crash rate at roundabouts with installed lighting is only 38 percent of the average crash rate at roundabouts without lighting. Therefore, it obvious that the set of roundabouts with installed lighting generally experienced a lower average crash rate than the set of roundabouts without lighting under both nighttime and daytime conditions. However, the presence of lighting at nighttime further reduced the crash rates experienced at the lighted roundabouts compared to that experienced at unlit roundabouts.

If the nighttime safety benefit of illumination at roundabouts, found in this study, was mainly due to the other safety influencing features rather than lighting then one would have expected the nighttime and daytime ratios calculated from Table 9 to be comparable. However, this is not the case; the nighttime ratios are about 19 percent less than the daytime ratios.

This shows that the unaccounted safety variables may not have a major impact on the findings from this study. Therefore, the observed findings can be attributed to intersection illumination. Although, a more detailed analysis would have been preferred, the analysis of these ratios presents the most practical approach given the current data limitations.

SUMMARY FINDINGS

This report presents the findings of a roundabout safety analysis performed with crash data from Minnesota. The results show the observed effect that the provision of lighting at roundabouts can have on safety.

While the data used in this study is believe to be the best currently available, the data retain significant issues that could impact the validity of the analysis. These include: (a) an inability to separate into before and after case scenarios; (b) the locations and types of roundabouts considered (i.e. only on the State or U.S. highway system) and (c) the number of roundabouts available to analyze (sample size). These challenges limit the scope and nature of analyses that can be performed and affects the level of detail that the analysis can achieve.

Despite these challenges, the results indicate that lighting can provide significant benefits at roundabouts relative to unlit roundabouts. This study finds that the mean nighttime crash rate for roundabouts without lighting is significantly higher than what is experienced at lighted roundabouts. For the studied roundabouts the illuminated roundabouts had an approximately 62 percent lower crash rate compared to unlit roundabouts.

The results also show that different illumination levels or categories provide direct safety benefits compared to the unilluminated situation. Also, there are incremental benefits in changing from one illumination category to a higher one. The study finds average reduced crash rates of between 55 percent and 73 percent respectively for partial and full illumination when compared to unilluminated. Also, converting from partial to full illumination can provide average incremental safety benefit ranging from 39 percent reductions in nighttime crash rate.

The main difference between “Partial” and “Full” lighting is that the transition zones on the approaches are also illuminated under “Full” lighting while “Partial” lighting focuses on only the roundabout circle. In NCHRP 672 the minimum recommendation for transition zone length was increased from 260ft (*4*) to 400ft (*5*). It is fair to assume that this increase of more than 50 percent in the recommended minimum transition zone length would help roundabouts with full illumination to provide significantly higher safety performance than those with only partial illumination. However, this study finds that about 68 - 83 percent of benefits that can be gained from full illumination can be achieved with only partial illumination.

Last, the results further show that the provision of lighting at roundabouts can significantly impact both fatal and severe injury crashes. However, it is critical in considering these potential benefits of lighting to recall that these comparisons are for unlit to lit roundabouts. As seen throughout the literature roundabouts generally have very low crash rates compared to conventional intersections. The impact in frequency of incidents due to lighting may not be justified in terms of an overall safety program where funds may be needed to reduce more substantial risks to the public elsewhere. Making these decisions requires access to additional decision making tools, such as a Benefit to Cost Model to be provided in Phase 2.

REFERENCES

1. Forrest, M. and M. Yussuf. Highway Safety Information System Guidebooks for the Minnesota State Data Files. 2007. Washington, DC
2. Modern Roundabout - Inventory Database. Downloaded on 12/22/2013. http://roundabout.kittelson.com/Roundabouts/Search
3. Isebrands, H., S. Hallmark, Z. Hans, T. McDonald, H. Preston, and R. Storm. Safety Impacts of Street Lighting at Isolated Rural Intersections. 2004. MDOT,
4. Robinson, B., L. Rodegerdts, W. Scarborough, W. Kittleson, R. Troutbeck, W. Brilon, L. Bondzio, K. Courage, M. Kyte, J. Mason, A. Flannery, E. Myers, J. Bunker, and G. Jacquemart. Roundabouts: An Informational Guide. FHWA-RD-00-067, 2000.
5. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnsonm, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R.B. Crown, B. Guichet, and A. O'Brin. Roundabouts: An Informational Guide, 2nd Ed. NCHRP 672, 2010. Transportation Research Board