# SCREENING NEEDS FOR ROADWAY LIGHTING BY EXPOSURE ASSESSMENT AND SITE-PARAMETERS

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## ABSTRACT

Current screening methods that assess the potential for roadway lighting to decrease nighttime crashes have not been updated since the 1970's. The existing methods dilute the influence of important factors and are inadequate for roadways where crash histories are unavailable. In this effort a two-part method for the screening of needs for roadway lighting is developed. First, an exposure assessment describes individual and population exposures to crashes, comparing projects by night-to-day crash rate ratios and traffic volumes. Outcomes of exposure assessment are based on potential crash reductions and costs of available lighting technologies. Second, a site specific analysis applies a set of eight engineering factors that suggest lighting would have benefit. Night crash histories on over eighty unlighted sections in three regions of Virginia are collected and studied in testing of the method. The effort has importance across transportation systems for screening of needs for visibility improvements.

## 1 INTRODUCTION

### 1.1 Background

A general understanding of fixed roadway lighting is built on studies by Wilken et al. (2001), Kramer (1999, 2001), ANSI (2000), Cottrell (2000), Edwards (2000), IES (2000), Walton (2000), Watson (2000), Gransberg (1998), Sandhu (1992), APWA (1986), and Janoff (1984, 1986). Safety benefits of lighting are investigated in Dewar and Olson (2002), Trivedi (1988), Janoff (1984, 1986), and Marshall (1970).

Benefit-to-cost analysis for lighting is described by IADOT (2001), NYMTC (2001), McFarland and Walton (2000), Janoff and McCunney (1979). Understanding of fixed roadway lighting design and engineering is provided by Staplin et al. (2001), Khan et al. (2000), Garber (2000), Couret (1999), Crawford (1999), Shaflik (1997), Jefferson (1994), FHWA (1993), and Janoff and Zlotnick (1985).

FHWA (1978) describes a lighting *warrant* as factual evidence that there is a reason for a proposed need and that meeting a warrant does not obligate an agency to undertake the project. Meeting of a warrant suggests that the proposed need be considered further in the view of what resources are available, the traffic, the severity of hazards, and other considerations. Warrants developed by the American Association of State Highway and Transportation Officials (AASHTO 1984) and the National Cooperative Highway Research Program (NCHRP 1974). The current screening methods which were developed in the 1970's require an update to account for the evolution of traffic volumes, automotive technology and modern roadway design. Furthermore, existing methods emphasize accident history, making it difficult to assess needs at new or rebuilt roadways. For example, if an old roadway does not have a high nighttime accident problem relative to daytime it is likely that it will not qualify for lighting unless the roadway has geometrical problems where headlamps become ineffective for illuminating the roadway.

In summary, roadway lighting is an effective safety countermeasure against night crashes and for a general safety improvement along our highways. Well-designed roadway lighting improves visibility during nighttime, thereby enhancing driving conditions. However, a highway agency has limited resources and cannot carry out all projects presented annually. There is thus the opportunity for research to develop a screening method of potential needs for fixed roadway lighting.

### 1.2 Purpose and Scope

The current effort develops a screening method to establish priorities for locations that are identified as being in need of fixed roadway lighting installation or upgrade. The overall approach is to develop and suggest needed evolutionary changes to the existing screening methods (AASHTO 1984 and NCHRP 1974). The effort ensures that an encompassing set of quantitative and qualitative assessments can be considered in the development of lighting needs screening method. The two situations addressed are: roads where there are data on existing travel conditions, and new or totally reconstructed roads where there are partial or no data on existing travel conditions. We have concentrated on fixed roadway lighting but the principle of the method developed can be adapted to screen other needs for visibility improvements. The effort does not address lighting design or particular lighting fixtures.

This report begins with the strategy followed to develop the screening method. Then the two constituents of the method, exposure assessment and site parameters assessment, are developed. Next the data collection and analysis that were performed to support the assumptions and validate the method are described. Then examples are provided to illustrate the use of screening method. Finally conclusions and recommendations are provided.

## 2 METHOD OF ANALYSIS

### 2.1 Overview

A new screening method to determine lighting warrants is developed. The context of the screening method is established and followed by the development of the two major parts of the method: exposure assessment and site-parameters assessment.

Potential lighting needs range from new construction, road alterations, to requests from localities to improve lighting. For example, a rural interstate may currently be unlighted but a newly constructed transit warehouse facility with a well lit parking area may cause veiling luminance problems prompting a request for installment of fixed roadway lighting to alleviate the problem. A screening decision is based on both exposure assessment and site parameters assessment. Exposure assessment relates individual and population exposures to crashes by comparing night-to-day crash rates with traffic volume. Site parameters assessment is performed by identifying a list of engineering factors that individually justify lighting as a beneficial method of visibility improvement for a specific section of road.

### 2.2 Exposure assessment

Exposure assessment, the first part of the screening method consists of a streamlined benefit-to-cost analysis, based on the relationship established among a set of regional parameters, lighting costs, night-to-day crash rate ratio, and average daily traffic (ADT). First, the concept will be detailed. Second, a graphical interpretation will be demonstrated to yield a screening decision for the exposure assessment.

A benefit-cost analysis for roadway lighting justification will consider several important attributes to determine whether the benefits of lighting potentially exceed the costs (Lambert and Turley 2003). A benefit-to-cost ratio is defined to be the ratio of the expected cost of the night crashes avoided per year by installing lighting to the annualized cost of lighting as follows.

$$B/C = \frac{365 \times ADT \times \%N\_ADT \times N/D \times DCR \times CRF \times ACC}{100{,}000{,}000 \times (AIC + AMC + AEC)}$$

The parameters ADT, %N_ADT, N/D, DCR, CRF, ACC, AIC, AMC, and AEC are as defined in Table 1.

Table 1. Benefit-to-cost ratio parameters for the exposure assessment

| Code | Parameter | Unit |
|---|---|---|
| **ADT** | Average daily traffic | vehicles per day |
| **%N ADT** | Percentage of night traffic | % of average daily traffic |
| **N/D** | Night-to-day crash rate ratio | - |
| **DCR** | Day crash rate | crashes per 10^8 miles traveled |
| **CRF** | Crash reduction factor | % of current crashes |
| **ACC** | Average crash cost | $ per crash |
| **AIC** | Annualized installation cost of lighting | $ per year per mile |
| **AMC** | Annual maintenance cost | $ per year per mile |
| **AEC** | Annual energy cost | $ per year per mile |

Figure 1 shows the application the equation to the screening of needs. For a benefit-to-cost ratio equal to 1.0, the extreme values of the interval calculation generate two curves separating three zones in the graph: (i) *accepted,* whose needs have exposure and severity such that the B/C ratio exceeds 1.0 for all possible values of the exogenous parameters, (ii) *marginal*, whose needs are such that the B/C ratio exceeds 1.0 for some possible values of the exogenous parameters, and (iii) *rejected*, whose needs are such that the B/C ratio cannot exceed 1.0 for any possible values of the exogenous parameters.

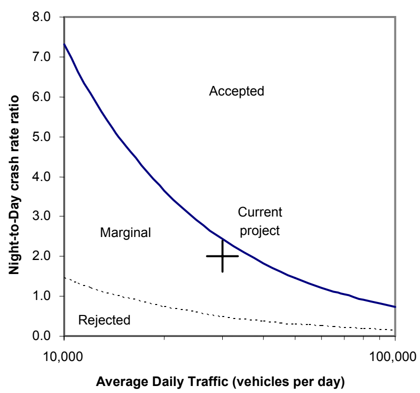


Figure 1. Display that assesses the exposure of the population versus the severity of crashes

Lighting needs can be plotted, such as at the cross, in such a graph and their position in terms of exposure and severity relative to the three zones yields the screening decision for the exposure-assessment phase.

**2.3 Site-parameters assessment**

An exposure assessment alone should not be sufficient for a screening decision in that a need justified by severity and exposure parameters may have no feasible remedy in roadway lighting. Thus this second phase of site-specific parameters assessment addresses the potential efficacy of a lighting remedy through development of a set of eight factors that represent local design and engineering characteristics of the road section. First the current the concept of site parameters assessment is detailed. Next the worksheet used to perform the site parameters assessment is shown and all parameters are described. Finally the method to evaluate a need in application of the site parameters assessment is explained.

Table 2 represents the worksheet developed for the site parameters assessment part of the screening method.

Table 2. Site parameters assessment worksheet

| Factor | Low | Moderate | High |
|---|---|---|---|
| Traffic mix (percentage of qualified trucks in the overall traffic) | 0 – 15 % | 15 – 25 % | > 25 % |
| Veiling Luminance (percentage of luminous development frontage) | 0 – 25 % | 25 – 70 % | 70 – 100 % |
| Curvature and grade | | | |
| Curvature | < 3 ° | 4 ° - 5 ° | ≥ 6 ° |
| Grade | Level - Rolling | Mountainous | No Score |
| Lane configuration (Lane width or | > 11 ft | < 10 ft | No Score |
| Number of lanes) | 6 or less lanes undivided | 6 or more lanes divided | |
| Section/Intersection geometry | | | |
| (Sight distance or | 500 ft | ≤ 400 ft | No Score |
| Median width or | 12 - 30 ft | ≤ 12 ft | |
| Shoulder width or | > 7 ft | ≤ 7 ft | |
| Intersection/Interchange frequency) | 2 /mile | ≥ 3 /mile | |
| Posted Speed | < 45 MPH | > 55 MPH | No Score |
| Level of Service | D or better | E or worse | No Score |
| Intermodal transactions | | | |
| Distance to tourist, elderly venues and intermodal platforms | 1 mile | ½ mile | No Score |
| Adjacent Parking Spaces | Prohibited both sides | Permitted both sides | No Score |
| **Number of grades** | 9 | 0 | 0 |

**3 RESULTS**

Several studies of crash data were performed in order to test the exposure assessment of the screening method. The studies included accident histories of three regions in Virginia. The results from these studies were used in conjunction with the screening method to produce appropriate warranting thresholds based on past crash data.

**3.1 Study of crash data from Richmond District: Unlighted nodes in crash record system**

We studied a five-year long data-set of all the recorded crashes in a region of central Virginia from January 1, 1997 through December 31, 2001 (over 122,000 crashes). The crashes were related to nodes, i.e.

intersections, landmarks or other milestones of the roadway formally described and stored in an agency database. The data set included many fields of information, including the lighting description at the time of the crash, ADT, lane configuration, and type of injury that occurred in the crash.

In order to evaluate the night-to-day crash rates from the data we used the following formula, based on the standard assumption that ¼ of the total traffic occurs at night in the dark hours:

$$Night-to-Day\_Crash\_Rate\_Ratio = 3 \times \frac{Night\_Crashes}{Day\_Crashes}$$

The first study analyzed the entire data set as well as three separate roads through Richmond: Routes 1, 60, and 250. The primary data included the night-to-day crash rate ratio, ADT, and the lane configuration of the roads. Table 3 shows the results from Route 60.

Table 3. Night-to-Day crash rate ratios on Rt. 60 in Richmond District

| ***Route 60*** | | Road Type | |
|---|---|---|---|
| ADT | 2 Lanes | 4 lanes undivided | 4 or more lanes divided |
| <10,000 | 2.25 | 1.82 | 3.01 |
| 10,000-20,000 | 1.78 | 1.02 | 2.31 |
| >20,000 | 0.33 | 1.15 | 0.93 |

From this study we can see that along Route 60 with lower ADT, there appears to be a much higher occurrence of crashes during dark hours. Typically, a night-to-day crash rate ratio of 2.0 or greater is an indication that lighting could be beneficial along that road.

The purpose of this study was to identify areas of the roads that were susceptible to higher nighttime accident rates. As a broad tool it was effective, but a more pointed study of individual nodes was needed. To obtain the night-to-day crash ratios for each node, we first had to decide which nodes we wanted to include in our analysis. We sought to find the nodes that had primarily unlighted crashes. However, there were very few nodes that were totally one type of crash (lighted or unlighted). We decided that nodes with 2/3 more crashes on unlit sections should be considered unlit nodes.

In order to analyze nodes that would have the greatest impact on our study, we focused on nodes with the highest crash totals in the database. The 60 nodes with 80 crashes or more were chosen. Out of these 60 nodes, 37 had two-thirds of their crashes reported as unlighted night crashes. The maximum crash rate was 2.73 out of these nodes, the mean was 1.18. Figure 2 shows the result of the above study in terms of nodes on a plot of ADT vs. night-to-day crash rate.

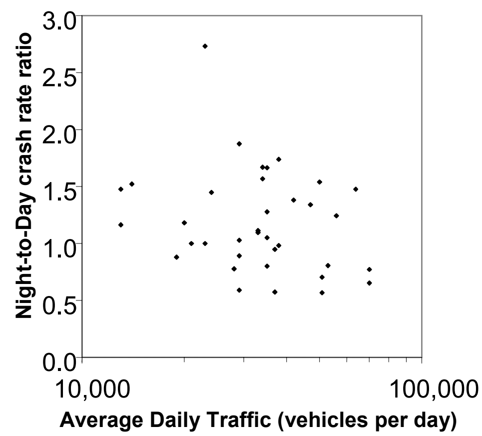


Figure 2. Summary of the Night-to-Day crash rate ratios collected for nodes in Richmond District

### 3.2 Study of crash data: Unlighted two-mile sections

Next, a study of night-to-day crash-rate ratios was performed on a selection of two-mile sections of unlighted road in a six-year period between January 1, 1996 and December 31, 2001. The sections were selected from three regions: Tidewater Virginia, Central Virginia, and Northern Virginia. The selected sections were stratified by average daily traffic, posted speed and lane configuration. We collected the number of crashes under each of daytime conditions and nighttime conditions, extracting the sum of property-damage-only, injury, and fatal crashes. In addition, we collected the average daily traffic for each section.

From the HTRIS database we collected three data for each section: number of daytime accidents, number of total accidents, and the exact length of the section. We searched the database for all accidents occurring between January 1, 1996 and December 31, 2001, resulting in a six-year period. The total number of crashes included property damage only (PDO) accidents, injury accidents, fatal accidents, and pedestrian accidents. Next, we calculated the indirect night-to-day crash rate ratios for each of the roadways. We made the typical assumption that the amount of traffic occurring at night is 25% of the total ADT. The exact values of the ADT were located in the 2001 Virginia Department of Transportation average daily traffic volumes record book.

The results produced by the HTRIS queries reveal a range of indirect night-to-day accident ratios between 0.25 and 10.32. The smallest reported crash ratios appear at an ADT of less than 10,000 (0.500 for 2-lane, and 0.789 for 4-lane divided road sections). A trend is that lower crash rates are associated with lower ADTs. However, it is also noteworthy that some of the highest crash rates are found at the higher speed stratification (3.0 and 3.5 at 55 MPH). This relationship indicates that a combination of more lanes, and higher ADTs would lead to the highest crash ratios, though currently there are no data points in these stratifications.

### 3.3 Indirect estimation of night-to-day crash rate ratio

An outcome of the two-mile sections study is to be able to predict potential crash ratios for roadways where accident data is not available, such as new or altered roads. For roads where accident data is not available, the stratification of the road can be compared to those provided in Table 3. The average night-to-day crash rate ratio for that stratification can be assumed for the corresponding roadway with no data.

Table 3. Indirect night-to-day crash rate ratio estimation table

| | ADT | | | | | |
|---|---|---|---|---|---|---|
| **Operating Speed MPH** | **<10,000** | | **10,000-20,000** | | | **>20,000** |
| | **2 lane** | **4 lane div.** | **2 lane** | **4 lane div.** | **4 lane undiv.** | **4 lane div.** |
| **45 MPH** | 1.33, 1.09, 10.32 | 1.67 | 0.38, 1.06, 1.52, 1.74 | - | 1.23, 1.33, 1.35, 1.40, 2.33, 3.32 | 1.08, 1.11, 1.50, 1.80, 1.93, 2.02, 2.09, 2.23, 2.28 |
| **55 MPH** | 0.25, 0.50, 1.24, 1.65, 1.83, 3.00 | 0.79, 1.50, 3.50 | 1.86 | 1.01, 1.48, 1.85, 2.01, 2.40, 3.21 | 1.00, 1.20, 2.16 | 1.25, 1.43 |

It is possible to predict the night-to-day crash rate ratio of a section of road knowing only its characteristics or stratification variables of the indirect night-to-day crash rate ratio estimation Table 3. This indirect evaluation is then used in the exposure assessment phase of the screening method. In order to account for the uncertainty introduced by this indirect estimation, the values of the "indirect night-to-day crash rate ratio" table can be rescaled by a coefficient. For example, on average, two lane roads with a posted speed below 45 MPH and an ADT below 10,000 were found to have a Night-to-Day crash rate ratio of 1.25, so the value used in the screening method for such a roadway considered is 1.25 x 0.50 = 0.63. Based on the AASHTO warranting method, a value of 0.50 would represent our most defensible value. In its warrants the AASHTO compares the Night-to-Day crash rate ratio of the considered roadway to the average on similar sections. The threshold value to pass the screening method is 2.0, which leads to our recommendation of the scaling factor of 0.50 stated above (AASHTO 1984). However, the use of the "indirect night-to-day crash rate ratio" table might be restricted to Virginia since it is based on data collected in this state. It should also be noted the regional table should be updated regularly to account for the evolution of the crash rate in the state.

### 3.4 Integration of two-mile sections study with unlighted nodes study

Figure 3 below shows the results of the data sets collected in three districts in Virginia: Richmond, Northern Virginia and Hampton Roads.

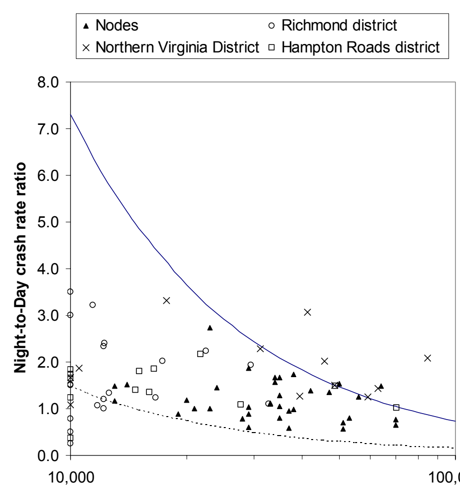


Figure 3. Exposure data display of the data collected in three districts in Virginia

The data set titled "Nodes" summarizes the data collected in the report section "Study of crash data: Unlighted nodes from Richmond district." The data sets with district names summarize the section "Study of crash data: Unlighted two-mile sections." Needs are displayed on the exposure assessment chart of the screening method, so that a particular need can be compared to a regional set of need for further investigation.

### 3.5 Application of the screening method

In order to illustrate the application of the screening method, four roadway sections were studied:

- Example 1: Intersection of Route 460 and Route 1
- Example 2: Intersection of Route 1 and Route 226
- Example 3: Interchange of Route 460 and Interstate 85
- Example 4: Section of Route 460 from Route 1 to Route 632

Figure 4 represents the exposure assessment evaluation for all four examples.

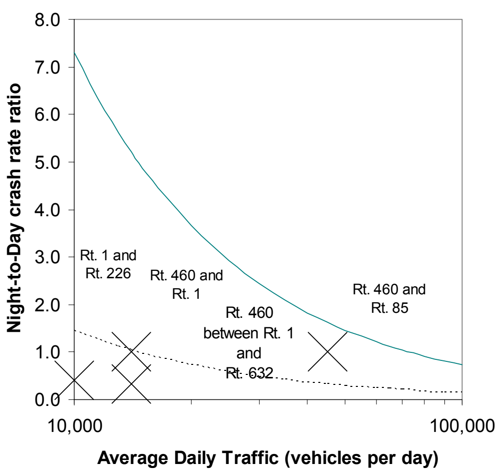


Figure 4. Summary of the exposure data for four examples of application of the screening method.

The first part of the screening method rejects Examples 1, 2, and 4, while Example 3 receives a score of "Marginal." The site-parameters assessment is now used to score the individual characteristics of the roads. Table 4 summarizes the site-parameters assessment for all four examples. The information for each was garnered from previous NCHRP forms and also shows their original NCHRP scores and warranting thresholds in order to evaluate the legitimacy of the new method.

Table 4. Summary of the evaluation process for the four examples of the screening method

| Site Parameters Factors | Example 1: Rt. 60 and Rt. 1 | Example 2: Rt. 1 and Rt. 226 | Example 3: Rt. 460 and Rt. 85 | Example 4: Rt. 460 between Rt. 1 and Rt. 632 |
|---|---|---|---|---|
| Traffic Mix | Low | Low | Low | Low |
| Veiling Luminance | Moderate | Low | Moderate | Moderate |
| Curves | Low | Moderate | Low | Low |
| Vehicle Conflict Opportunities | Low | Low | Low | Low |
| Section/Intersection Geometry | Low | Low | Low | Low |
| Adjacent Parking Spaces | Low | Low | Low | Low |
| Posted Speed | Moderate | Moderate | Moderate | Moderate |
| Level of Service | Low | Low | Low | Low |
| Tourist and Elderly Drivers | Low | Low | Low | Low |
| Site Parameters | Marginal | Marginal | Marginal | Marginal |
| Exposure Assessment | Rejected | Rejected | Marginal | Rejected |
| Recommended Decision | Rejected | Rejected | Marginal | Rejected |
| NCHRP Score / Threshold | 38.9 / 75.0 | 46.6 / 75.0 | 45.5 / 75.0 | 37.2 / 85.0 |

Example 3 receives a "Marginal" score for the site-parameters assessment, and it is therefore selected for an expert decision on whether to undertake the lighting project. The other three examples received "Marginal" scores as well, but were ultimately rejected through the filtering process due to their "Rejected" scores from the exposure data.

The NCHRP warranting method rejected all four examples outright based on their score in relation to the warranting threshold. The new screening method shows that for Example 3 there may be a benefit for roadway lighting in order to reduce accidents and potentially save lives.

## 4 CONCLUSIONS

A method has been developed to screen road sections to which the addition of fixed roadway lighting could have significant benefits to reduce crashes. The developed method accounts for the exposure of a motoring population and the severity of the night-to-day effect, particularly with imprecise knowledge of benefit-to-cost ratio parameters. The method furthermore develops a set of engineering factors to address the design configuration and other relevant characteristics of the sections. The use of the method is to recommend needs that qualify for further investigation. The method thus promotes a reasoned and effective use of resources in the implementation of roadway lighting. The developed screening method can be incorporated with holistic master planning of roadway lighting, which can reflect the needs and values of regions and localities. A method to assess indirect crash rate has been devised when no crash history is available. It uses a stratification of roadways by traffic volume, posted speed and lane configuration.

This effort focused on fixed roadway lighting as a means to improve safety in driving at night. It would be beneficial to have lighting compete against other technologies for the most cost-effective safety improvement.

## 5 RECOMMENDATIONS

The overall recommendations of this study are as follows: VDOT should train appropriate staff in the use of the screening method. The method presented in this report should supersede the NCHRP and AASHTO methods developed since the 1970's. The results of this study should be explored at the national level with AASHTO, FHWA, LITES, and NCHRP. Regional data collection and screening should be made regular using the method. Study of roadway lighting should be harmonized with the generation of critical rate listings. The method should be revisited as technology evolves and use pattern change, in particular in distinguishing (i) evidence that any visibility improvement is beneficial to safety from (ii) evidence that lighting or any other available technology is uniquely beneficial. A trial period should be planned for the purpose of evaluation and refinement of the developed screening method. The method should be incorporated in the development of holistic master planning that reflects the specific needs of regions and localities. Overall, lighting should be taken seriously as a measure for crash prevention. Localities and regions should have designated budgets for lighting and our developed screening method should support the allocation of these funds. Implementation of the above recommendations will involve various personnel and resources at residency, district and central offices.

## 6 ACKNOWLEDGEMENTS

We would like to thank the following members of the Lighting Project Steering Committee for their guidance and support: Benjamin Cottrell, Wayne Ferguson, Michael Perfater, Steve Brich, Travis Bridewell, Pamela Brookes, Chandra Clayton, Butch Cubbage, Jim Gillespie, Mark Hodges, Ilona Kastenhofer, Karen Rusak, Jon Sayyar, Al Smith, and Carl Anderson. We appreciate the help of Bob Rasmussen, Ralph Jones, and Llewellyn Slayton with data collection.

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