Accident Analysis and Prevention 53 (2013) 65–77

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

To illuminate or not to illuminate: Roadway lighting as it affects traffic safety at intersections

John D. Bullough [a], Eric T. Donnell [b], Mark S. Rea [a,*]

[a] Lighting Research Center, Rensselaer Polytechnic Institute, 21 Union Street, Troy, NY 12180, USA
[b] Department of Civil and Environmental Engineering, The Pennsylvania State University, University Park, PA 16802, USA

ARTICLE INFO

Article history:
Received 14 May 2012
Received in revised form 3 October 2012
Accepted 20 December 2012

Keywords:
Lighting
Safety
Regression analysis
Visual performance
Crash reduction

ABSTRACT

A two-pronged effort to quantify the impact of lighting on traffic safety is presented. In the statistical approach, the effects of lighting on crash frequency for different intersection types in Minnesota were assessed using count regression models. The models included many geometric and traffic control variables to estimate the association between lighting and nighttime and daytime crashes and the resulting night-to-day crash ratios. Overall, the presence of roadway intersection lighting was found to be associated with an approximately 12% lower night-to-day crash ratio than unlighted intersections. In the parallel analytical approach, visual performance analyses based on roadway intersection lighting practices in Minnesota were made for the same intersection types investigated in the statistical approach. The results of both approaches were convergent, suggesting that visual performance improvements from roadway lighting could serve as input for predicting improvements in crash frequency. A provisional transfer function allows transportation engineers to evaluate alternative lighting systems in the design phase so selections based on expected benefits and costs can be made.

1. Introduction

A primary purpose for installing roadway lighting is to increase the visual range afforded by vehicle headlamps while driving at night (IES, 2000). It is generally believed that roadway lighting improves safety by reducing the frequency of crashes occurring at night through improvements in driver visibility. Some studies have examined statistical associations between roadway lighting presence and traffic safety, making no explicit assumptions about the role of visibility in mitigating nighttime crashes. Generally, the results from these studies (IES, 1989; Elvik, 1995) have led to the general conclusion that roadway lighting is associated with a reduction in the night-to-day crash ratio (CIE, 1992). A night-to-day crash ratio reduction of approximately 30% has been suggested for the overall crash safety effect from roadway lighting (CIE, 1992).

Most studies of roadway lighting and safety consider lighting as a binary variable (i.e., present or not), but several attempts to relate specific characteristics of roadway lighting and safety have been made, using various photometric measures as surrogates for visibility. One early study was undertaken by Box (1971) where he compared the ratio of night-to-day crash rates along 22 lighted and unlighted highway sections. The author grouped the highway sections into categories corresponding to mean horizontal illuminance levels between 3 and 6 lx, between 8 and 11 lx, and between 13 and 15 lx. Presumably, higher illuminances would result in greater visibility and might be expected to yield fewer nighttime crashes. The lighted sections had lower night-to-day crash rate ratios than the unlighted sections, but the lowest night-to-day crash rate ratio was found for the 3-to-6 lx category, with higher night-to-day crash rate ratios for the two higher illuminance categories. In a different study, Box (1976) evaluated the impact of reducing illuminance levels along a major highway from 14 lx to 9 lx and found that nighttime crash frequency increased by 10%, although daytime crash frequency also increased (by 4%). In comparison, Scott (1980) measured roadway luminance levels along 89 (each at least 1 km in length) two-lane roadway sections. Despite a great deal of variability in night-to-day crash ratios among all of the sites, a best-fitting exponential function to the data yielded a monotonically decreasing relationship between night-to-day crash ratios and luminance level, consistent with Box (1976) but inconsistent with Box (1971). The lack of agreement across these studies could be related to differences among the specific locations studied (e.g., roadway geometry or traffic control) or different evaluation paradigms (e.g., before/after or with/without comparisons). Even considering these differences, it is important to account for all the factors that could affect visibility. In particular, the impact of lighting on visual performance depends upon the contrast and the size of a hazard, not simply upon illuminance or luminance levels provided by the roadway lighting system.

* Corresponding author. Tel.: +1 518 687 7100; fax: +1 518 687 7120.
E-mail addresses: ream@rpi.edu (M.S. Rea).
URL: http://www.lrc.rpi.edu (M.S. Rea).

0001-4575/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aap.2012.12.029

In an attempt to relate specific measures of visibility associated with roadway lighting to safety, Janoff et al. (1978) studied nighttime crash frequency and measured photometric conditions along several roadways, and found nighttime crash frequency to have a weak inverse relationship with a visibility metric they derived, which was based on the ratio between an object's luminance contrast and the contrast it would require to be just visible. Also, Keck (2001) summarized a different study of roadway lighting, visibility and safety and reported that a similar visibility metric was not correlated with the frequency of nighttime crashes unless headlamp illumination was also considered. Even then, the statistical association was modest in magnitude (coefficient of determination $r^2 = 0.12$).

In addition to the above issues related to study locations and evaluation methods, a factor that makes it difficult to assess the relationship between fixed roadway illumination systems and traffic safety is that lighting is installed for a variety of reasons (e.g., security, esthetics). Moreover, lighting is usually not the only roadway safety feature that is installed when a roadway is designed or improved (IES, 1989). For example, lighting may be installed when converting a stop-controlled to a signalized intersection, or may be installed when threshold levels of pedestrian or vehicular volumes, or annual crash frequencies, are exceeded. Thus, the estimates of association between roadway lighting presence and nighttime crashes in past studies may be confounded by other modifications to the study site.

In the present paper, an exploratory strategy is presented to test the theoretical links among roadway lighting, visibility, and safety while accounting for as many potential safety-influencing variables as possible. To overcome previous limitations in the literature, our goal was to determine if we could establish convergence between statistical and analytical approaches to crash safety. Thus, both statistical and analytical approaches were undertaken to relate crash frequencies to visual performance levels for *the same set of roadway lighting conditions*. Donnell et al. (2010) merged roadway lighting presence and roadway geometric and traffic volume and control data with daytime and nighttime crash data to assess the statistical association between roadway intersection lighting presence and the night-to-day crash ratio in Minnesota. In their study, many potential safety-influencing variables that were not considered in previous lighting-safety research were included in the statistical model estimation. In a parallel but independent investigative domain, Rea et al. (2010) developed photometric simulations of a large variety of roadway intersection lighting configurations to make context-specific predictions of visual performance levels provided by roadway lighting systems varying in light level, spatial configuration, and ambient characteristics for drivers of different ages.

Here we present a methodology to link roadway lighting characteristics to visual performance levels and, therefore, to traffic crashes. Importantly, our objective was to test whether there is convergence between statistical and analytical approaches, which would bolster the expected relationships among lighting presence, improved visibility, and improved safety. Each approach reduces the inherent uncertainty associated with the other by providing an independent basis to explore the theoretical relationship between roadway intersection lighting and reductions in nighttime crashes through improvements in driver visual performance.

The present paper summarizes the parallel statistical and analytical approaches, developed by Donnell et al. (2010) and by Rea et al. (2010), respectively, used to probe the theoretical relationship described above. First, the background, methods and results of each independent approach are provided; next, the evidence for the convergence of these approaches is described. As stated above, the approaches used in this paper are described in previous publications (Donnell et al., 2010; Rea et al., 2010); the present paper describes how these approaches were adapted for different roadway intersection types in Minnesota.

If the necessary links between roadway lighting, visual performance and traffic safety can in fact be forged through converging approaches, it could then be possible for traffic engineers to improve traffic safety by considering the visual performance levels and the costs of proposed roadway illumination systems through a provisional proposed transfer function relating visibility from lighting to crash safety.

2. Description of parallel approaches

In the present section, the statistical modeling and the visual performance modeling are described together with the findings from these two approaches.

2.1. Statistical modeling

2.1.1. Background

A significant body of published literature consistently shows that fixed roadway lighting improves intersection safety. Observational before-after studies and with–without cross-sectional comparisons have been used to support these findings. The measures used to evaluate the effects of roadway lighting differ across studies. With regard to observational before-after studies, several authors used reported nighttime crash rates (Walker and Roberts, 1976; Lipinski and Wortman, 1978) as the safety performance measure. These studies found that roadway lighting was associated with reduced nighttime crash rates of 45–52%. Other authors (Walker and Roberts, 1976; Schwab et al., 1982; Green et al., 2003; Isebrands et al., 2004, 2006) reported 13–49% reductions in reported nighttime crash frequencies attributed to lighting. Reductions in reported night-to-day crash ratios of 22–40% have been documented in other observational before-after studies related to roadway lighting (Lipinski and Wortman, 1978; Preston and Schoenecker, 1999; Isebrands et al., 2004, 2006).

With regard to with–without cross-sectional comparisons, the published literature also indicates that roadway lighting appears to be an effective safety countermeasure. The results of previous studies have found that nighttime crash rates are 25% lower at lighted intersections when compared to unlighted intersections (Preston and Schoenecker, 1999); reported nighttime crash frequencies are 39% lower at lighted intersections (Schwab et al., 1982). Night-to-day crash ratios are 31% lower at intersections with lighting when compared to intersections without lighting (Isebrands et al., 2004, 2006).

More recently, an estimate of the safety effect of at-grade intersection lighting was published by Harwood et al. (2007), using the results of a meta-analysis of published literature from Elvik and Vaa (2004). Harwood et al. (2007) estimated that an appropriate accident modification factor for the presence of lighting is 0.96, or a 4% reduction in total crashes after the installation of roadway lighting (this corresponds to a larger percentage of nighttime crashes, since roadway lighting is only of benefit at night). This result is published in the first edition of the American Association of State Highway and Transportation Officials' *Highway Safety Manual* (AASHTO, 2010).

While many of the previous lighting-safety studies appear to offer similar results using a variety of measures (i.e., nighttime crash rates, nighttime crash frequencies, night-to-day crash ratios), there are limitations to these studies. First, much of the published literature evaluates the safety effects of roadway lighting based on crash rates or crash frequencies using reported crash data. Crash rates assume a linear relationship between crashes and traffic volume, which may not necessarily be the case, particularly at intersection locations (e.g., Poch and Mannering, 1996;