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Safety effects of reducing freeway illumination for energy conservation

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ABSTRACT

The addition of illumination where none was present is generally believed to have a positive effect on motor vehicle safety; reducing the frequency, as well as the severity of crashes. The operational cost of illumination, however, can make it a candidate for conservation during periods of high energy costs. In response to a forecasted energy shortage, the Oregon Department of Transportation selectively reduced illumination on interstate highways as part of an energy-saving effort. The reductions occurred at 44 interchanges and along 5.5 miles of interstate highway. This paper presents the results of a crash-based analysis of the changes in safety performance using an empirical-Bayes observational methodology. The study found an increase in reported crashes where the lineal lighting was reduced both in total crashes (28.95%, $P = 0.05$) and injury night crashes (39.21%, $P = 0.07$). Where full interchange lighting was reduced to partial lighting, a 2.46% increase ($P = 0.007$) in total night crashes was observed. Injury night crashes, however, decreased by 12.16% ($P < 0.001$) though day injury crashes also decreased at these locations. Unexpectedly, for interchanges where illumination was reduced from partial plus to partial, a 35.24% decrease ($P < 0.001$) in total crashes and 39.98 ($P < 0.001$) decrease in injury night crashes was found, though again, day crashes also decreased.

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1. Introduction

The addition of illumination where none was present is generally believed to have a positive effect on motor vehicle safety; reducing the frequency, as well as the severity of crashes. The operational cost of illumination, however, can make it a candidate for conservation during periods of high energy costs. In 2001, illegal manipulations of the energy markets in the Pacific Northwest and lower than average snowpack in the Cascade mountains created the perception that future energy shortages were likely. In response, Oregon's governor directed all state agencies to reduce power consumption by 10%. After review of power saving opportunities, the Oregon Department of Transportation (ODOT) elected to selectively reduce illumination on Oregon interstate highways as part of their energy-saving strategy. The illumination reductions occurred at both interchanges and along lineal freeway sections beginning in October 2001. The reductions occurred statewide, with a heavy focus on the Portland metropolitan area freeways (I-5, I-205, I-84, and US-26). An internal agency memorandum directed traffic engineers to select candidate locations for illumination modifications with above average conditions such as good striping, retroreflective signing, standard acceleration and deceleration lanes, typical geometry, and low crash history. Locations with adjacent pedestrian and bicycle facilities (e.g. paths) where highway illumination helped provide security were avoided. In a sense, only the safest locations were chosen for modification.

The reductions that were made fall into three general categories: (1) interchanges where lighting was reduced from a full lighting design to a partial design; (2) interchanges where lighting was from a partial plus design to partial lighting configuration; and (3) interstate freeway sections where mainline lineal lighting was reduced. Definitions of these categories are presented in a later section. A total of 44 interchanges and 5.5 miles of interstate freeway were modified. With the exception of 2.5 miles of the freeway sections, some level of illumination remained on at all locations. While the energy crisis did not materialize, the reductions were kept in place until an evaluation could be conducted since some of the locations were viewed to have excess illumination.

The objective of this paper is to quantify the safety effects of the reductions at these specific locations using an empirical-Bayes observational before–after methodology. Crash, geometry, weather, and volume information were collected for each of the modified locations as well as for a selected reference group. It is important to note that this research was not designed to study the safety effects of alternative lighting configurations at each

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interchange and no conclusions should be drawn about the safety effects of those designs. Changes in illumination were broadly classified and no before or after field measurements were taken of actual luminance values, lighting coverage, or other design specific values.

2. Previous evaluations

Previous work suggests that adding illumination where none was present has a positive effect on motor vehicle safety; reducing the frequency, as well as the severity of crashes on urban streets, highways, and at intersections (Elvik, 1995; Isebrands et al., 2006; Lamm et al., 1985; Walker and Roberts, 1976). Freeway-type facilities with their high speeds, volumes, and design standards are often strong candidates for illumination. There have been several cross-sectional comparisons of the safety differences of lighted and unlighted sections on freeways. An analysis of Minnesota freeways concluded that freeway sections with continuous lighting had significantly less crash potential than unlighted ones (Griffith, 1994). In an another study, Box (1972) studied 203 miles of freeways from the metropolitan areas of Toronto, Chicago, Atlanta, Dallas, Phoenix and Denver and found an average night–day crash rate ratio for lighted sections of 1.43 and 2.37 for unlighted sections. He established that as a group, lighted freeway sections had a lower (better) night/day ratio than unlighted sections. Many other studies are consolidated in Elvik and Vaa's (2004) handbook of road safety measures. Their meta-analysis approach suggests that adding illumination reduces fatal crashes by 64% (−74, −50, 95% CI) and injury crashes by 28% (−32, −25, 95% CI).

The operational cost of illumination can make it a target for conservation during periods of high energy costs. Recent attention to global warming issues has brought renewed interest in efficient consumption of energy. Adaptive lighting system (controlling lighting levels based on traffic demand) have been demonstrated in Netherlands, Japan, and most recently Prince George, Canada (Maclean, 2006). There are, however, few before–after studies of illumination reductions as energy conservation measures on freeway-type facilities. In the late 1970s, a number of state DOTs and local agencies pursued lighting reductions during the energy crisis (AASHTO, 1977). Box (1976) conducted a before-and-after safety evaluation of reducing roadway lighting on State Highway 60 (Gulf-to-Bay Boulevard) in Clearwater, Florida and found that by de-energizing alternate lighting poles day crashes increased by about 4%, while night crashes increased by 10 times as much. The day change was proportional to the 2.5% change in volume which occurred between the two study years involved. In another study, the City of Austin, Texas turned off the continuous freeway lighting on a 7.2 mile stretch of southbound I-35. Crash frequency increased 47% on the unlit southbound sections at night while overall crash frequency declined 22% due in part to the reduction of the speed limit to 55 mph (Richards, 1981). In addition to the studies cited here, a number of other studies are consolidated in Elvik and Vaa's (2004) recent handbook of road safety measures using the meta-analysis approach. The best estimates of safety change following reductions in lighting were reported as a 17% increase (+9, +25, 95% CI) for injury crashes and a 27% increase (+9, +50, 95% CI) for property-damage-only crashes.

Following the energy crisis, there was interest in alternative lighting designs with the goal of energy conservation. Janoff et al. (1986) completed a study comparing six strategies for reduced lighting by conducting field experiments on I-95 in Pennsylvania. The study concentrated on reducing lighting on mainline sections (but a pilot study concluded that driver performance was significantly affected when lights were extinguished at ramp interchanges). Six lighting strategies were compared in a field experiment that determined the distance at which drivers could identify a 6 in. object in the roadway under the various lighting scenarios. In terms of driver performance the strategies from best to worst were full lighting, 75% power, 50% power, every other luminaire extinguished, other side luminaries extinguished, and no lighting. While crash reductions have generally been observed for improvements in lighting, some studies have noted that risk compensation may be present as drivers may increase speed and decrease concentration with the addition of lighting—both of which may reduce safety (Assum et al., 1999; Jorgensen and Pedersen, 2002).

3. Research method

In the literature, a number of methods have been used for observational before–after studies of highway safety: (1) simple approach (naïve before–after); (2) yoked comparison site; (3) comparison group; and (4) empirical-Bayes (EB) methods. The primary challenge in highway safety evaluations is an accurate prediction of the expected number of crashes in the after period had the treatment not been implemented. After this prediction, a comparison can then be made with the estimated number of crashes with the treatment in place. The EB method is considered the state of the art evaluation procedure and can address the regression-to-the-mean phenomena and properly account for changes in traffic volumes and other variables (weather, land use, crash reporting levels, and long-term trends). In the EB method, a multivariate regression model (sometimes referred to as a safety performance function (SPF) is used to estimate the expected crash frequency at the treated locations had modifications not been made. The method has been pioneered by Hauer (1997) and used by many others in recent evaluations (Council et al., 2005; Harwood et al., 2002; Persaud et al., 2001, 2003).

In this study, multivariate regression models calibrated from data of similar sites (reference group) were used as SPFs. The development of these models is discussed in a later section. The procedure for conducting the before–after evaluation is described briefly in the following paragraphs. Complete descriptions of the methodologies are presented elsewhere (Hauer, 1997; Persaud et al., 2003). For each entity (j) for each year (y), the predicted crash count from the SPF – $E(\tau_{j,y})$ – was estimated. The total predicted crashes are then summed; C_b is the sum of predicted crashes in the before period and C_a is the sum of predicted crashes in the after period given in the following equations:

$$C_b = \sum_{j=1}^{n} [E(\tau_{j,y})] \tag{1}$$

and

$$C_a = \sum_{j=1}^{n} [E(\tau_{j,y})] \tag{2}$$

The variance of these counts is estimated with (3) and (4) where ϕ is the overdispersion parameter estimated from the SPFs:

$$\mathrm{VAR}\{C_b\} = \frac{(C_b)^2}{\phi} \tag{3}$$

and

$$\mathrm{VAR}\{C_a\} = \frac{(C_a)^2}{\phi} \tag{4}$$