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Effects of road lighting: An analysis based on Dutch accident statistics 1987–2006

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ABSTRACT

This study estimates the safety effect of road lighting on accidents in darkness on Dutch roads, using data from an interactive database containing 763,000 injury accidents and 3.3 million property damage accidents covering the period 1987–2006. Two estimators of effect are used, and the results are combined by applying techniques of meta-analysis. Injury accidents are reduced by 50%. This effect is larger than the effects found in most of the earlier studies. The effect on fatal accidents is slightly larger than the effect on injury accidents. The effect during twilight is about 2/3 of the effect in darkness. The effect of road lighting is significantly smaller during adverse weather and road surface conditions than during fine conditions. The effects on pedestrian, bicycle and moped accidents are significantly larger than the effects on automobile and motorcycle accidents. The risk of injury accidents was found to increase in darkness. The average increase in risk was estimated to 17% on lit rural roads and 145% on unlit rural roads. The average increase in risk during rainy conditions is about 50% on lit rural roads and about 190% on unlit rural roads. The average increase in risk with respect to pedestrian accidents is about 140% on lit rural roads and about 360% on unlit rural roads.

1. Introduction

The effects on accidents of providing or improving road lighting have been studied extensively. Some studies deal with the effect on injury accidents on urban roads (Tanner and Christie, 1955; Tanner, 1958; Transportforskningskommissionen, 1965; Christie, 1966; Tennessee Valley Authority, 1969; Walthert et al., 1970; Fisher, 1971; Box, 1972a, 1976; Cornwell and Mackay, 1972; Sabey and Johnson, 1973; Fisher, 1977; Jørgensen, 1980; Scott, 1980; Box, 1989), some deal with the effect on injury accidents on rural roads (Transportforskningskommissionen, 1965; Christie, 1966; Walthert et al., 1970; Box, 1972a; Cornwell and Mackay, 1972; Sabey and Johnson, 1973; Mäkelä and Kärki, 2004), some deal with the effect on motorway accidents (Billon and Parsons, 1962; Christie, 1962, 1966; Walthert et al., 1970; Box, 1971, 1972b; Cornwell and Mackay, 1972; Nishimori, 1973; Andersen, 1977; Ketvirtis, 1977; Hilton, 1979; Lamm et al., 1985; De Clercq, 1985; Cobb, 1987; Griffith, 1994; Bruneau et al., 2001), some deal with the effect on pedestrian accidents (Jørgensen and Rabini, 1971; Pegrum, 1972; Polus and Katz, 1978; Zegeer and Zegeer, 1988; Huang et al., 1993; Jensen, 1998), and some deal with the effect on accidents at junctions (Onser, 1973; Lipinski and Wortman, 1976; Walker and Roberts, 1976; Salminen, 1978; Brude and Larsson, 1981, 1985; Schwab et al., 1982; Preston and Sshoenecker, 1999; Green et al., 2003; Isebrands et al., 2004).

The International Commission on Illumination analysed 62 studies from 15 countries about the effect of road lighting (CIE, 1992) on accidents. The average effect of installation of road lighting based on 23 before-and-after studies was 30% reduction in night-time injury accidents. Only one study showed an increase in accidents. The effect on pedestrian accidents was larger than the effect on all accidents.

Elvik and Vaa (2004), in the Handbook of Road Safety Measures, have summarised evidence from 38 studies that evaluated the effects of providing lighting on previously unlit roads. The best summary estimates of effect, based on a meta-analysis of the studies, were a 64% reduction of fatal accidents in darkness, a 28% reduction of injury accidents, and a 17% reduction of property damage only accidents. Elvik and Vaa also summarised evidence from 26 studies that evaluated the effects of upgrading existing lighting. Improving the quality of lighting was found to reduce the number of accidents in darkness; the more so, the greater the improvement. However, a precise description of the measures taken to improve lighting was not given. It is therefore difficult to develop practical guidelines based on the information given by Elvik and Vaa. Finally, Elvik and Vaa summarised evidence from eight studies that evaluated the effects of reducing road lighting to save energy. These studies

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found that reducing lighting was associated with an increase of the number of accidents in darkness.

Elvik (2004) updated the meta-analyses presented by Elvik and Vaa (2004) as part of the ongoing development of a Highway Safety Manual in the United States. The update added new studies and included an assessment of study quality, based on criteria proposed for the Highway Safety Manual by Ezra Hauer. A study was rated as good if it controlled adequately for potentially confounding factors. The most common design in studies evaluating the effects of road lighting is a simple before-and-after study, using accidents in daytime as a comparison group. This study design will not control for long-term trends with respect to the distribution of accidents between day and night, nor will it control for regression-to-the-mean attributable to an abnormally high number of accidents in darkness in the before period. Most studies that have evaluated the effects of road lighting were therefore rated as poor.

While it seems clear that road lighting in most cases reduces the number of accidents in darkness, less is known about variation in the effect of road lighting with respect to the quality of lighting and various background characteristics. Elvik (2004) found that the effects of road lighting were almost the same in rural areas, urban areas and on freeways. Future road lighting systems are likely to be adaptive, i.e. it will be possible to vary the intensity of lighting depending on the need for it. To apply adaptive lighting in a way that does not greatly reduce the safety benefits associated with lighting, more needs to be known about variation in the effects of road lighting with respect to various environmental characteristics and types of accident (not all types of accident are equally likely to occur at any time of the day).

A controlled before-and-after study comprising 125 Norwegian main road sections found a 34% reduction in the number of injury accidents and a 53% reduction in the number of fatalities during darkness (Wanvik, submitted for publication). The results of this study confirmed the results of earlier studies. However, the results were uncertain, due to a small number of accidents. The total number of injury accidents (sum before-and-after) was 1185.

In principle, the effects of road lighting can be evaluated by means of a cross-section study design, preferably employing data for an extensive road system in order to increase the size of the accident sample. A good example is the study made by Griffith (1994). A comparison of safety on lit and unlit roads eliminates two of the most important confounding factors in before-and-after studies: regression-to-the-mean and long-term trends in the number of accidents. On the other hand, there is a risk of endogeneity bias (Kim and Washington, 2006). This bias is, in a sense, a mirror image of the bias attributable to regression-to-the-mean. It arises because sites tend to be selected for treatment because they have a particular safety problem, e.g. an abnormally high proportion of accidents in darkness. Installing lighting may reduce that proportion, but not always to the level found on unlit roads. Thus, when lit and unlit roads are compared in a cross-section study, the lit roads may have a higher proportion of accidents in darkness than the unlit roads, which erroneously suggests an adverse effect of road lighting. A very instructive example of endogeneity bias and how it can be controlled for by statistical techniques is given by Kim and Washington (2006).

The present study relies on aggregate data that do not allow for the use of econometric techniques to control for endogeneity bias. The potential for this bias has been minimised by using a large sample of roads and data for a long period of time. It is unlikely that all lit roads in a large sample will have a higher-than-average proportion of accidents in darkness. Also, by using data that refer to a long period of time, random fluctuations are greatly reduced and the recorded number of accidents will more accurately reflect the long-term expected number.

The study in this paper is based on the information available in an interactive Internet database (SWOV, 2007) containing 762,835 injury accidents and 3,271,343 property damage accidents in Dutch road traffic during the period 1987–2006. Selections of accidents are easily made by defining the content of a range of variables related to the road characteristics, traffic and road user characteristics, weather conditions, etc. By also defining "light conditions" and "street lighting", accidents can be sorted by daylight and darkness conditions on lit roads and unlit roads, respectively, with respect to the selected set of background variables. The distribution of accidents by daylight conditions on lit and unlit roads was compared in order to evaluate the effects of road lighting on Dutch roads.

2. Methods of analysis

2.1. The odds ratio estimator of effect

Two estimators of effect have been applied in this study. The first is the odds ratio, defined as follows:

$$\text{Odds ratio} = \frac{\text{Number of accidents in darkness on lit roads/number of accidents in daylight on lit roads}}{\text{Number of accidents in darkness on unlit roads/number of accidents in daylight on unlit roads}}$$

The odds ratio is based on the number of accidents only. It does not refer to any data regarding to the distribution of traffic between daylight and darkness. This distribution may differ between lit and unlit roads, and this could bias the odds ratio. In order to minimise the potential for bias, the odds ratio has been estimated for each hour of the day separately. Only hours that have at least 15 accidents in each of the four groups used to estimate the odds ratio were included. This leaves only hours 7, 8, and 18–22 for analysis. All other hours of the day are omitted. In this way night-time hours, when fatigue, alcohol and speeding are frequent causes of accidents, are excluded.

The idea of confining the analysis to certain hours for the purpose of controlling for confounding factors that tend to be associated with darkness, such as fatigue or drinking and driving, has previously been suggested by Sullivan and Flannagan (2002) and Johansson (2007). By doing the analysis hour-by-hour, the effects of potential differences between lit and unlit roads with respect to the distribution of traffic are also minimised. Estimates referring to different hours have been combined by applying the log odds technique, see Section 2.3.

2.2. The ratio of odds ratios estimator of effect

The second estimator of effect used in the study is the ratio of odds ratios. This estimator is based on a method for assessing the risk associated with darkness, developed by Johansson (2007). The idea is that by studying how the number of accidents in a specific hour of the day changes throughout the year, it is to a large extent possible to eliminate the effects of confounding variables when estimating the change in accident risk associated with darkness. Certain hours, such as hours 8 (07:00–07:59) and 18 (17:00–17:59) are dark part of the year, but have full daylight in another part of the year. If darkness contributes to more accidents, one would expect these hours to have more accidents in the part of the year when there is darkness than in the part of the year when there is daylight. An hour that has daylight the whole year is used as a comparison group, to control for seasonal variations in the number of accidents.