Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure

RUNE ELVIK

A meta-analysis of 37 studies evaluating the safety effects of public lighting is reported. The 37 studies contain a total of 142 results. The studies included were reported from 1948 to 1989 in 11 different countries. The presence of publication bias was tested by the funnel graph method. It was concluded that there is no evidence of publication bias and that it makes sense to estimate a weighted mean safety effect of public lighting on the basis of the 142 individual results. This is done by the log-odds method of meta-analysis. The validity of the combined results was tested against a number of rival hypotheses. It was concluded that the results are unlikely to have been caused by regression-to-the-mean and secular accident trends. The results were robust with respect to research design, decade of study, country of study, and type of traffic environment studied. The safety effects of public lighting were, however, sensitive to accident severity and type of accident. It was concluded that the best current estimates of the safety effects of public lighting are, in rounded values, a 65 percent reduction in nighttime fatal accidents, a 30 percent reduction in nighttime injury accidents, and a 15 percent reduction in nighttime property-damage-only accidents.

Public lighting of roads is widely accepted as an effective road accident countermeasure. Numerous studies have been done to determine the effects of public lighting on the number of accidents. In a synthesis of safety research related to traffic control and roadway elements, Schwab et al. (*1*) summarized the results of research by stating that "night accidents can be substantially reduced in number and severity by the use of good road lighting." This interpretation of the evidence from evaluation studies is not accepted by Vincent (*2*). In a critical review of 29 publications on road lighting and accidents, he concludes that "All of the studies claiming statistically significant accident reductions resulting from road lighting are deficient in any or all of: site selection, types of comparison, accident measures, measures of lighting and statistical evaluation techniques."

In nonexperimental accident research numerous threats to the validity of results exist. It is rarely possible to deal with all of them in a fully satisfactory way. Most literature surveys do not discuss the threats to validity at all or treat them informally, as Vincent (*2*) did. This paper argues that some issues that arise in studies attempting to summarize and interpret evidence from a number of evaluation studies can be resolved by quantitative meta-analysis. Three issues lend themselves to treatment by quantitative meta-analysis:

1. Is it meaningful to summarize the results of a number of studies of the effects of a certain accident countermeasure into an estimate of the mean effect on safety of the countermeasure? If yes, what is the best estimate of mean safety effects?
2. Which are the most and least valid and reliable results of studies that have evaluated the effects of an accident countermeasure? How can the most valid results be identified?
3. Why do the results of different evaluation studies concerning the same countermeasure vary? What are the most important sources of variation in study results?

Institute of Transport Economics, P.O. Box 6110 Etterstad, N-0602 Oslo, Norway.

This paper reports the results of a quantitative meta-analysis of evaluation studies concerning the safety effects of public lighting. Those studies were designed to address the three issues raised in the preceding paragraph. The studies have evaluated the effects on safety of public lighting on any type of road, including residential streets, rural highways, and freeways and covered both rural and urban areas and lighting of intersections as well as continuous roadway segments.

EVALUATION STUDIES INCLUDED IN META-ANALYSIS

Thirty-seven studies evaluating the effects of public lighting on road safety are included in the meta-analysis. The 37 studies contained a total of 142 results concerning the effects of road lighting on road safety; these results were expressed in terms of either changes in the number of nighttime accidents or changes in the nighttime accident rate per million vehicle kilometers of travel. The studies were retrieved by a systematic literature survey. A detailed description of how the literature survey was conducted is given elsewhere (*3*). The final sample consisted of evaluation studies that satisfied the following requirements:

1. The study contained one or more numerical estimates of the effects of public road lighting on the number of accidents or the accident rate.
2. The study primarily assessed the effects of introducing lighting at unlit locations. Studies that primarily assessed the effects of changing the level of existing lighting were not included.
3. The study presented the number of accidents on which estimates of the effects of lighting were based. Studies giving only accident rates, without stating the number of accidents used to estimate those rates, were not included.
4. The study was published. Unpublished studies were not included.

In the meta-analysis each estimate of safety effect was used as the unit of analysis. A total of 142 results were included. The results that were included in the analysis are provided in a later section (see Table 4). For each result, data concerning the following variables were collected:

1. Author or authors of study,
2. Year of publication,
3. Country to which each result refers,
4. Study design (coded variable with seven categories),
5. Type of traffic environment studied (coded variable with three categories),
6. Type of accident studied (coded variable with five categories),
7. Accident severity (coded variable with four categories),
8. Number of nighttime accidents before or without lighting,
9. Number of nighttime accidents after or with lighting,
10. Number of daytime accidents before or without lighting,
11. Number of daytime accidents after or with lighting, and
12. Estimate of the effect of lighting on road safety.

Table 1 describes in more detail how the variables included in the analysis were coded.

In terms of study design a broad distinction can be made between various forms of before-and-after studies on the one hand and various forms of comparative studies on the other. Conforming to the language of epidemiology [see, e.g. Hennekens and Buring (*4*)], the comparative studies will be referred to as case–control studies, in which one or more lit locations constitute the cases, whereas one or more unlit locations constitute the controls. The two main groups of research design differ in terms of the criterion of safety (CS) effect generally adopted. In before-and-after studies the basic CS effect is the odds ratio, commonly defined as

CS effect = (no. of nighttime accidents after/no. of nighttime accidents before)
÷ (no. of daytime accidents after/no. of daytime accidents before)

If this ratio is less than 1.0 lighting reduces the number of nighttime accidents. If it is more than 1.0 lighting increases the number of nighttime accidents. In some before-and-after studies, as well as in all case–control studies, the odds ratio is expressed in terms of accident rates rather than the number of accidents. If the introduction of public lighting does not affect exposure, the odds ratio of accident rates will be identical to the odds ratio of accident frequencies. The comparability of the two measures of safety effect is discussed in a subsequent section of the paper.

TECHNIQUES OF META-ANALYSIS

Meta-analysis can be done by several techniques (*5–9*). The simplest kind of meta-analysis is the vote counting method, which consists of compiling a frequency distribution of results by safety effect. A vote count of the 142 results concerning the safety effects of road lighting included in the present study shows that 115 results (81 percent) indicate that safety has improved and 27 results (19 percent) indicate that safety has deteriorated. Since the majority of results indicate that safety has improved, it is concluded that road lighting is likely to improve safety in most cases.

TABLE 1 Variables Included in Meta-Analysis

Variable	*Categories of the variable*
Author	Listed alphabetically
Year of publication	1948 through 1989
Country of origin	11 different countries represented
Study design	(1) 22 = before-and-after study with nighttime accidents on unlighted road sections as comparison group (2) 23 = before-and-after study with daytime accidents as comparison group (3) 2223 = before-and-after study with daytime accidents as comparison group and an additional comparison group of unlighted road sections (4) 2331 = before-and-after study with daytime accidents as comparison group and data on traffic volume by time of day before and after lighting (5) 26 = case-control study where comparisons between cases and controls are stratified according to one or more confounding variables (6) 27 = case-control study where cases and control have been matched according to one or more confounding variables (7) 33 = simple case-control study; cases and controls are compared directly with no control for confounding variables
Traffic environment	(1) Urb = urban; (2) Rur = rural; (3) Mwy = Motorway (freeway)
Type of accident	(1) All = all accidents; (2) Ped = pedestrian accidents; (3) Veh = accidents involving just vehicles; (4) Junc = accidents at junctions; (5) Sec = accidents between junctions
Accident severity	(1) Du = Fatal accidents; (2) Psu = injury accidents, (3) Msu = property-damage-only accidents (4) All = accidents of unspecified severity; all accidents included
Number of accidents	Recorded directly, in the following four categories: (1) NL = nighttime, lit road; (2) = NU = nighttime, unlit road; (3) DL = daytime, lit road; (4) DU = daytime, unlit road
Effect of lighting	Defined in terms of the odds ratio = O = (NL/NU)/(DL/DU), which may be equivalently expressed in terms of accident rates (number of accidents per million vehicle kilometres of travel)

A simple vote count is, however, not very informative. A refinement of the vote counting method consists of grouping results according to their statistical significance. Applied to the 142 results concerning the safety effects of road lighting, this version of the vote counting method shows that 45 results indicated a statistically significant safety improvement at the 5 percent level of significance. Ninety-seven results did not show any statistically significant changes in safety at this level of significance (*5*). This result illustrates the point raised by Hauer (*10*) about the danger of relying on tests of statistical significance alone in summarizing the results of several evaluations of a safety measure. Evidence of safety effects typically comes in small doses that are not always statistically significant. When a large number of studies are put together, however, their combined evidence can be very strong indeed.

The basic idea in more sophisticated techniques of meta-analysis is to combine statistically the evidence from several studies by computing a weighted mean result. Weighting can be done by several techniques, depending on the statistical properties of the results that are combined. In the present study the log-odds method described by Fleiss (*5*) was used.

Once a method for combining the results of different studies has been chosen, it is possible to study the effects of several variables on the combined result of case studies. Does, for example, the combined safety effect of public lighting vary according to the research design used in different studies? In meta-analysis this question can be answered by defining a variable describing study design (Table 1), combining evidence from all studies that use the same design, and comparing the combined evidence from studies that use different designs. In this paper the effects of several variables on the results of evaluation studies have been analyzed in this manner.

IS THERE A GENERAL EFFECT OF PUBLIC LIGHTING ON ROAD SAFETY?

Vincent (*2*) argues that it does not make sense to estimate a mean safety effect of public lighting, because the locations studied have not been sampled at random from a known sampling frame. Besides, the safety effect of public lighting is likely to vary substantially from one case to another, depending, inter alia, on luminance levels, traffic environment, and predominant type of accident at the location. In meta-analysis three requirements must be fulfilled for a weighted mean estimate of safety effect to make sense: (a) there should not be publication bias, (b) the assumption that all results belong to a distribution having a well-defined mean value should be reasonably well supported, and (c) all studies should use comparable measures of safety effect.

Testing for Publication Bias

The term *publication bias* refers to the tendency not to publish results that are unwanted or believed not to be useful, for example, because they show an increase in accidents or because they are not statistically significant (*6*).

Light and Pillemer (*6*) have developed a graphical technique of testing for publication bias called the *funnel graph method*. It relies on visual inspection of a diagram in which each study result is plotted in a coordinate system. The horizontal axis shows each result. The vertical axis shows the sample size on which each result is based. The idea is that if there is no publication bias the scatter plot of study results should resemble the form of a funnel turned upside down. The dispersion of points in the diagram should narrow as sample size increases, since large sample sizes provide more precise estimates of effects than small sample sizes. If the tails of the scatter plot are symmetrical and the density of points is the same in all areas of the diagram, this indicates that there is no publication bias.

Figures 1 to 4 show funnel graph diagrams of study results for studies of the effects of public lighting on fatal accidents (Figure 1), injury accidents (Figure 2), property-damage-only accidents (Figure 3), and accidents of unspecified severity (Figure 4). The latter category presumably includes accidents at all levels of severity. Statistical weight is used as a measure of sample size. The statistical weight of a result is proportional to the inverse of the variance of that result. For example, for a result based on 45 (dark, before), 25 (dark, after), 90 (day, before) and 85 (day, after) accidents, the statistical weight is 1/(1/45 + 1/25 + 1/90 + 1/85). Accidents of different degrees of severity were treated separately, because both safety effects and sample sizes are likely to differ across severity levels.

Inspection of Figures 1 to 4 does not give any indication of a clear publication bias. There is, however, a considerable amount of spread in the results. This indicates that statistically aggregating the results in terms of a weighted mean estimate of safety effect may be problematic.

Is There a True Mean Safety Effect?

The shape of scatter plots in funnel graph diagrams indicates if it makes sense to estimate a weighted mean safety effect. If the funnel graph is bimodal (has two humps) or multimodal or if there is no clear pattern in the scatter plot, a weighted mean will not be very informative. If a funnel pattern is clearly visible, estimating a weighted mean safety effect will be informative and will indicate the size of the effect that studies tend to converge to as sample size increases. In Figures 1 to 4 the funnel pattern is visible and a weighted mean value of the safety effects of lighting has been estimated.

In addition, Fleiss (*5*) describes a formal test of the homogeneity of the results. This test indicates that the results referring to fatal accidents and property-damage-only accidents are homogeneous, whereas there is a statistically significant heterogeneity in the results referring to injury accidents and accidents of unspecified severity. It was nevertheless decided to combine evidence from the various studies referring to injury accidents and accidents of unspecified severity to explore some of the sources of heterogeneity in the results.

Comparability of Measures of Effect

As pointed out earlier two measures of safety effect have been used in studies evaluating the safety effects of public lighting: changes in the odds ratio based on the number of accidents and changes in the odds ratio based on accident rates. In the funnel graph diagrams these two measures of safety effect have been mixed, relying on the assumption that neither the total amount of exposure nor its distribution between daytime and nighttime is affected by road lighting.

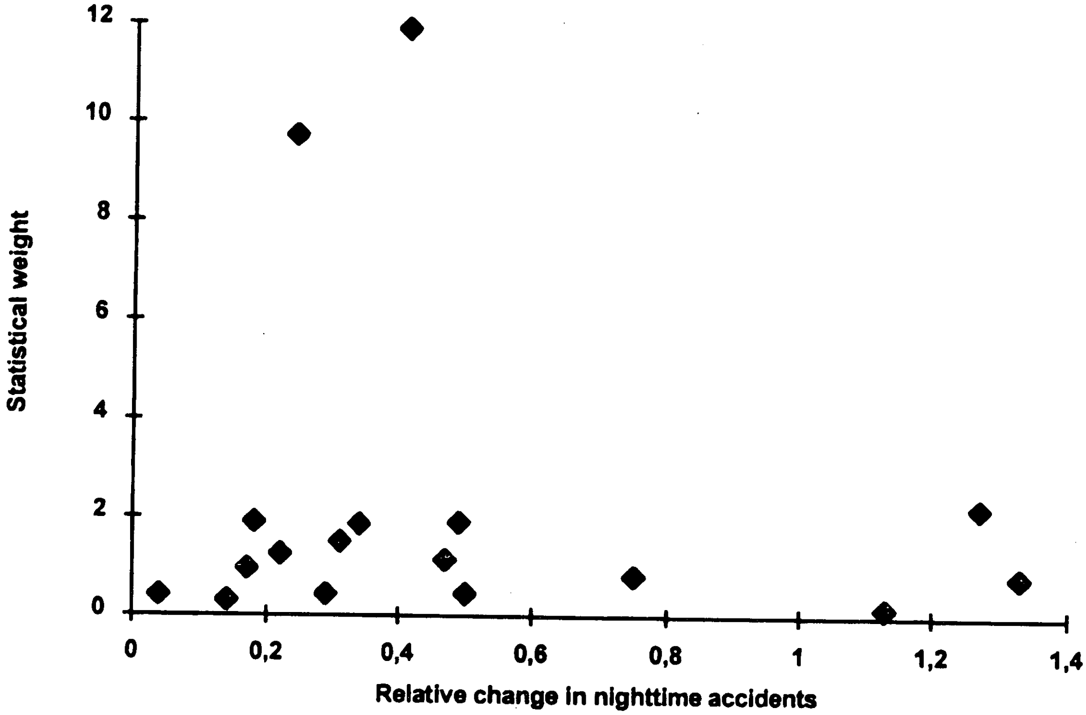

FIGURE 1 Funnel graph diagram for fatal accidents.

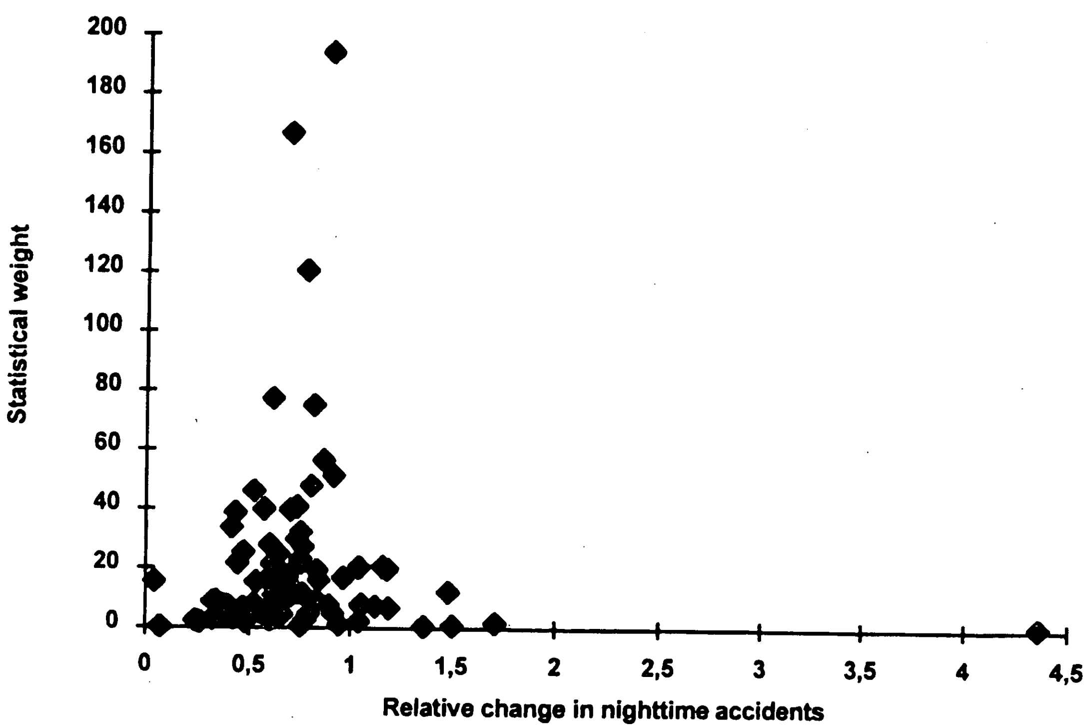

FIGURE 2 Funnel graph diagram for injury accidents.

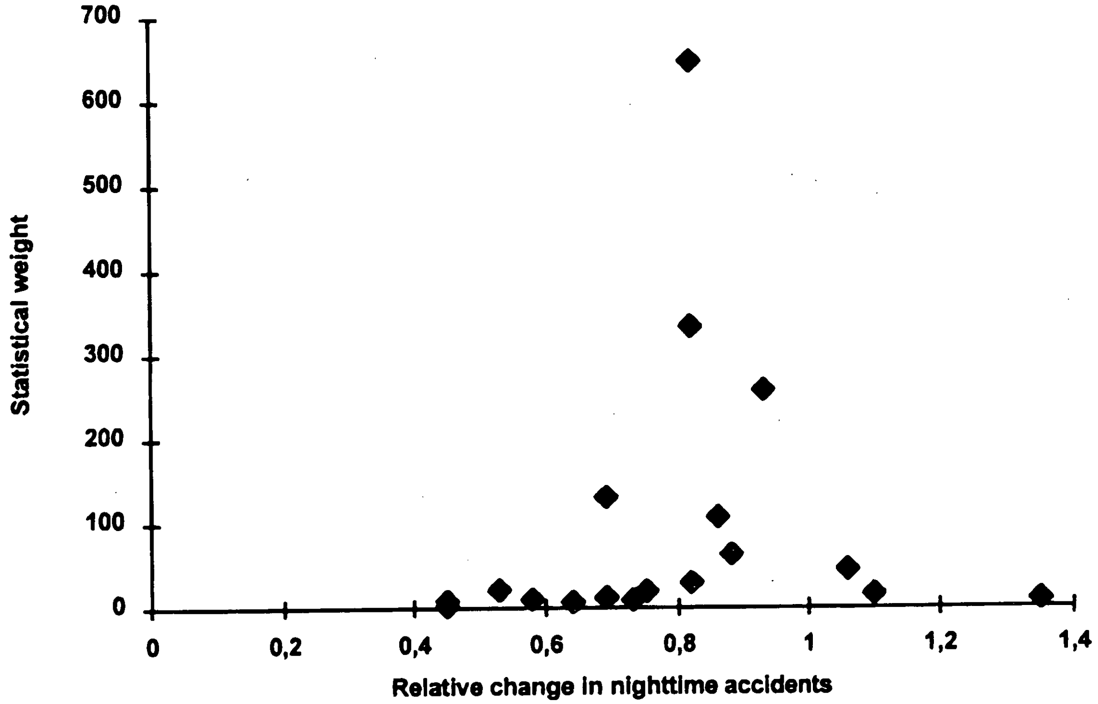

FIGURE 3 Funnel graph diagram for property-damage-only accidents.

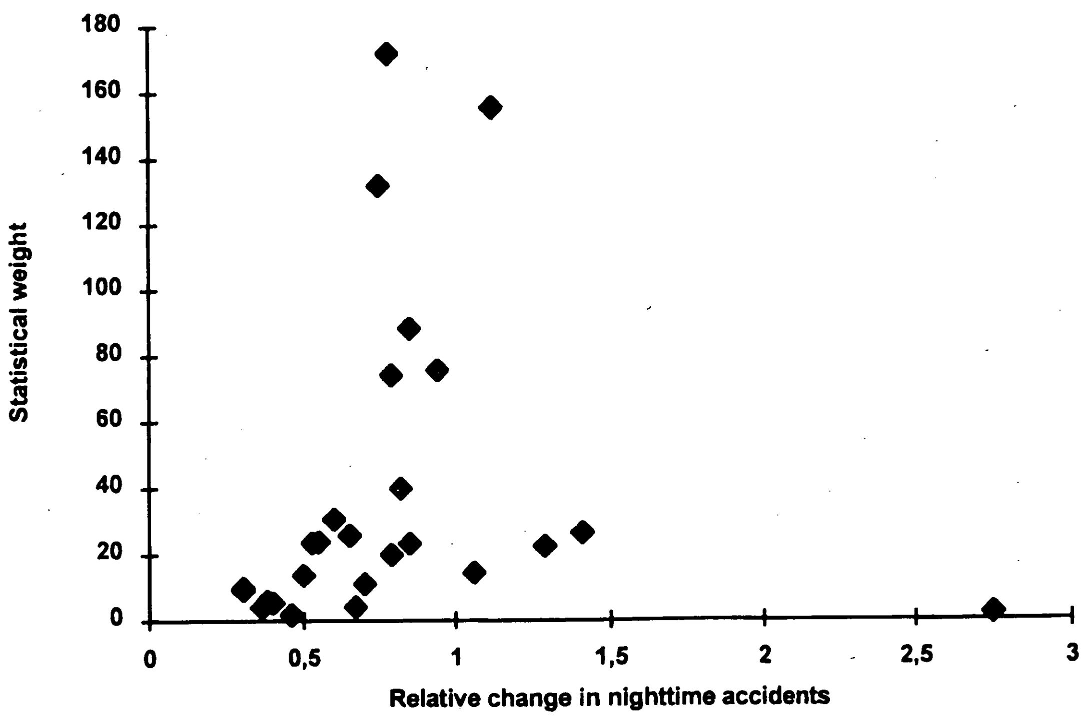

FIGURE 4 Funnel graph diagram for accidents of unspecified severity.

The validity of this assumption can be tested by relying on before-and-after studies in which both measures of safety effect can be estimated and compared. This can be done in all before-and-after studies in which exposure data are available for both the before and after periods. The studies of Tamburri, et al. (*11*), Box (*12*), Lipinski and Wortman (*13*), Walker and Roberts (*14*), Jørgensen (*15*), and Lamm et al. (*16*) allow this kind of comparison to be made. The combined estimate of the safety effect of lighting, based on these studies and measured by means of the number of accidents, is a 30 percent reduction in the number of nighttime accidents (lower 95 percent confidence limit, 21 percent reduction; upper limit, 38 percent reduction). If the safety effect is measured by means of accident rates, the combined estimate is a 33 percent reduction in nighttime accident rate (lower 95 percent confidence limit, 25 percent reduction; upper limit, 41 percent reduction). These values are very close to each other. It is concluded that changes in accident rates and changes in accident frequency can be interpreted as equivalent measures of the changes to be expected in the number of accidents with the introduction of road lighting.

VALIDITY OF EVALUATIONS OF PUBLIC LIGHTING

All of the evaluation studies included in this meta-analysis are nonexperimental. In this section, a number of threats to the validity of these studies will be discussed, including

1. Regression to the mean,
2. Secular accident trends, and
3. Contextual confounding variables.

Regression to the Mean

The most common research design in evaluation studies concerning the safety effects of public lighting is a before-and-after design, in which nighttime accidents form the experimental group and daytime accidents are used as a comparison group. In this kind of research design, regression to the mean (*17,18*) may jeopardize the validity of the results. In particular, if road lighting is introduced because of an abnormally high recorded number of accidents in the before period, a subsequent decline in the number of accidents must be expected even if lighting has no effect.

The use of daytime accidents as a comparison group in before-and-after studies will take care of the regression-to-the mean effect, provided that this effect affects daytime accidents to the same extent as nighttime accidents. This is not likely to be the case if road lighting was introduced because an abnormally high proportion of all accidents occurred in darkness. In that case one might expect the percent decline in nighttime accidents because of regression to the mean to be greater than the corresponding percent decline in daytime accidents, thus creating an apparent effect of road lighting.

On the other hand, a high percentage of nighttime accidents could indicate a real problem. In that case one would expect the true effect of road lighting to be greater when the percentage of nighttime accidents is high than when it is low. By juxtaposing the results of before-and-after studies and case–control studies made at locations with various percentages of nighttime accidents, it is possible to get an indication of whether a greater effect of road lighting at locations with a high percentage of nighttime accidents reflects regression to the mean or a genuine accident problem in the darkness.

If the regression-to-the-mean hypothesis is correct, one would expect the apparent effect of lighting to vary according to the percentage of all accidents occurring at night in before-and-after studies but not in case–control studies. If the real-darkness-problem hypothesis is correct, one would expect the effect of road lighting to vary according to the percentage of all accidents occurring at night in both before-and-after and case–control studies.

Table 2 presents data that are relevant for the two hypotheses. Study locations have been grouped according to the percentage of all accidents occurring at night (in the before period in before-and-after studies). In both before-and-after studies and case–control studies the effect of road lighting on the number of nighttime accidents is found to be greater at locations where more than 50 percent of all accidents occur at night than at locations where fewer than 50 percent of all accidents occur at night. This result weakens the regression-to-the-mean hypothesis and strengthens the real-darkness-problem hypothesis. However, the validity of the assumptions underlying the comparison cannot be tested directly. Hence, the comparison is just an indication, not a stringent test.

Secular Accident Trends

Over time the percentage of all accidents occurring at night may change. Changes in traffic distribution by hour of the day, improved vehicle headlights, and changes in the driver population are some of the factors that could generate such changes. In before-and-after studies with just one before period and just one after period and no comparison group consisting of locations where road lighting was

TABLE 2 Results of Before-and-After Studies and Case–Control Studies by Proportion of Nighttime Accidents: Weighted Mean Effect of Public Lighting on Nighttime Accidents

			Per cent change in nighttime accidents		
Study design	Percentage of accidents at night	Proportion of statistical weights	Lower 95%	Best estimate	Upper 95%
Before-and-after designs (cf table 1)	> 50%	0.089	-28	-35	-41
	33-50%	0.326	-17	-21	-25
	< 33%	0.231	-17	-22	-26
Case-control designs (cf table 1)	> 50%	0.071	-24	-32	-39
	33-50%	0.136	-7	-15	-21
	< 33%	0.147	-14	-21	-27
All designs	All	1.000	-20	-23	-25

TABLE 3 Weighted Mean Effect of Public Lighting on Nighttime Accidents According to Potential Confounding Variables

Variable	Category	Proportion of statistical weights	Per cent change in nighttime accidents		
			Lower 95%	Best estimate	Upper 95%
Accident severity	(1) Fatal	0.008	-52	-65	-75
	(2) Injury	0.387	-26	-29	-32
	(3) PDO	0.381	-13	-17	-21
	(4) Unspecified	0.224	-13	-18	-23
Study design (cf table 1 for fuller description)	(A) Fatal accs				
	(2) Design 23	0.798	-48	-63	-74
	(3) Design 2223	0.161	-40	-73	-88
	(5) Design 26	0.041	+95	-59	-91
	(B) Injury accs				
	(1) Design 22	0.036	-5	-26	-32
	(2) Design 23	0.526	-25	-30	-34
	(3) Design 2223	0.080	-16	-29	-39
	(4) Design 2331	0.007	-32	-60	-77
	(5) Design 26	0.154	-17	-26	-35
	(6) Design 27	0.044	-24	-39	-51
	(7) Design 33	0.153	-15	-25	-34
	(C) PDO accs				
	(2) Design 23	0.868	-11	-16	-20
	(4) Design 2331	0.008	+35	-19	-51
	(5) Design 26	0.038	+9	-15	-33
	(7) Design 33	0.086	-17	-30	-40
	(D) Unspec accs				
	(2) Design 23	0.024	-25	-50	-66
	(4) Design 2331	0.217	-18	-29	-37
	(5) Design 26	0.593	-1	-8	-15
	(6) Design 27	0.166	-17	-28	-38
Decade of publication	(1) 1940s	0.125	-8	-15	-22
	(2) 1950s	0.052	-21	-30	-39
	(3) 1960s	0.174	-14	-19	-25
	(4) 1970s	0.523	-19	-22	-26
	(5) 1980s	0.126	-25	-31	-37
Country	(1) Australia	0.198	-14	-19	-25
	(2) Denmark	0.024	-0	-17	-31
	(3) Finland	0.015	-1	-22	-38
	(4) France	0.017	-24	-39	-51
	(5) Germany	0.010	+1	-24	-43
	(6) Great Britain	0.123	-27	-32	-38
	(7) Israel	0.003	-8	-46	-68
	(8) Japan	0.005	-32	-56	-71
	(9) Sweden	0.063	-14	-24	-32
	(10) Switzerland	0.015	+0	-21	-38
	(11) United States	0.527	-17	-20	-23
Traffic environment	(1) Urban	0.593	-19	-22	-25
	(2) Rural	0.117	-19	-26	-32
	(3) Motorways	0.290	-20	-23	-25
Type of accident	(1) Not stated	0.478	-18	-21	-24
	(2) Pedestrian	0.045	-45	-52	-58
	(3) Vehicles only	0.312	-13	-17	-21
	(4) Junctions	0.125	-24	-30	-36
	(5) Midblocks	0.040	-0	-14	-25
All	All	1.000	-20	-23	-25

Note: The statistical weights sum to 1.000 for each variable (each severity level for the variable study design)

not introduced, the possibility that secular accident trends are confounded with the effects of road lighting cannot be ruled out. However, in all other research designs that have been used in evaluations of the safety effect of public lighting, this particular source of error can be ruled out.

Table 3 compares the results of evaluations that have relied on different research designs. With a few exceptions the weighted mean safety effect of lighting is virtually identical in all research designs. It is therefore highly unlikely that the results of before-and-after studies with only daytime accidents as a comparison group could be explained in terms of secular accident trends alone. The study results that were included in the analysis are listed in Table 4.

Contextual Confounding Variables

To what extent do variables related to study context affect the results of evaluations of the safety effects of public lighting? Table

TABLE 4 Data from 37 Studies of Safety Effects of Public Lighting

Study	Year	Country	Design	Environment	Type of accident	Accident severity	Night before/without	Night after/with	Day before/without	Day after/with	Effect
(19)	1948	USA	23	Urb	All	Du	3	1	3	2	0,500
			23	Urb	All	Psu	45	34	47	57	0,623
			23	Urb	All	Msu	201	200	324	365	0,883
			23	Urb	All	Du	17	5	10	6	0,490
			23	Urb	All	Psu	210	135	172	152	0,727
			23	Urb	All	Msu	828	789	1411	1443	0,932
			23	Urb	All	Du	8	4	3	2	0,750
			23	Urb	All	Psu	96	51	75	59	0,675
			23	Urb	All	Msu	323	340	547	672	0,857
			23	Urb	All	Psu	67	86	80	99	1,037
			23	Urb	All	Psu	173	82	126	99	0,603
			23	Urb	All	Psu	43	23	45	23	1,047
			23	Urb	All	Psu	72	28	31	36	0,335
(20)	1955	GB	23	Urb	Ped	Du	6	1	1	4	0,042
			23	Urb	Ped	Psu	31	19	73	71	0,630
			23	Urb	Kjt	Du	4	2	8	3	1,333
			23	Urb	Kjt	Psu	120	98	283	330	0,700
(21)	1958	CH	23	Urb	All	Psu	70	65	159	231	0,639
(22)	1958	GB	23	Urb	Ped	Du	15	6	5	11	0,182
			23	Urb	Ped	Psu	144	85	314	323	0,574
			23	Urb	Kjt	Du	13	9	11	6	1,269
			23	Urb	Kjt	Psu	333	303	918	1086	0,769
(23)	1960	USA	26	Mwy	All	All	52	168	71	177	1,291
(24)	1962	USA	26	Mwy	All	Psu	8	2	13	2	4,361
			26	Mwy	All	All	27	108	42	316	0,500
(25)	1962	GB	23	Mwy	All	Psu	8	7	13	19	0,599
			23	Mwy	All	Psu	41	3	71	22	0,236
(26)	1962	USA	26	Mwy	All	All	184	1004	172	997	0,943
			26	Mwy	All	All	401	1004	514	997	1,120
(27)	1965	S	23	Urb	All	Psu	14	13	41	69	0,552
			23	Urb	All	Msu	48	52	96	95	1,095
			23	Rur	All	Psu	23	15	35	42	0,543
			23	Rur	All	Msu	27	20	85	86	0,732
(28)	1966	GB	23	Urb	Ped	Psu	7	0,5	1	1	0,071
			23	Urb	Kjt	Psu	2	3	5	5	1,500
			23	Rur	All	Psu	40	22	37	39	0,522
			23	Mwy	All	Psu	82	54	123	132	0,614
(29)	1966	USA	33	Mwy	All	Psu	588	706	547	950	0,691
			33	Mwy	All	Msu	395	576	430	911	0,688
(11)	1968	USA	2331	Urb	Junc	All	75	27	39	39	0,304
			2331	Urb	Junc	All	25	11	31	34	0,396
			2331	Urb	Junc	All	33	13	31	34	0,377
			2331	Urb	Junc	All	37	15	12	12	0,355
			2331	Urb	Junc	All	11	5	7	8	0,455

* Number of nighttime accidents on unlit roads before and after.

(continued on next page)

3 presents results that shed light on this question for the variables (a) definition of accident severity, (b) study design, (c) decade of publication of study, (d) country where the study was performed, (e) traffic environment where the study was performed, (f) type of accident studied.

The effects of road lighting vary significantly with respect to accident severity. Nighttime fatal accidents are reduced by about 65 percent, nighttime injury accidents are reduced by about 30 percent, and nighttime property-damage-only accidents are reduced by about 15 percent. This means that studies that do not specify the severity of accidents are less informative than studies that specify accident severity. The observed weighted mean safety effect in studies of accidents of unspecified severity is an 18 percent reduction in nighttime accidents. This indicates that most of the accidents probably were property-damage-only accidents.

These results hold when controlling for study design. In general, study design appears to have a minor effect on study results. As argued earlier the robustness of the results with respect to study design indicates that the results are valid and not just the product of various confounding factors that are left uncontrolled by the various research designs. Different research designs take different confounding factors into account. Therefore, agreement of results across research designs indicates that uncontrolled confounding factors are not major sources of variation in the results of different studies.

The oldest study included was reported in 1948; the most recent was reported in 1989. Studies performed in different decades have yielded similar results. There is no indication that the safety effects of road lighting have diminished over time. Eleven different countries are represented in this analysis. Studies performed in different countries have also yielded similar results. It should be noted, however, that most studies have been performed in the United States, Great Britain, and Australia. Studies performed in other countries have been on a smaller scale, as indicated by their contribution to the statistical weights.

Three types of traffic environment have been identified: urban, rural, and freeways. The results of evaluation studies are the same for all three environments. This holds when controlling for accident severity. With respect to type of accident, studies can be divided into three groups. The first and largest group consists of studies that do not specify the types of accident studied. A second group consists of studies in which a distinction is made between pedestrian accidents and other accidents. A third group consists of studies in which a distinction is made between accidents at junctions (inter-

TABLE 4 *(continued)*

Study	Year	Country	Design	Environment	Type of accident	Accident severity	Night before/without	Night after/with	Day before/without	Day after/with	Effect
(30)	1969	USA	23	Urb	All	All	13	9	37	38	0,674
(31)	1969	USA	26	Urb	All	Du	4	14	2	15	0,468
			26	Urb	All	Psu	203	309	295	551	0,811
			26	Urb	All	Msu	83	240	220	592	1,062
(32)	1970	CH	23	Rur	All	Psu	64	77	92	94	1,178
			23	Mwy	All	Psu	10	5	25	12	1,042
			23	Mwy	All	Psu	18	5	41	27	0,422
			23	Mwy	All	Psu	4	6	25	22	1,705
			23	Urb	All	Psu	36	14	104	36	1,123
(33)	1971	AUS	23	Urb	Ped	Psu	10	6	23	18	0,767
			23	Urb	Ped	Psu	16	10	18	19	0,592
			23	Urb	Ped	Psu	15	6	16	20	0,320
			23	Urb	Ped	Psu	17	6	28	20	0,494
		USA	23	Urb	Ped	Psu	175	122	221	294	0,524
			23	Urb	Kjt	Psu	152	317	176	427	0,860
			23	Urb	Kjt	Msu	983	1674	1069	2215	0,822
			23	Urb	Ped	Du	84	22	42	46	0,239
			23	Urb	All	Du	60	38	40	62	0,409
			23	Urb	All	Psu	48	37	52	53	0,756
			23	Urb	All	All	38	30	62	70	0,699
(34)	1971	DK	2223	Urb	Ped	Psu	20	21	58	93	1,047
(12)	1972	USA	2331	Urb	All	Psu	23	10	15	17	0,384
			2331	Urb	All	Psu	52	20	30	30	0,385
			2331	Urb	All	Msu	23	4	25	12	0,448
			2331	Urb	All	Msu	53	33	75	49	0,687
			26	Mwy	Rear	All	176	198	614	863	0,794
			26	Mwy	Kjt	All	69	48	142	123	0,786
			26	Mwy	Ped	All	11	11	11	4	2,750
			26	Mwy	Off	All	102	102	132	92	1,410
			26	Mwy	All	All	356	697	888	2184	0,784
			26	Mwy	All	All	270	72	428	192	0,822
(35)	1972	GB	2223	Urb	All	Du	4	0,5	2	2	0,140
			2223	Urb	All	Psu	85	60	134	138	0,750
			2223	Rur	All	Du	11	3	5	6	0,220
			2223	Rur	All	Psu	73	56	121	145	0,620
			2223	Mwy	All	Du	8	2	4	6	0,170
			2223	Mwy	All	Psu	54	50	99	95	0,960
			2223	Urb	All	Du	1	1	0,5	0,5	1,130
			2223	Urb	All	Psu	18	9	37	32	0,660
			2223	Rur	All	Du	11	3	9	8	0,310
			2223	Rur	All	Psu	84	56	132	118	0,750
			2223	Mwy	All	Du	13	4	10	9	0,350
			2223	Mwy	All	Psu	110	75	186	175	0,730
(36)	1972	AUS	23	Urb	Ped	Psu	32	13	57	58	0,399

* Number of nighttime accidents on unlit roads before and after.

(continued on next page)

sections) and accidents at road sections (midblock accidents). On the basis of these classifications, road lighting appears to have a greater effect on pedestrian accidents than on other types of accidents and a greater effect at junctions than at other locations.

The general impression is that the contextual variables have a rather small impact on the results of evaluation studies. It is particularly reassuring that results are robust with respect to study design. Study decade, the country where the study was performed, and type of traffic environment hardly affect study results. On the other hand, accident severity and type of accident seem to be of some importance for study results. These variables are not directly related to study design. However, any good study should specify clearly the severity of the accidents that are studied and indicate clearly the types of accidents that are studied.

DISCUSSION OF RESULTS

The analysis presented here shows that the results of studies that have evaluated the effects of public lighting on road safety are quite robust with respect to a number of potentially confounding variables. These results cannot be dismissed as merely showing the vagaries of poor data, inadequate research design, or peculiarities of the locations that have been investigated. There is little to support the misgivings voiced by Vincent (*2*) with respect to these and related points.

On the other hand, the present analysis did not consider every conceivable source of error in previous studies. In particular, errors that may arise from an inappropriate choice of comparison groups in case–control studies or from the use of an inappropriate statistical technique in analyzing data were not considered. Most studies provide few details concerning the sampling of cases and controls. It is therefore difficult to know whether biased sampling is found and how it may have affected evaluation results. As far as statistical techniques for data analysis are concerned, most studies have relied on quite simple techniques, like estimating an odds ratio and testing it for statistical significance. More advanced multivariate analyses, in which the choice of statistical techniques is more important, are not found in this area.

The effect of public lighting on road safety was found to vary with respect to accident severity and type of accident. There are no doubt a large number of other variables with respect to which the effects of public lighting might be expected to vary. It would, for example, be of interest to know whether lighting satisfying current

TABLE 4 *Continued*

Study	Year	Country	Design	Environ-ment	Type of accident	Accident severity	Night before/without	Night after/with	Day before/without	Day after/with	Effect
(37)	1973	GB	22	Urb	All	Psu	44	26	*12532	*8785	0,840
			22	Urb	All	Psu	23	16	*3924	*3286	0,830
			22	Rur	All	Psu	23	27	*3381	*2681	1,480
			22	Rur	All	Psu	93	35	*9027	*7245	0,470
(38)	1976	GB	23	Mwy	All	All	52	24	34	53	0,296
(13)	1976	USA	2331	Rur	Junc	All	356	438	656	1022	0,748
(14)	1976	USA	2331	Rur	Junc	All	90	46	225	207	0,551
(39)	1977	DK	33	Mwy	All	Psu	91	434	191	1006	0,905
			33	Mwy	All	Psu	91	289	191	759	0,799
(40)	1977	AUS	23	Urb	Ped	Psu	162	87	219	276	0,426
			23	Urb	Kjt	Psu	779	762	746	820	0,890
			23	Urb	Kjt	Msu	1908	1840	3854	4510	0,824
(41)	1977	JPN	23	Mwy	All	Psu	95	52	109	135	0,442
		USA	26	Mwy	All	Du	6	36	0,5	14	0,288
			26	Mwy	All	Psu	38	639	28	804	0,533
			26	Mwy	All	Msu	45	1372	41	2454	0,533
(42)	1978	SF	23	Urb	Sec	Psu	104	67	181	153	0,762
			23	Urb	Sec	Msu	112	75	187	153	0,818
			23	Urb	Junc	Psu	19	12	36	25	0,909
			23	Urb	Junc	Msu	26	15	43	39	0,636
(43)	1978	ISR	2223	Urb	Ped	Psu	79	34	77	61	0,623
(15)	1980	DK	2331	Urb	All	Psu	8	5	10	13	0,480
(44)	1981	S	26	Rur	Junc	Psu	58	11	90	36	0,474
			26	Rur	Junc	Psu	27	3	26	11	0,263
			26	Rur	Junc	Psu	153	34	306	82	0,829
			26	Rur	Junc	Psu	104	48	194	77	1,163
			26	Rur	Junc	Psu	19	20	58	69	0,885
			26	Rur	Junc	Psu	1	3	4	16	0,750
			26	Rur	Junc	Psu	31	13	102	36	1,188
			26	Rur	Junc	Psu	21	9	57	31	0,788
(1)	1982	D	23	Urb	Ped	Psu	51	19	44	51	0,321
		CH	23	Urb	Ped	Psu	34	15	52	60	0,382
		F	27	Urb	Junc	Psu	290	209	389	459	0,611
		USA	23	Mwy	Junc	Psu	76	43	83	80	0,587
(45)	1985	S	23	Rur	Junc	Psu	58	19	137	64	0,701
(16)	1985	D	2331	Mwy	All	All	30	77	61	148	1,062
			2331	Mwy	All	All	46	121	102	316	0,845
(46)	1986	S	27	Rur	Junc	All	114	63	258	236	0,604
			27	Rur	Junc	All	449	157	1256	517	0,849
			27	Rur	Junc	All	93	43	251	218	0,532
			27	Rur	Junc	All	119	43	390	218	0,646

* Number of nighttime accidents on unlit roads before and after.

Study	Year	Country	Design	Environ-ment	Type of accident	Accident severity	Night before/without	Night after/with	Day before/without	Day after/with	Effect
(47)	1987	GB	26	Mwy	All	Psu	669	212	264	51	0,412
			26	Mwy	All	Psu	71	57	256	35	1,037
			26	Mwy	All	Psu	58	24	267	44	0,733
			26	Mwy	All	Psu	61	35	301	116	0,681
			26	Mwy	All	Psu	59	144	218	398	0,749
(48)	1989	USA	33	Urb	Junc	Psu	1	42	3	93	1,355
			33	Urb	Junc	Msu	15	160	19	447	0,453
			33	Urb	Sec	Psu	36	2	51	3	0,944
			33	Urb	Sec	Msu	133	19	218	23	1,354
			23	Urb	Junc	Psu	21	15	29	36	0,575
			23	Urb	Junc	Msu	51	57	117	174	0,752
			23	Urb	Sec	Psu	15	8	28	31	0,482
			23	Urb	Sec	Msu	29	23	84	114	0,584
							15879	18769	54272	57940,5	0,737

* Number of nighttime accidents on unlit roads before and after.

warrants is more effective than lighting not satisfying current warrants. However, few studies provide information concerning this. The availability of data limits the topics that can be included in a meta-analysis.

CONCLUSIONS

The following conclusions summarize the results of the research reported in this paper.

1. A meta-analysis of 37 evaluation studies of the safety effect of public lighting containing 142 results has been performed. The log-odds method was applied.
2. The presence of publication bias was tested. No evidence of publication bias was found.
3. Changes in accident rate were found to predict accurately changes in the number of accidents associated with the introduction of public lighting. These two measures of safety effect were therefore treated as equivalent in the meta-analysis.

4. The validity of research results was tested with respect to (a) regression to the mean; (b) secular accident trends; and (c) contextual confounding variables, including definition of accident severity, study design, decade of publication, country where the study was performed type of traffic environment, and type of accident studied. It was concluded that regression to the mean and secular accident trends are unlikely to have affected the results of evaluation studies materially. As far as confounding variables are concerned, accident severity and type of accident studied were found to affect study results. The other confounding variables did not affect study results.

5. The best current estimate of the safety effects of road lighting in rounded values is a 65 percent reduction in nighttime fatal accidents, a 30 percent reduction in nighttime injury accidents, and a 15 percent reduction in nighttime property-damage-only accidents.

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