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EVALUATIONS OF ROAD ACCIDENT BLACKSPOT TREATMENT: A CASE OF THE IRON LAW OF EVALUATION STUDIES?

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Abstract—Numerous evaluation studies have reported large accident reductions when road accident blackspots are treated. A critical examination of these studies reveals that many of them do not account for the effects of well known confounding factors, like the regression-to-the-mean effect that is likely to occur at road accident blackspots. This paper shows that the more confounding factors evaluation studies account for, the smaller becomes the accident reduction attributed to blackspot treatment. Studies that account for both regression-to-the-mean and a possible accident migration to neighbouring untreated sites do not show any net accident reduction at all. This tendency conforms to the so called Iron Law of evaluation studies, which states that the more confounding factors an evaluation study accounts for, the less likely it is to show beneficial effects of the programme evaluated. Possible explanations of accident migration are discussed in the paper. © 1997 Elsevier Science Ltd. All rights reserved

Keywords—Road accident, Blackspot, Treatment, Evaluation study, Meta-analysis

INTRODUCTION

The identification, analysis and treatment of road accident blackspots is widely regarded as one of the most effective approaches to road accident prevention. In its *Guidelines for Accident Reduction and Prevention*, the Institution of Highways and Transportation (1990) states (p. 2):

> It is well established that considerable safety benefits may accrue from application of appropriate road engineering or traffic management measures at hazardous road locations. Results from such applications at "blackspots" demonstrating high returns from relatively low cost measures have been reported worldwide.

It is correct that a number of studies from different parts of the world have reported large reductions in the number of accidents when safety measures were introduced at road accident blackspots. Many of these studies are, however, simple before-and-after studies that do not take account of any confounding factors that might affect the number of accidents. In particular, it is known that an abnormally high recorded number of accidents at a certain location can result from random fluctuation in the number of accidents. To the extent that an abnormally high number of accidents, or an abnormally high accident rate, is the result of random fluctuations, a subsequent decline in the number of accidents (or the accident rate) must be expected even if no safety treatment is applied. This phenomenon is known as regression to the mean and has been found in several studies (see, for example, Forbes, 1939; Brüde and Larsson, 1982; Hauer and Persaud, 1983).

This source of confounding is particularly important in evaluations of road accident blackspot treatment. Rossi and Freeman (1985) have proposed what they term "The Iron Law of Evaluation Studies" in these terms (p. 391): "The better an evaluation study is technically, the less likely it is to show positive program effects". The purpose of this paper is to investigate whether the Iron Law of Evaluation Studies applies to studies that have evaluated the effects on safety of road accident blackspot treatment. To what extent do the effects on accidents attributed to blackspot treatment disappear as more confounding factors are controlled in evaluation studies? In order to shed light on this question, a meta-analysis has been made of 36 studies that have evaluated the effects on accidents of road accident blackspot treatment.

DATA AND METHOD

Evaluation studies included

A total of 36 evaluation studies are included. The studies were retrieved by means of a systematic literature survey. The literature survey consisted of scanning peer reviewed journals like *Accident Analysis and Prevention*, *ITE-Journal*, *Journal of Safety Research*, *Traffic Engineering and Control* and *Transportation Research Record*. In addition, publications issued by highway agencies and research institutes in the Nordic Countries were included, as well as publications of highway agencies and major institutions in Australia, Great Britain and the United States.

Studies were included if: (1) they stated that the treatment evaluated was applied at an 'accident blackspot' or because of a 'bad accident record' or an 'abnormal accident experience', (2) they reported the number of accidents their results were based on and (3) the research design was described in sufficient detail to determine which confounding factors a study controlled for. A number of different formal, statistical definitions of a road accident blackspot have been proposed (Hauer, 1996). However, most evaluation studies describe the selection of locations for treatment only in general terms and do not state explicitly if a formal, statistical blackspot definition was applied. It was therefore not possible to confine the analysis to studies relying on a formal blackspot concept. Studies included are listed in Appendix A.

Statistical weighting of results

Each of the studies included contains one or more results of an evaluation of the effects on safety of one or several treatments carried out at one or several locations. All studies are non-experimental before-and-after studies. Some of the studies included comparison groups in addition to the treated sites. Weighted mean results were estimated by means of the logodds method of meta-analysis (Fleiss, 1981). Each result was assigned a statistical weight inversely proportional to the variance of the logodds of the estimated effect:

$$W_i = 1/(1/B_i + 1/A_i)$$

where B_i denotes the number of accidents at treated sites in the before-period for result i and A_i denotes the corresponding number of accidents in the after-period. This choice of weights for each result minimizes the variance of the weighted mean. In studies using comparison sites, the variance of the estimated effect of treatment depends on the number of accidents at both the treatment and comparison sites. However, many evaluation studies do not state the number of accidents recorded at comparison sites. Hence, the contribution of fluctuations in comparison group accidents to the variance of the estimated effects of treatment had to be ignored. This raises the value of the statistical weights assigned to results of studies using comparison groups. For example, the statistical weight of a result based on 38 accidents before and 22 accidents after in the treatment group, and 245 accidents before and 218 accidents after in the comparison group is 13.9, if accidents in the comparison group are ignored, but 12.4 if they are included when calculating the statistical weight.

In order to test if the method of estimating statistical weights might introduce bias in the weighted mean results, the weighted results were compared to simple unweighted mean results. The weighted and unweighted results were very similar and no systematic bias in any direction was found. Only the weighted mean results are presented in this paper, as they are statistically more precise than unweighted results. Weighted mean safety effects for groups of evaluation studies were estimated according to the following formula (Fleiss, 1981):

$$\text{Weighted mean safety effect} = \exp[(\Sigma \ln(\theta_i) \cdot W_i)/\Sigma W_i]$$

where exp denotes the exponential function, ln the natural logarithm, θ_i each estimate of treatment effect and W_i the statistical weight of each estimate of treatment effect. A 95% confidence interval for the weighted mean safety effect was estimated by applying methods described by Fleiss (1981).

Controlling for confounding factors

Confounding factors are all factors that weaken the basis for inferring a causal relationship between blackspot treatment and changes in road safety. Confounding factors represent alternative interpretations to the findings and ought ideally to be eliminated. Complete control of confounding factors is possible only by using an experimental research design, involving the random assignment of study units to a treatment or non-treatment condition. In non-experimental research, control of confounding factors will always be incomplete and imperfect. But the more known confounding factors a study controls for, the better becomes the basis for concluding that observed changes in road safety were caused by the treatment rather than the confounders. The confounding factors considered in this study are:

(1) Changes in traffic volume
(2) General trends in the number of accidents
(3) Regression to the mean
(4) Accident migration

These are some of the most important known confounding factors present in non-experimental before-and-after studies of road accident blackspot treatment.

Changes in traffic volume are usually controlled for by estimating accident rates (accidents per million vehicle kilometers or per million passing or entering vehicles) and using changes in these as the measure of effect in evaluation studies. It is normally assumed that the number of accidents is a linear function of traffic volume (Hauer, 1995). This assumption is not always correct. Hence, the use of changes in accident rates as the measure of effect in before-and-after studies does not necessarily remove the effects of changes in traffic volume on the number of accidents. In this paper, however, evaluation studies using changes in accident rates as the measure of effect have been classified as controlling for changes in traffic volume.

The presence of general trends in the number of accidents is usually controlled for by using a comparison group, often consisting of the total number of accidents in a country or in the area where the treated blackspots are located. The use of a comparison group relies on the assumption that changes in the number of accidents in the comparison group correctly predicts the changes that would have occurred at the treated sites in the absence of treatment. As shown by Hauer (1991), this assumption will not always be correct. On the other hand, this assumption has traditionally been accepted, at least as approximately correct. Hence, studies using comparison groups have been classified as taking account of general trends in the number of accidents, except when the comparison group consisted of untreated blackspots exclusively (see comment below).

Two methods have been used to control for regression to the mean in studies evaluating blackspot treatments. One method is to use a comparison group of untreated blackspots. Changes in the number of accidents at untreated blackspots are assumed to reflect mainly regression to the mean, rather than general trends. This interpretation is accepted in this paper. The other method of controlling for regression to the mean is to estimate this effect by means of a statistical model (Brüde and Larsson, 1982; Hauer, 1980, 1986, 1992). There are several models that differ in both assumptions and estimation techniques. A detailed discussion of these differences is beyond the scope of this paper. In this paper, all studies using one of the two methods for removing regression to the mean have been classified as controlling for this confounding factor.

Accident migration denotes the transfer of accidents from the blackspots to surrounding locations as a result of blackspot treatment. The usual way of controlling for accident migration is to include the surrounding locations to which accidents are supposed to migrate in the treated group. Changes in the number of accidents for the enlarged group of locations will then reflect both the treatment effect at the treated sites and the accident migration effect at the surrounding sites. Some studies in addition estimate regression to the mean at both treated and surrounding sites by means of a statistical model, while other studies accept the recorded number of accident at treated and surrounding sites as unbiased estimates of the expected number of accidents. Studies using either of these designs have been classified as controlling for accident migration.

Design of analysis

Figure 1 shows the design of analysis used in the present study.

Blackspots were classified as road sections, junctions (intersections) and unspecified types of locations. For each type of blackspot, a distinction was made between injury accidents, accidents involving property damage only (PDO-accidents) and accidents of unspecified severity (generally including both injury and PDO-accidents in unknown proportions). For each type of blackspot and level of accident severity, the results of evaluation studies were compared with respect to which of the confounding factors, or combination of confounding factors, that were controlled.

RESULTS

All types of treatment combined

Table 1 shows the weighted mean results of studies that have evaluated the safety effects of road accident blackspot treatment, expressed in terms of percent change in the number of accidents attributed to the treatment. In Table 1 all types of treatment have been combined.

The results presented in Table 1 show that the size of the effect attributed to blackspot treatment in evaluation studies varies substantially depending on which confounding variables are controlled. This is seen by comparing the results printed in boldface italics in Table 1. In general, studies that do not control for any confounding factors find the largest effects of treatment. Studies that control simultaneously for general trends in the number of accidents, regression to the mean and accident migration do not find any statistically significant changes in the number of accidents due to blackspot treatment. The more confounding factors accounted for, the smaller the effect attributed to blackspot treatment becomes. This finding applies both to junctions and other locations and both to injury accidents and PDO-accidents. Most of the evidence refers to injury accidents. The results for PDO-accidents are more uncertain.

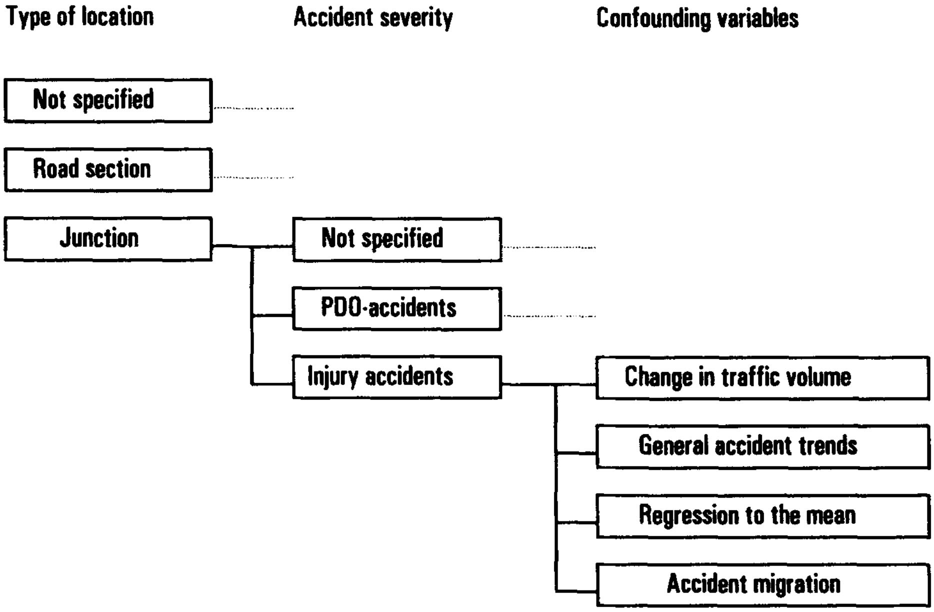

Fig. 1. Classification of types of location, accident severity and confounding variables controlled.

Some of the results are based on just one or two studies. In order to increase sample size, results that refer to injury accidents were combined for all types of location. The combined results are shown in the bottom of Table 1 (the results that refer to all types of location). There is a very clear tendency for the effect attributed to treatment to become smaller as more confounding factors are controlled. Studies that account for accident migration are, however, the only category which do not show statistically significant accident reductions following blackspot treatment.

Results for different kinds of treatment

An objection to this analysis is that different kinds of treatment are likely to have different effects; hence it does not make sense to estimate the weighted mean safety effects of different treatments combined. Estimates of effects ought to be made for each kind of treatment by itself. Table 2 presents an analysis of five common safety treatments at junctions, for studies with different degrees of control of confounding factors.

The tendency found when all treatments were combined is reproduced when different treatments are studied by themselves. In general, the more confounding factors studies account for, the smaller are the effects attributed to the treatment. This pattern is evident for all five treatments included in Table 2. Once again, however, some of the estimates are based on just one of two studies. There were too few studies to do a similar analysis of different treatments applied to road sections.

DISCUSSION

Road accident blackspot treatment has for a long time been accepted as an effective way of preventing road accidents. The results presented in this paper, if taken at face value, indicate that this belief is unfounded. The belief that blackspot treatment is particularly effective seems to have rested on an uncritical acceptance of the results of simple before and after studies that fail to account for confounding factors that may explain the observed reductions in the number of accidents or the accident rate.

Today, most researchers accept that in non-experimental before-and-after studies of treatments at locations that were selected for treatment because of their bad accident record, it is necessary as a minimum to remove the effects of changes in traffic volume, general trends in the number of accidents and regression to the mean before anything can be concluded with respect to the effects of the treatment. Some researchers were aware of the need to remove the effects of regression to the mean as early as 1968. Thus, Tamburri et al. (1968)(p. 38):

> The possibility always exists that an improvement project may have been initiated because of an unusually high accident experience which was merely a reflection of a temporary condition in the before period. In such cases, even if nothing had been done, an accident reduction would probably have been observed in the after period (regression to the mean theory). The possibility of such an influence was investigated.

Tamburri et al. (1968) go on to state that it was found that some locations had a permanent high level

Table 1. Weighted mean effects of blackspot treatment on the number of accidents by type of location, accident severity and confounding variables controlled

Type of location	Accident severity	Confounding variables controlled	Number of studies	Proportion of statistical weights	Percent change in accidents: Lower 95%	Best estimate	Upper 95%
Junction	Injury accidents	None	6	0.048	−66	*−60*	−54
		Traffic volume	5	0.093	−49	*−43*	−37
		Trend	4	0.359	−36	*−33*	−29
		Regression to mean	1	0.028	−44	*−31*	−16
		Trend, regression to mean	2	0.023	−31	*−14*	+7
		Trend, accident migration	1	0.449	−8	*−4*	+1
			19	1.000	−26	−24	−21
Junction	PDO-accidents	None	5	0.405	−46	*−37*	−25
		Traffic volume	3	0.483	−51	*−42*	−33
		Trend, regression to mean	1	0.112	−27	*+0*	+38
			9	1.000	−43	−36	−29
Junction	Not specified	None	3	0.265	−48	*−42*	−36
		Traffic volume	1	0.032	−60	*−46*	−29
		Trend, regression to mean	3	0.490	−46	*−42*	−38
		Trend, regression to mean, accident migration	1	0.213	−12	*−2*	+9
			8	1.000	−39	−36	−32
Road section	Injury accidents	None	3	0.123	−57	*−51*	−43
		Traffic volume	2	0.030	−23	*+3*	+37
		Trend	6	0.332	−19	*−12*	−3
		Trend, traffic volume	1	0.127	−42	*−33*	−23
		Trend, regression to mean	1	0.018	−61	*−44*	−18
		Trend, accident migration	1	0.370	−6	*+2*	+11
			14	1.000	−21	−16	−12
Road section	PDO-accidents	None	2	0.031	−95	*−92*	−86
		Traffic volume	1	0.084	−50	*−29*	−0
		Trend, traffic volume	1	0.787	−36	*−29*	−20
		Trend, regression to mean	1	0.098	−39	*−16*	+15
			5	1.000	−39	−32	−25
Not stated	Injury accidents	Traffic volume, regression to mean	2	0.103	−34	*−24*	−12
		Trend, regression to mean	4	0.392	−22	*−16*	−10
		Trend, regression to mean, accident migration	3	0.505	−7	*+0*	+7
			9	1.000	−13	−9	−5
All types	Injury accidents	None	8	0.052	−60	*−55*	−50
		Traffic volume	5	0.054	−45	*−39*	−32
		Trend	6	0.259	−30	*−28*	−24
		Regression to mean	3	0.041	−34	*−26*	−17
		Trend, traffic volume	1	0.029	−42	*−33*	−23
		Trend, regression to mean	7	0.119	−22	*−17*	−11
		Trend, accident migration	1	0.313	−6	*−2*	+2
		Trend, regression to mean, accident migration	3	0.133	−6	*+0*	+7
			34	1.000	−20	−18	−16

of accident experience, not just during the few years that were the before period in their study. For other locations, planning took so long that the number of accidents had already regressed to a more normal level when the safety treatment was carried out. In general, prolonging the before and after periods will water down the regression to the mean effect, but not remove it altogether (Nicholson, 1988). On the other hand, long before and after periods enlarge the influence of general trends in accidents on the results of a study.

The need to control for regression to the mean in before-and-after studies of safety measures introduced at high accident locations can be deduced from elementary statistical theory. Despite this fact, studies that do not remove this important source of bias are still published (see, for example, the papers by Wong, 1990 and Proctor, 1995).

The possibility of accident migration, and the consequent need to control for it, was first raised by Boyle and Wright (1984). Their paper was criticized for not controlling for regression to the mean (McGuigan, 1985). Subsequent papers by Maher (1987, 1990) suggested that accident migration is a statistical artefact, generated mainly by a combination of regression to the mean downwards of abnormally high accident counts at treated sites and regression to the mean upwards of abnormally low

Table 2. Weighted mean safety effects of some common blackspot treatments in junctions by confounding variables controlled

Type of location	Treatment	Confounding variables controlled	Number of studies	Proportion of statistical weights	Percent change in accidents: Lower 95%	Best estimate	Upper 95%
Junction	Channelization	None	3	0.324	−58	*−52*	−45
		Traffic volume	3	0.138	−52	*−40*	−25
		Trend	1	0.193	−50	*−40*	−28
		Trend, regression to mean	1	0.077	−24	*+2*	+37
		Trend, accident migration	4	0.268	−12	*+2*	+20
			12	1.000	−38	−32	−27
Junction	Four way stop	Traffic volume	1	0.020	−85	*−76*	−64
		Trend, regression to mean	2	0.669	−50	*−46*	−41
		Trend, regression to mean, accident migration	1	0.311	−12	*−2*	+9
			4	1.000	−40	−36	−32
Junction	Traffic signals	None	1	0.025	−84	*−70*	−44
		Trend	5	0.443	−56	*−49*	−40
		Trend, regression to mean	2	0.073	−22	*+12*	+62
		Trend, accident migration	1	0.459	−20	*−7*	+8
			9	1.000	−36	−29	−22
Junction	Traffic signal improvements	None	2	0.140	−50	*−44*	−37
		Traffic volume	1	0.024	−60	*−47*	−29
		Trend	4	0.386	−31	*−26*	−21
		Trend, regression to mean	1	0.008	−26	*+21*	+98
		Trend, accident migration	1	0.442	−9	*−3*	+3
			9	1.000	−24	−20	−17
Junction	Surface friction improvement	None	1	0.630	−44	*−35*	−26
		Trend	1	0.075	−79	*−68*	−54
		Traffic volume, regression to mean	2	0.295	−44	*−31*	−16
			4	1.000	−44	−38	−31

accident counts at surrounding sites. The studies of Persaud (1987), Mountain and Fawaz (1989, 1992) and Mountain et al. (1992, 1994) have, however, controlled for regression to the mean, but nevertheless find some support for a hypothesis of accident migration. This raises the question of whether plausible explanations of accident migration are known or can be imagined.

Boyle and Wright (1984) proposed the following explanation: "It can be hypothesized that where an accident blackspot is treated, drivers will be subjected to fewer "near-misses" at that site, and consequently will be less aware of the need for caution. This reduced awareness may persist for some distance downstream, and consequently the risk of an accident in the area surrounding the blackspot may be increased." They do not produce any evidence to support this hypothesis. Several considerations suggest that the hypothesis is not a very plausible explanation for accident migration.

There seems to be an element of logical inconsistency in the hypothesis. If it is true that exposure to near-misses induces driver caution, and if, as the hypothesis seems to assume, the number of accidents is positively related to the number of near-misses, it is difficult to see how an accident blackspot could arise in the first place. If drivers experienced more near-misses before the blackspot was treated, their level of caution at that site, ought, according to Boyle and Wright, to have been higher before treatment than after. This makes it difficult to understand how treating a blackspot could really reduce the number of accidents at the blackspot itself. Boyle and Wright suggest that a reduced level of caution persists 'some distance' downstream. Why should this be the case, if drivers continuously adapt their level of caution to the number of near-misses they experience at any site?

The mechanism suggested by Boyle and Wright rests on the assumption that the number of accidents is related to the level of driver caution. The number of near-misses is obviously one of the factors that may influence the level of driver caution, but it is unlikely to be the only factor, and perhaps not even a very important one. In a study in Uppsala in Sweden, Johansson and Naeslund (1986) found that there was no correlation at all between the subjective hazard ratings drivers gave to specific locations in the city and the accident experience at those sites. The worst blackspots were not rated by drivers as particularly hazardous; perhaps that is one the reasons why these sites developed into blackspots. At sites that were perceived as hazardous, there were few accidents because drivers were careful. The perception of a site as hazardous was related to sight distance, traffic volume and driving speed. Unfortunately, the study did not examine the influence of near-misses on subjective hazard ratings.

Persaud (1987) suggests that changes in driver expectancy may explain accident migration, when most intersections in Philadelphia were converted to four way stop control. Once four way stop control became the norm, drivers started to expect drivers entering from the major road in intersections with two way stop control to stop as well. Persaud does not produce direct evidence of such changes in driver expectancy, but the changes observed in accident counts for intersections with different types of traffic control (four way stop, two way stop, traffic signals) support the hypothesis.

It is not known if the mechanism suggested by Persaud applies to blackspot treatment in general. It does not seem likely that every kind of treatment will lead to similar changes, or any changes at all, in driver expectancy. The signing of hazardous curves may be a case in point. If hazard warning signs are put up in almost every curve, two things may happen. One, drivers will not take the signs seriously and two, the few curves where no hazard warning sign has been put up will become more surprising and therefore perhaps more prone to accidents. But if the use of hazard warning signs at curves is more restrictive, such adaptations seem less likely to occur.

More research is clearly needed to establish more firmly how real and widespread accident migration is. The changes in driver perception, expectancy or behaviour that may lead to accident migration have to be studied more in detail before it can be concluded that accident migration is a real phenomenon that will occur often or whenever accident blackspots are treated. The evidence presented in this paper is inconclusive.

CONCLUSIONS

The main conclusions of the research reported in this paper are:

(1) Based on before-and-after studies reporting large reductions in the number of accidents following road accident blackspot treatment, this is widely believed to be a particularly effective approach to road accident prevention. Some of these studies are simple before-and-after studies that do not account for any of the confounding factors known to affect the results of such studies.

(2) A meta-analysis of 36 before-and-after studies of road accident blackspot treatment was performed in order to determine how the degree of control for known confounding factors affected the results of those studies. Four known confounding factors were considered: (i) changes in traffic volume, (ii) general trends in the number of accidents, (iii) regression to the mean and (iv) accident migration. The logodds method of meta-analysis was used.

(3) It was found that the results of before-and-after studies of road accident blackspot treatment depend strongly on which of the confounding factors studies control for. Large reductions in the number of accidents, generally in the order of 50–90%, were found in studies not controlling for any confounding factors. The more confounding factors studies controlled for, the smaller were the effects attributed to blackspot treatment. Studies simultaneously controlling for general trends, regression to the mean and accident migration did not find any statistically reliable effect of blackspot treatment on the number of accidents.

(4) The need to control for changes in traffic volume, general trends in accident occurrence and regression to the mean in before-and-after studies of blackspot treatment is accepted by most researchers. Accident migration is a more controversial phenomenon. More research is needed to determine how widespread accident migration is and the mechanisms explaining it.

REFERENCES

Boyle, A. J. and Wright, C. C. (1984) Accident "migration" after remedial treatment at accident blackspots. *Traffic Engineering and Control* **25**, 260–267.

Brüde, U. and Larsson, J. (1982) Regressionseffekt. Några empriska exempel baserade på olyckor i vägkorsningar. (VTI-rapport 240). Statens väg-och trafikinstitut (VTI), Linköping, Sweden.

Christensen, P. (1988) Utbedringer av ulykkespunkter på riksveger og kommunale veger i perioden 1976–1983. Erfaringsrapport. (TØI-rapport 0009). Transportøkonomisk institutt, Oslo.

Corben, B. F., Ambrose, C. and Wai, F. C. (1990) Evaluation of accident black spot treatments. (Report 11).: Accident Research Centre, Monash University, Melbourne, Australia.

Dearinger, J. A. and Hutchinson, J. W. (1970) Cross section and pavement surface. In *Traffic Control and Roadway Elements—Their Relationship to Highway Safety*, Chapter 7. Revised Edition. Highway Users Federation for Safety and Mobility, Washington, DC.

Duff, J. T. (1971) The effect of small road improvements on accidents. *Traffic Engineering and Control* **12**, 244–245.

Elvik, R. (1985) Regresjonseffekt i ulykkespunkter. En empirisk undersøkelse på riksveger i Vest-Agder. (Arbeidsdokument av 9.9.1985 (prosjekt O-1146)).: Transportøkonomisk institutt, Oslo.

Exnicios, J. F. (1967) Accident reduction through channelization of complex intersections. In *Improved Street Utilization Through Traffic Engineering*, pp. 160–165.

(Special Report 93).: Highway Research Board, Washington, DC.

Flagstad, K. (1990) Før-etter analyse av trafikksikkerhetstiltak i Bergen. Hovedoppgave i samferdselsteknikk. Trondheim. Norges Tekniske Høgskole, Institutt for samferdselsteknikk.

Fleiss, J. L. (1981) *Statistical Methods for Rates and Proportions*. 2nd edn. John Wiley and Sons, New York.

Forbes, T.W. (1939) The normal automobile driver as a traffic problem. *Journal of General Psychology* **20**, 471–474.

Gregory, M. and Jarrett, D. F. (1994) The long-term analysis of accident remedial measures at high-risk sites in Essex. *Traffic Engineering and Control* **35**, 8–11.

Hammer, C.G. (1969) Evaluation of minor improvements. *Highway Research Record* **286**, 33–45.

Hatherly, L.W. and Lamb, D. R. (1971) Accident prevention in London by road surface improvements. *Traffic Engineering and Control* **12**, 524–529.

Hatherly, L.W. and Young, A.E. (1977) The location and treatment of urban skidding hazard sites. *Transportation Research Record* **623**, 21–28.

Hauer, E. (1980) Bias-by selection: Overestimation of the effectiveness of safety countermeasures caused by the process of selection for treatment. *Accident Analysis and Prevention* **12**, 113–117.

Hauer, E. (1986) On the estimation of the expected number of accidents. *Accident Analysis and Prevention* **18**, 1–12.

Hauer, E. (1991) Comparison groups in road safety studies: An analysis. *Accident Analysis and Prevention* **23**, 609–622.

Hauer, E. (1992) Empirical Bayes approach to the estimation of "unsafety": The multivariate regression approach. *Accident Analysis and Prevention* **24**, 457–477.

Hauer, E. (1995) On exposure and accident rate. *Traffic Engineering and Control* **36**, 134–138.

Hauer, E. (1996) Identification of "sites with promise". (Paper 960995).: Transportation Research Board, 75th Annual Meeting, Washington, DC.

Hauer, E. and Persaud, B. N. (1983) Common bias in before-and-after accident comparisons and its elimination. *Transportation Research Record* **905**, 164–174.

Holmskov, O. and Lahrmann, H. (1993) Er sortpletbekæmpelse vejen frem? *Dansk Vejtidsskrift* **2**, 3–9.

Hvoslef, H. (1974) *Trafikksikkerhet i Oslo. Problemstilling, analyse og løsninger*. Oslo veivesen, Oslo.

Institution of Highways and Transportation (1990) *Guidelines for Accident Reduction and Prevention*. International Edition. London.

Johansson, R. and Naeslund, A-L. (1986) Upplevd och verklig olycksrisk—möjligheter till påverkan. (TFB-rapport 1986:18). Transportforskningsberedningen, Stockholm, Sweden.

Jørgensen, E. (1979) Sikkerhedsmæssig effekt af mindre anlægsarbejder. Effektstudie. Næstved, Vejdirektoratet, Sekretariatet for Sikkerhedsfremmende Vejforanstaltninger (SSV).

Karr, J. I. (1972) Evaluation of minor improvements—part 8, grooved pavements. Final Report. (Report CA-HY-TR-2151-4-71-00). California Division of Highways, Sacramento, CA.

Kolster Pedersen, S., Kulmala, R., Elvestad, B., Ivarsson, D. and Thuresson, L. (1992) Trafiksäkerhetsåtgärder i Väg-och Gatumiljö. Exempel hämtade från de nordiska länderna under 1980-talet. Nordiske Seminar-og Arbejdsrapporter 1992:607. København, Nordisk Ministerråd.

Lalani, N. (1991) Comprehensive safety program produces dramatic results. *ITE-Journal* **61** (10), 31–34.

Legassick, R. (1995) The case for route studies in road traffic accident analysis investigations. Paper presented at the *Conference on Strategic Highway Research Program and Traffic Safety*, Prague, The Czech Republic. Preprint for Sessions 21/9.

Lovell, J. and Hauer, E. (1986) The safety effect of conversion to all-way stop control. *Transportation Research Record* **1068**, 103–107.

Maher, M.J. (1987) Accident migration—a statistical explanation. *Traffic Engineering and Control* **28**, 480–483.

Maher, M.J. (1990) A bivariate negative binomial model to explain traffic accident migration. *Accident Analysis and Prevention* **22**, 487–498.

Malo, A. F. (1967) Signal modernization. In *Improved Street Utilization Through Traffic Engineering*, pp. 96–113. (Special Report 93). Highway Research Board, Washington, DC.

McGuigan, D.R.D. (1985) Accident "migration"—or a flight of fancy? *Traffic Engineering and Control* **26**, 229–233.

Mountain, L. and Fawaz, B. (1989) The area-wide effects of engineering measures on road accident occurrence. *Traffic Engineering and Control* **30**, 355–360.

Mountain, L. and Fawaz, B. (1992) The effects of engineering measures on safety at adjacent sites. *Traffic Engineering and Control* **33**, 15–22.

Mountain, L., Fawaz, B. and Sineng, L. (1992) The assessment of changes in accident frequencies on link segments: a comparison of four methods. *Traffic Engineering and Control* **33**, 429–431.

Mountain, L., Fawaz, B., Wright, C., Jarrett, D. and Lupton, K. (1994) Highway improvements and maintenance: their effects on road accidents. Paper presented at the *22nd PTRC Summar Annual Meeting*, Proceedings of Seminar J, pp. 151–161.

Nicholson, A. (1988) Accident count analysis: the classical and alternative approaches. *Proceedings of Session 2, Models for Evaluation, Traffic Safety Theory and Research Methods*, Amsterdam, The Netherlands. SWOV Institute for Road Safety Research.

OECD Road Research Group (1976) *Hazardous Road Locations. Identification and Countermeasures*. OECD, Paris.

Persaud, B.N. (1987) "Migration" of accident risk after remedial blackspot treatment. *Traffic Engineering and Control* **28**, 23–26.

Proctor, S. (1995) An independent review of 3M "Road Safety" products. Paper presented at the *Conference on Strategic Highway Research Program and Traffic Safety*, Prague, The Czech Republic. Preprint for Sessions 22/9.

Retting, R. A. (1991) *Improving Urban Traffic Safety: A Multidisciplinary Approach. Experiences From New York City 1983–1989*. Prepared in conjunction with the Volvo Traffic Safety Award 1991. Thompson Printing, Belleville, NJ.

Rossi, P. H. and Freeman, H. E. (1985) *Evaluation. A Systematic Approach*, 3rd edn. Sage Publications, Beverley Hills, CA.

Statens vegvesen (1983) *Veiledning. Håndbok 115. Analyse av ulykkessteder*. Statens vegvesen, Oslo.

Sørensen, M. (1991) Forsøg med særlig afmærkning af uheldskryds. *Dansk Vejtidsskrift* **5**, 17–19.

Tamburri, T.N., Hammer, C. J., Glennon, J. C. and Lew, A. (1968) Evaluation of minor improvements. *Highway Research Record* **257**, 34–79.
Vodahl, S. B. and Johannessen, S. (1977) Ulykkesfrekvenser i kryss. Arbeidsnotat nr 7. Resultater av før/etterundersøkelsen. (Oppdragsrapport 178). Norges Tekniske Høgskole, Forskningsgruppen, Institutt for samferdselsteknikk, Trondheim.
Værø, H. (1992a) *Effekt af sortpletbekæmpelse i Hillerød.* København, Vejdirektoratet, Trafiksikkerhedsafdelingen.
Værø, H. (1992b) *Effekt af sortpletbekæmpelse i Nyborg.* København, Vejdirektoratet, Trafiksikkerhedsafdelingen.
Værø, H. (1992c) *Effekt af sortpletbekæmpelse i Silkeborg.* København, Vejdirektoratet, Trafiksikkerhedsafdelingen.
Værø, H. (1992d) *Effekt af sortpletbekæmpelse i Skælskør.* København, Vejdirektoratet, Trafiksikkerhedsafdelingen.
Wilson, J. E. (1967) Simple types of intersection improvements. In *Improved Street Utilization Through Traffic Engineering*, pp. 144–159. (Special Report 93). Highway Research Board, Washington, DC.
Wong, S-Y. (1990) Effectiveness of pavement grooving in accident reduction. *ITE Journal* **60**(6), 34–37.

APPENDIX A

List of studies included in meta-analysis and characteristics of each study.

Authors (Year)	Country	Types of locations studies	Types of treatment specified	Confounding variables controlled
Exnicios (1967)	United States	Junctions	Yes	None
Malo (1967)	United States	Junctions	Yes	None; traffic volume
Wilson (1967)	United States	Junctions	Yes	Traffic volume
Tamburri et al. (1968)	United States	Junctions	Yes	Traffic volume
Hammer (1969)	United States	Junctions; sections	Yes	None; traffic volume
Dearinger and Hutchinson (1970)	United States	Junctions; sections	Yes	None
Duff (1971)	Great Britain	Junctions; sections	Yes	None
Hatherly and Lamb (1971)	Great Britain	Junctions	Yes	None
Karr (1972)	United States	Sections	Yes	Trend; traffic volume
Hvoslef (1974)	Norway	Junctions; sections	Yes	Trend
OECD (1976)	France	Junctions	Yes	Trend
Hatherly and Young (1977)	Great Britain	Junctions	Yes	Regression
Vodahl and Johannessen (1977)	Norway	Junctions	Yes	Trend; regression
Jørgensen (1979)	Denmark	Junctions; sections	Yes	Trend
Statens vegvesen (1983)	Norway	Sections	Yes	Trend
Boyle and Wright (1984)	Great Britain	Junctions; sections	Yes	Trend; migration
Elvik (1985)	Norway	Not stated	No	Regression
Lovell and Hauer (1986)	United States	Junctions	Yes	Trend; regression
Persaud (1987)	United States	Junctions	Yes	Trend; regression; migration
Christensen (1988)	Norway	Not stated	No	Regression
Mountain and Fawaz (1989)	Great Britain	Not stated	No	Trend; regression; migration
Corben et al. (1990)	Australia	Junctions; sections	Yes	Trend
Flagstad (1990)	Norway	Junctions; sections	No	Traffic volume
Wong (1990)	United States	Sections	Yes	None
Lalani (1991)	United States	Junctions	Yes	Trend
Retting (1991)	United States	Sections	No	None
Sørensen (1991)	Denmark	Junctions	Yes	None
Kolster Pedersen et al. (1992)	Denmark	Junctions; sections	Yes	None
Mountain and Fawaz (1992)	Great Britain	Not stated	No	Trend; regression; migration
Mountain et al. (1992)	Great Britain	Not stated	No	Trend; regression
Værø (1992a,b,c,d)	Denmark	Junctions; sections	Yes	Trend; regression
Holmskov and Lahrmann (1993)	Denmark	Junctions; sections	Yes	Trend; regression
Gregory and Jarrett (1994)	Great Britain	Not stated	No	Trend; regression
Mountain et al. (1994)	Great Britain	Not stated	No	Trend; regression; migration
Legassick (1995)	Great Britain	Sections	Yes	Trend
Proctor (1995)	Great Britain	Sections	Yes	None