Accident Analysis and Prevention 41 (2009) 876–880

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

An exploratory analysis of models for estimating the combined effects of road safety measures

Rune Elvik

Institute of Transport Economics, Gaustadalléen 21, NO-0349 Oslo, Norway

ARTICLE INFO

Article history:
Received 30 December 2007
Received in revised form 10 April 2009
Accepted 8 May 2009

Keywords:
Road safety measures
Combined effects
Models for estimation
Exploratory analysis

ABSTRACT

Road safety programmes consisting of a large number of road safety measures have been developed in many countries. To estimate the effects of such programmes on the number of accidents, models for estimating the combined effects of road safety measures are needed. This paper presents an exploratory analysis of such models. There is very little empirical evidence to support model building. Based on a few studies that have evaluated the effects of multiple road safety measures introduced at the same locations, the paper compares two models. One of the models, the common residuals model, assumes that the (percentage) effect of a road safety measure remains unchanged when it is combined with other road safety measures. The other model, the dominant common residuals model, assumes that the most effective measure in a set of measures has a dominant effect that weakens the effects of other road safety measures it is combined with. Evidence from the few studies that were found is consistent with both these models. A study of the effects of a road safety programme implemented in Victoria, Australia between 1990 and 1996 indicated that the effects of safety measures are weakened when these measures are combined with other road safety measures.

1. Introduction

Consider the case of a policy maker who wants to introduce three road safety measures. One of them will reduce accidents by 30%. The second measure will reduce accidents by 40%. The third measure will reduce accidents by 50%. What will be the total effect on accidents of introducing all three measures? Surely, accidents will not be reduced by 120%, which is the sum of the effects of the three measures. It is logically impossible to reduce anything by more than 100%.

The most common model used to estimate the combined effects of road safety measures is to assume that effects are independent and combine multiplicatively. Such a model was proposed by Smeed (1949, page 13), who wrote that: . . .” if the number of accidents can be reduced by fractions $\varepsilon_1, \varepsilon_2, \ldots \varepsilon_n$ by n different and mutually exclusive methods, the resultant reduction will of course be to $(1-\varepsilon_1)\times(1-\varepsilon_2)\ldots(1-\varepsilon_n)$ of its former value.” Thus, in the example above, 70% of accidents will remain once the measure that reduces accidents by 30% has been implemented. Denote the effect of a measure by E, and the proportion of accidents the measure does not prevent by R, the “residual” of the measure. Both E and R are stated as proportions and sum to 1. Then, in the example above, the combined effect of the three measures is usually estimated as follows:

$$\text{Combined effect} = 1-[(1-E_1)(1-E_2)(1-E_3)]$$
$$= 1-(0.7\times 0.6\times 0.5) = 0.79$$

The combined effect of the three measures is an accident reduction of 79%. This method for estimating the combined effects of road safety measures will be denoted as the method of common residuals. It could also be termed the method of independent accident modification factors, as accident modification factors tend to be presented as residuals, i.e. an accident modification factor of 0.7 corresponds to an accident reduction of 30%. It is perhaps the simplest method that can be conceived. It assumes that the effect of a road safety measure is independent of the effects of any other road safety measure and remains, in percentage terms, unaltered when several road safety measures are combined. The method of common residuals ensures that the combined effects of several road safety measures will never exceed 100%.

The objective of this paper is to compare empirically how well various models for estimating the combined effects of several road safety measures perform. The basic question is: does the method of common residuals estimate the combined effects of road safety measures with sufficient accuracy, or can better models be developed?

E-mail address: re@toi.no.

0001-4575/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2009.05.003

Table 1
Models for estimating the combined effects of road safety measures.

Model of combined effects	Measure A	Measure B
Accidents affected	100 accidents before any measure is introduced	
First order effect (%)	−40	−30
First order residual (proportion)	0.60	0.70
Model 1: Additive effects	70 accidents prevented, 30 remaining,	
Model 2: Independent effects	58 accidents prevented, 42 remaining	
Model 3: Correlated effects	51 accidents prevented, 49 remaining	
Model 4: Dominated effects	40 accidents prevented, 60 remaining	

2. Models for estimating the combined effects of road safety measures

Several models can be imagined for estimating the combined effects of road safety measures. Table 1 illustrates four models.

The first of the models listed in Table 1, additive effects, implies that the first order effects of two or more measures can be added to obtain their combined effect. In Table 1, the first order effects of the two measures are 40% and 30%. The term first order effect refers to the effect each of the measures has when it alone is introduced. The combined effect according to the additive model is $(40+30)\% = 70\%$, corresponding to 70 accidents prevented. This model lacks plausibility and is likely to produce nonsensical estimates if several road safety measures are combined, as indicated in the introduction.

Model 2 in Table 1, independent effects, is identical to the method of common residuals. According to this method, the assumption is made that the first order effects of a measure, stated in percentage terms, are independent of the effects of other road safety measures. Applied to the numbers used in Table 1, the residuals are 0.60 and 0.70. The combined effect is $1-(0.7\times0.6)=1-0.42=58\%$ accident reduction, which corresponds to 58 accidents prevented.

Model 3 in Table 1, correlated effects, represents a case in which the introduction of one road safety measure weakens the effect of another road safety measure, but not to the point of making it entirely ineffective. It could be the case, for example, that the most effective measure in a set of measures reduces the effects of the other measures once it is introduced. Measure A is the most effective of the two measures, reducing accidents by 40%. Suppose that measure A influences some of the same risk factors for accidents as measure B, so that once measure A has been introduced, the effect of measure B is reduced by 40%, i.e. from 30% to 18%. In such a case, the combined effect of the two measures would be: $1-(0.6\times0.82)=1-0.492=50.8\%$, which, rounded to the nearest whole number, corresponds to 51 accidents prevented.

Model 4 in Table 1, dominated effects, describes a situation in which the introduction of one road safety measure makes another measure entirely ineffective. Thus, once, for example measure A has been introduced, measure B is entirely ineffective and the combined effect of the two measures will be identical to the effect of a single measure. While such cases can be imagined, the model lacks plausibility and will not be investigated further. The two most plausible models in Table 1 are the models assuming independent effects or correlated effects. Below, a few studies that provide data on the combined effects of road safety measures are reviewed in order to assess which model performs best in estimating these effects.

3. Review of studies that have estimated the combined effects of road safety measures

A computer search for studies that have estimated the combined effects of road safety measures was performed, using "combined effects of road safety measures" as search term. A search of the TRANSPORT literature database yielded a single study only (Broughton et al., 2000). That study, however, did not provide evidence on the combined effects of road safety measures. It was rather a study discussing the problem of how best to estimate the combined effect of road safety measures.

The review presented here is therefore based on a few studies that the author has collected over the years. Six studies have been found that have evaluated empirically the combined effect of introducing more than one road safety measure influencing the same group of accidents. The studies will be presented chronologically.

The oldest study is a study by Bali et al. (1978) of the effects of various road markings. The study employed a cross-sectional design and compared accident rates at locations that had different combinations of road marking treatments. Care was taken to ensure that the locations were as similar as possible with respect to all other characteristics that might influence safety. Whether this procedure successfully eliminated all confounding is not a key issue in the present context. Here, the study is of interest mainly because it enables a comparison of the effects of 1, 2 or 3 road marking treatments.

The second study is an evaluation of various junction improvements by Brüde and Larsson (1985). The study employed a before-and-after design controlling for regression-to-the-mean and long-term trends. Ten types of treatment were defined. Unfortunately, the number of accidents in many of the 10 groups is too small to consider them separately; hence mean estimates of effect have been developed for all types of treatment put together. Up to 10 different treatments were introduced in the same junction. Comparisons were made of the estimated mean effects of 1, 2, 3, 4 and 5 or more (mean 5.71) treatments at the same site.

The third study was reported by Bach and Jørgensen in 1986. It refers to treatments in signalised junctions and enables a comparison of the effects of 1 and 2 treatments. The study was a before-and-after study controlling for long-term trends, but not for regression-to-the-mean. The fourth study, by Kulmala (1995) evaluated a number of junction treatments. The study employed the empirical Bayes method to control for regression-to-the-mean and long-term trends. Like the study of Brüde and Larsson (1985), the number of accidents for each type of treatment is too small to evaluate the difference in effect between a single treatment and two treatments. All types of treatment were therefore analysed together.

The fifth study, by Gitelman et al. (2001) was a before-and-after study employing the empirical Bayes technique to evaluate a number of junction treatments in Israel. The study controlled for regression-to-the-mean and long-term trends. It enables a comparison of the effects of 1, 2 or 3 treatments.

The sixth study is a retrospective evaluation of factors that contributed to improving road safety in Victoria, Australia in the period from 1989 to 1996 (Newstead et al., 1998). The study identified and estimated the first order effects of six factors: unemployment, alcohol sales, a speed camera programme, a publicity campaign, drink-driving enforcement and treatment of hazardous road locations. Multivariate techniques were applied to estimate the effects of all these factors, except for treatment of hazardous road locations, whose effects were estimated by a different technique. The study differs from the other studies, in that it did not compare the com-