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Safety-in-numbers: A systematic review and meta-analysis of evidence

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ABSTRACT

This paper presents a systematic review and meta-analysis of studies that have estimated the relationship between the number of accidents involving motor vehicles and cyclists or pedestrians and the volume of motor vehicles, cyclists and pedestrians. A key objective of most of these studies has been to determine if there is a safety-in-numbers effect. There is safety-in-numbers if the number of accidents increases less than proportionally to traffic volume (for motor vehicles, pedestrians and cyclists). All studies reviewed in the paper are multivariate accident prediction models, estimating regression coefficients that show how the number of accidents depends on the conflicting flows (pedestrians, cyclists, motor vehicles), as well as (in some of the models) other factors that influence the number of accidents. Meta-analysis of regression coefficients involves methodological problems, which require careful consideration of whether the coefficients are sufficiently comparable to be formally synthesised by means of standard techniques of meta-analysis. The comparability of regression coefficients was assessed. It was concluded that a formal synthesis of regression coefficients in studies of the safety-in-numbers effect is defensible. According to a random-effects inverse-variance meta-analysis, the summary estimates of the regression coefficients for traffic volume are 0.50 for motor vehicle volume, 0.43 for cycle volume and 0.51 for pedestrian volume. Estimates are highly consistent between studies. It is concluded that a safety-in-numbers effect exists. It is still not clear whether this effect is causal, nor, if causal, which mechanisms generate the effect.

1. Introduction

Sustainable transport is an increasingly important objective of transport policy. In Norway, a policy objective in the current national transport plan (Samferdselsdepartementet, 2013) is that any growth in traffic in major cities should be by means of public transport or non-motorised transport. Car traffic should not grow. Non-motorised transport is, however, associated with a higher risk of injury per kilometre of travel than most forms of motorised transport (Bjørnskau, 2011). An increase in walking or cycling may therefore be associated with an increased number of injured road users.

On the other hand, a number of studies indicate that there is a so-called safety-in-numbers effect for pedestrians and cyclists. This means that when the number of pedestrians and cyclists increases, there is a less than proportional increase in the number of accidents involving them. However, the number of accidents involving pedestrians or cyclists and motor vehicles depends both on the volume of pedestrians or cyclists and on the volume of motor vehicles. To determine if there is a safety-in-numbers effect, one therefore needs data on all conflicting flows (motor vehicles, pedestrians, cyclists).

The objective of this paper is to systematically review studies of the safety-in-numbers effect and synthesise their findings by means of meta-analysis. Studies that use the number of injury accidents involving both a motor vehicle and a cyclist or pedestrian as dependent variable were treated as relevant. Studies of accidents involving pedestrians or cyclists exclusively were not included.

2. Study retrieval and classification

A literature search was performed to identify relevant studies. The search employed "safety in numbers" as search term and searched the Transport database provided by Ovid and the Web of Science database provided by Thomson Reuters. Details of the literature survey are described elsewhere (Bjørnskau, 2013). Studies judged as relevant for the analyses reported in this paper are listed in Table 1.

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Table 1
Studies identified in systematic literature survey.

Study	Type of location studied	Inclusion in synthesis	Study classification; reason for exclusion from meta-analysis
Inwood and Grayson (1979)	Pedestrian crossings	Included	Type 4: Several independent variables; standard errors reported
Maycock and Hall (1984)	Roundabouts	Excluded	States coefficient only for cross-product of flows, not for cars and pedestrians
Hall (1986)	Signalised junctions (urban)	Included	Type 2: Traffic volume only; standard errors reported
Brüde and Larsson (1993)	Urban junctions (mixed)	Included	Type 1: Traffic volume only; no standard errors reported
Summersgill and Layfield (1996)	Urban road links	Included	Type 4: Several independent variables; standard errors stated
Leden et al. (1998)	Urban junctions	Excluded	Contains data on cyclist volume only
Leden (2002)	Signalised junctions (urban)	Included	Type 1: Traffic volume only; no standard errors reported
Lyon and Persaud (2002)	Signalised junctions (urban)	Included	Type 2: Traffic volume only; standard errors reported
Jacobsen (2003)	Cities in many countries	Excluded	Statistical relationship may be an artefact; data on cyclist volume only
Jonsson (2005)	Urban road links	Included	Type 4: Several independent variables; standard errors reported
Robinson (2005)	Australian states	Excluded	Statistical relationship may be an artefact; data on cyclist volume only
Zegeer et al. (2005)	Pedestrian crossings	Included	Type 4: Several independent variables; standard errors reported
Bonham et al. (2006)	Urban traffic zones	Excluded	Contains cyclist volume only; data not presented
Geyer et al. (2006)	Urban junctions (mixed)	Included	Type 4: Several independent variables; standard errors reported
Turner et al. (2006)	Signalised junctions (urban)	Included	Type 3: Several independent variables; no standard errors reported
Harwood et al. (2008)	Signalised junctions (urban)	Included	Type 4: Several independent variables; standard errors reported
Knowles et al. (2009)	British municipalities	Excluded	Statistical relationship may be an artefact; data on cyclist volume only
Vandenbulcke et al. (2009)	Belgian municipalities	Excluded	Statistical relationship may be an artefact; data on cyclist volume only
Miranda-Moreno et al. (2011)	Signalised junctions (urban)	Included	Type 4: Several independent variables; standard errors derived from *p*-values
Schepers et al. (2011)	Junctions (mostly suburban)	Included	Type 4: Several independent variables; standard errors reported
Schepers (2012)	Dutch municipalities	Excluded	Contains data on cyclist volume only
Buch and Jensen (2013)	Junctions (mixed rural and urban)	Included	Type 4: Several independent variables; standard errors reported
Elvik et al. (2013)	Pedestrian crossings (urban)	Included	Type 4: Several independent variables; standard errors reported
Schepers and Heinen (2013)	Dutch municipalities	Included	Type 4: Several independent variables; standard errors reported
Nordback et al. (2014)	Signalised junctions (urban)	Included	Type 4: Several independent variables; standard errors reported
Prato et al. (2014)	Urban traffic zones	Included	Type 4: Several independent variables; standard errors reported

Table 1 lists 26 studies. All these studies are multivariate accident modelling studies. Table 1 identifies four types of studies. These four types differ with respect to the number of variables included and the information given about the regression coefficients. The four types are defined as follows:

(1) Studies that included traffic volume variables only and did not report the standard errors of regression coefficients.
(2) Studies that included traffic volume variables only and reported the standard errors of regression coefficients.
(3) Studies that included both traffic volume variables and at least one additional independent variable (potentially confounding factor), but did not report the standard errors of regression coefficients.
(4) Studies that included both traffic volume variables and at least one additional independent variable (potentially confounding factor) and reported standard errors of regression coefficients.

A synthesis was made of the findings of studies in all four groups, but only studies in groups 2 and 4 were included in the inverse-variance meta-analysis. In most of the studies listed, the accident models have the following form:

$$\text{Number of accidents} = e^{\beta_0} MV^{\beta_1} CYCL^{\beta_2} e^{\left(\sum_{n}^{i=1} \beta_n X_n\right)} \quad (1)$$

where e denotes the exponential function, i.e. the base of the natural logarithms (2.71828) raised to the power of a regression coefficient β. The first term is the constant term. The next two terms refer to traffic volume. MV denotes motor vehicles, CYCL denotes cyclists (PED for pedestrians in models including pedestrian volume). Traffic volume typically enters models in the form of average daily traffic (AADT). The final term ($e^{(\sum \beta n X n)}$) is a set of predictor variables (X) other than traffic volume, which may influence the number of accidents. Please note that the following formulations are mathematically identical:

$$MV^{\beta_1} = e^{(\beta_1 \cdot \ln(MV))} \quad (2)$$

Thus, the terms for traffic volume, given as power terms in Eq. (1), can be reformulated as exponential terms. All terms in Eq. (1) may then be expressed as a single exponential function. If a model of the form shown in Eq. (1) has been fitted to the data, a regression coefficient for traffic volume (MV, CYCL or PED) with a value less than one indicates that the number of accidents increases less than proportionally to traffic volume.

It deserves to be mentioned that models of the form presented in Eq. (1) have a long history in road safety research. Smeed (1974), as well as Hakkert and Mahalel (1978), discuss the use of such models to predict the number of accidents in junctions, mentioning studies from the early nineteen-fifties employing a model identical to the one in Eq. (1). The two terms for traffic volume in these models represent vehicles entering from the major and minor approaches to a junction.

Some of the studies listed in Table 1 have employed a different model of the relationship between traffic volume and the number of accidents, first proposed by Jacobsen (2003):

$$\text{Injury rate} = \frac{Injuries}{km\ travelled} = \alpha \cdot \left(\frac{km\ travelled}{Number\ of\ inhabitants}\right)^{(\beta-1)} \quad (3)$$

Studies relying on this type of model were not included in the formal synthesis of study findings. The reason for omitting these studies is that the definitions of risk (injuries/km travelled) and exposure (km travelled/number of inhabitants) may give rise to a spurious negative relationship between the variables (Knowles et al., 2009; Elvik, 2013), which looks like a safety-in-numbers effect, but is merely a statistical artefact.

Table 1 indicates for each study the type of locations that were studied. According to the type of location, a distinction can be made between three levels for the study units:

(1) Micro-level studies, in which typical study units are pedestrian crossings or junctions.
(2) Meso-level studies, in which typical study units are street networks or urban traffic zones. Each network or zone consists of several streets and junctions.