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A synthesis of studies of access point density as a risk factor for road accidents

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ABSTRACT

Studies of the relationship between access point density (number of access points, or driveways, per kilometre of road) and accident frequency or rate (number of accidents per unit of exposure) have consistently found that accident rate increases when access point density increases. This paper presents a formal synthesis of the findings of these studies. It was found that the addition of one access point per kilometre of road is associated with an increase of 4% in the expected number of accidents, controlling for traffic volume. Although studies consistently indicate an increase in accident rate as access point density increases, the size of the increase varies substantially between studies. In addition to reviewing studies of access point density as a risk factor, the paper discusses some issues related to formally synthesising regression coefficients by applying the inverse-variance method of meta-analysis.

1. Introduction

It has been known for a long time that many access points, also known as driveways, along a road increases the risk of accidents. David Schoppert (1957) reported that accident rate (number of accidents per vehicle kilometre of travel) increased as the number of residential driveways per kilometre of road increased. Traffic engineers have understood for at least sixty years that to make a road safe, it cannot have direct accesses to abutting properties. Access free roads are known as freeways in the United States and motorways in Europe.

Although the fact that high access point density is associated with high accident risk has been known for a long time, the precise shape of the relationship is less known. For a long period, there was little research into the relationship, but following the introduction of accident prediction models suitable for analysing count data (Jovanis and Chang 1986), several studies have been made, particularly in the United States. In recent years, the number of papers dealing with access point density appears to be increasing (Cafiso et al., 2010; Brimley et al., 2012; Avelar et al., 2013; Huang et al., 2014; Alluri et al., 2015). The increasing interest in the topic raises the issue of whether studies reach consistent or discrepant findings. A tool for investigating this issue is meta-analysis. As far as is known, no meta-analysis has tried to summarise the findings of studies dealing with access point density as a risk factor for accidents.

The main objective of this paper is to synthesise the results of studies of the relationship between access point density and accident rate, applying inverse-variance meta-analysis. Such a synthesis will show the typical or "average" relationship between access point density and accident rate, as well as the variability of the relationship.

To obtain a synthesis of studies, it is necessary to perform a meta-analysis of regression coefficients. This raises methodological problems. A secondary objective of the paper is to discuss methodological problems in meta-analysis of regression coefficients.

2. Literature survey and study coding

Relevant studies were identified by searching the Handbook of Road Safety Measures (Høye et al., 2017), Sciencedirect, Google Scholar and the Transportation Research Board online library. Search terms used were "driveways and safety", "access points and safety", "driveways and accidents" and "access points and accidents". A total of 27 studies were identified, of which 20 were included in the meta-analysis. Table 1 lists all studies and gives the reason why some studies were not included in the meta-analysis.

Studies were omitted from the meta-analysis for three main reasons: (1) The access point density variable was not defined the same way as in other studies; (2) The standard errors of regression coefficients were not reported; (3) The statistical model was of a different form than other studies, making the regression coefficients incomparable. As will be discussed in the next section, it is essential that all studies included in a meta-analysis define access point density the same way and apply models of the same mathematical form reporting both regression coefficients and their standard errors.

For each of the studies included in the meta-analysis, the following

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Table 1
List of studies.

Study (chronologically)	Authors	Country	Inclusion in meta-analysis
1	Jensen (1968)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
2	Grimsgaard (1976)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
3	Hvoslef (1977)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
4	Amundsen (1979)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
5	Grimsgaard (1979)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
6	Hovd (1979)	Norway	Yes, merged with other Norwegian studies before 1980 into a single study
7	Muskaug (1985)	Norway	Yes, re-analysed by means of meta-regression to obtain relevant coefficients
8	Vogt and Bared (1998)	United States	Yes, coefficients converted to metric scale
9	Wang et al. (1998)	United States	Yes, coefficients converted to metric scale
10	Brown and Tarko (1999)	United States	Yes
11	Mouskos et al. (1999a)	United States	Yes, coefficients from one of a total of ten models
12	Mouskos et al. (1999b)	United States	No, duplicates (Mouskos et al., 1999a)
13	Papayannoulis et al. (1999)	United States	Yes, coefficients converted to metric scale
14	Ivan et al. (2000)	United States	Yes, coefficients converted to metric scale
15	Hauer et al. (2004)	United States	No, model of different form and standard error of coefficients not reported
16	Eisele and Frawley (2005)	United States	Yes, relationship estimated based on data in Table 3 of the paper
17	Schultz et al.(2007)	United States	Yes, relationship estimated based on data in Fig. 5 in the paper
18	Flintsch et al. (2008)	United States	No, different definition of access point density and standard errors of coefficients not reported
19	Fitzpatrick et al. (2008)	United States	Yes, coefficients converted to metric scale
20	Liu et al. (2008)	United States	No, different definition of access point density and different model form
21	Cafiso et al. (2010)	Italy	Yes
22	Brimley et al. (2012)	United States	Yes, coefficients converted to metric scale
23	Avelar et al. (2013)	United States	No, different definition of access point density variable
24	Xu et al. (2013)	United States	No, model of different form making coefficients incomparable to other studies
25	Huang et al. (2014)	United States	Yes, data were re-analysed using negative binomial regression (see text)
26	Williamson and Zhou (2014)	United States	No, does not deal with access point density
27	Alluri et al. (2015)	United States	No, not sufficient data about relevant variables and coefficients

information was coded (in addition to bibliographic information for study identification):

1. Publication year
2. Country of origin
3. Type of accident prediction model
4. Accident severity
5. Type of accidents included
6. Coefficient for access point density as originally stated
7. Coefficient for access point density converted to metric scale (if needed)
8. Standard error of coefficient for access point density
9. Number of covariates included in accident prediction model
10. If a separate coefficient has been estimated for traffic volume
11. Number of accident prediction models fitted and reported

Table 2 shows information regarding most of these characteristics for the studies included in the meta-analysis. It is seen that quite many studies had to be re-analysed to be included in the meta-analysis. The reasons for this are explained below.

3. Problems of formally synthesising regression coefficients

Meta-analysis of regression coefficients fitted in multivariate models is only feasible if some conditions are fulfilled (Becker and Wu 2007; Card 2012). First, the dependent variable, Y, (in this study: accident rate) must be identically defined and measured in all studies. This is necessary because regression coefficients depend on scale. Second, the independent variable of principal interest, X, (in this study: access point density) must be identically defined and measured in all studies. The reason is again that if X has a different scale in different studies, the regression coefficients will not be comparable. Third, additional variables included in a model, Zs, (in this study, for example, number of lanes) included in the regression models should be the same in all studies. The last condition is almost never fulfilled. There are differences of opinion among analysts as to whether the third condition must be fulfilled.

Becker and Wu (2007) discuss a number of approaches that have been taken by meta-analysts, including a standard inverse-variance approach. Each regression coefficient is then assigned a statistical weight which is inversely proportional to its sampling variance. Sampling variance is estimated as the squared standard error of the coefficient. This approach is very often feasible, as almost any statistical software used in regression modelling will report the standard errors of the regression coefficients. It has been applied in a previous paper by Elvik and Bjørnskau (2017) and will be taken in this paper. Regression coefficients included in a meta-analysis must comparable in terms of:

1. Being estimated by means of models of the same mathematical form
2. Referring to an identically defined access point density variable
3. Stating the standard error of the coefficient

The studies listed in Table 2 differ with respect to their mathematical form. The dependent variable is either accident rate (number of accidents per million vehicle kilometres of travel) or the number of accidents. Studies using accident rate as dependent variable are either purely descriptive studies in which no model has been fitted to the data or linear regression models of the following form (see e.g. Mouskos et al., 1999a):

$$Accidentrate = \alpha + \beta_1 \cdot AADT + \beta_2 \cdot Accesspointdensity + \beta_n \cdot Z_n \quad (1)$$

In Eq. (1), α is the constant term and the β_i-s are coefficients for the independent variables. Models of this form usually include traffic volume (AADT), access point density and one or more additional variables (Zs). It is seen that this type of model assumes a linear relationship between traffic volume and accident rate.

Models in which the number of accidents is dependent variable often have the following form (Lord and Mannering 2010):

$$Predictednumberofaccidents = e^{\beta_0} L^{\beta_1} AADT^{\beta_2} e^{\left(\sum_n^{i=1} \beta_n X_n\right)} \quad (2)$$

In Eq. (2) 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 the length of road sections (L) and traffic volume (AADT). The final