Accident Analysis and Prevention 59 (2013) 487–496

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

International transferability of accident modification functions for horizontal curves

Rune Elvik*

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

ARTICLE INFO

Article history:
Received 16 April 2013
Received in revised form 28 June 2013
Accepted 10 July 2013

Keywords:
Horizontal curves
Radius
Accident modification functions
International transferability
Synthesis

ABSTRACT

Studies of the relationship between characteristics of horizontal curves and accident rate have been reported in several countries. The characteristic most often studied is the radius of a horizontal curve. Functions describing the relationship between the radius of horizontal curves and accident rate have been developed in Australia, Canada, Denmark, Germany, Great Britain, New Zealand, Norway, Portugal, Sweden, and the United States. Other characteristics of horizontal curves that have been studied include deflection angle, curve length, the presence of transition curves, super-elevation in curves and distance to adjacent curves. This paper assesses the international transferability of mathematical functions (accident modification functions) that have been developed to relate the radius of horizontal curves to their accident rate. The main research problem is whether these functions are similar, which enhances international transferability, or dissimilar, which reduces international transferability. Accident modification functions for horizontal curve radius developed in the countries listed above are synthesised. The sensitivity of the functions to other characteristics of curves than radius is examined. Accident modification functions developed in different countries have important similarities. The functions diverge with respect to accident rate in the sharpest curves.

1. Introduction

The international transferability of accident modification functions, i.e. functions describing the effects of highway design elements or road safety measures, is a topic of great interest and was recently examined by an OECD-group (OECD, 2012). Small countries cannot always perform national research about every topic, but may have to rely on studies made in other countries. It then becomes important to assess whether knowledge can be transferred internationally.

The topic of this paper is the international transferability of accident modification functions for horizontal curve radius. An accident modification function for horizontal curve radius is a mathematical function that relates accident rates in horizontal curves to the radius of the curves. Since horizontal curves are a design element of highways in all countries, such functions have been developed in a number of countries. The main question to be examined in this paper is whether accident modification functions for horizontal curve radius developed in different countries are similar, supporting a formal synthesis of these functions in the form of an average function, or whether the functions are too different for such a formal synthesis to make sense.

2. Study retrieval

Relevant studies were retrieved by consulting the Handbook of Road Safety Measures (Elvik et al., 2009). In addition, relevant papers were identified from the online archive of Transportation Research Record by using "horizontal curve radius" as search term. A similar search for papers published in Accident Analysis and Prevention was made in ScienceDirect. Studies that have developed models of the relationship between horizontal curve radius and either: (1) the number of accidents per curve; (2) accident rate (number of accidents per million vehicle kilometres of travel), or: (3) accident modification factors (AMFs) in horizontal curves were identified for ten countries (alphabetically): Australia, Canada, Denmark, Germany, Great Britain, New Zealand, Norway, Portugal, Sweden and the United States. The three measures of safety in curves are not directly comparable; the relationship between them is discussed in Section 3 (below).

No attempt was made to identify every study that has dealt with the relationship between horizontal curve radius and safety in curves. Priority was given to obtaining a sample of studies that included as many countries as possible and spanned as long a period as possible. The chief reason for applying these selection criteria

* Tel.: +47 48943353; fax: +47 22 609200.
E-mail address: re@toi.no

0001-4575/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aap.2013.07.010

was to obtain the largest possible range of replications (Elvik, 2012), as a large range of replications permits a more stringent assessment of international transferability than a smaller range of replications.

3. Measures of safety in horizontal curves

The literature reviewed for this paper contains three measures of safety in horizontal curves:

1. Number of accidents per curve per unit of time.
2. Accident rate in curves (accidents per million kilometres of travel).
3. Accident modification factors associated with curves (i.e. the ratio: accidents in curves/accidents on straight sections).

These measures of safety do not necessarily produce the same results. To see why, consider Fig. 1.

Fig. 1 contains two curves with the same deflection angle (90°). The radius of the lower curve is three times the radius of the upper curve. Vehicles travelling in the lower curve will produce three times as many vehicle kilometres as vehicles travelling in the upper curve. To see how the different measures of safety can assume different values, applying the models developed by Persaud et al. (2000) will be instructive. Persaud et al. developed the following accident prediction model for horizontal curves:

$$\text{Accidents per curve per year} = (\text{AADT})^b (L)^g R^p e^{(a+h(L/R))} \qquad (1)$$

AADT is annual average daily traffic. L is the length of the curve in kilometres. R is the radius of the curve in metres. L/R is the ratio of the length of the curve (kilometres) to the radius of the curve (metres) and a, b, g, h and p are coefficients estimated by means of negative binomial regression. For tangent (straight) sections, the following accident prediction model was developed:

$$\text{Accidents per section per year} = (L)(\text{AADT})^b e^a \qquad (2)$$

L is the length of a road section; AADT is annual average daily traffic. These models will be used to compare the safety of curves with radius 100, 300 and 500 m. The length of curves is highly correlated with their radius. Curves with small radius tend to be shorter than curves with large radius. Persaud et al. provide data on radius and length for 15 curves; omitting one of these as an outlying data point, Fig. 2 gives a plot of radius and length for the remaining 14 curves.

The power function fitted to the data points in Fig. 2 will be used to describe the relationship between curve radius and curve length. According to this function, a curve with a radius of 100 m will have a length of 205 m, a curve with a radius of 300 m will have a length of 376 m and a curve with a radius of 500 m will have a length of 498 m. Based on Table 5 in the paper by Persaud et al., an AADT of 6700 will be assumed. Model coefficients referring to injury accidents will be applied.

Inserting the values into Eq. (1), the model-predicted number of accidents was estimated to be 0.868 for a curve with radius 100 m, 0.455 for a curve with radius 300 m and 0.399 for a curve with radius 500 m. The corresponding accident rates (accidents per million vehicle kilometres) were estimated, respectively, to be 1.733, 0.496 and 0.328. For straight road sections of the same length as the curves (205, 376 and 498 m), applying Eq. (2) resulted in a model-predicted annual number of accidents of, respectively, 0.101, 0.185 and 0.245. Straight section accident rate (accidents per million vehicle kilometres of travel) was 0.201 in all cases. Based on these numbers, the effects of curve radius on safety in curves can be stated in terms of different estimates of relative risk. Thus, applying the predicted number of accidents:

$R(100)$:$R(300)$:$R(500)$ = 0.868:0.455:0.399 = 2.175:1.140:1.000.

Curves with a radius of 500 m have then been used as reference and the numbers indicate how many more accidents are to be expected in curves with radii of 300 or 100 m. Expressing the same ratios in terms of accident rates gives (100, 300, 500):

5.284:1.512:1.000.

The increase in accident rate associated with smaller curve radius is considerably greater than the increase in the number of accidents. Finally, the same two comparisons can be made using straight road sections of the same length as the curves as reference. Relying on the number of accidents, this gives (100, 300, 500):

8.603:2.462:1.627.

This shows that even curves with a radius of 500 m are expected to have more accidents than a straight road section of the same length as the curves. Applying accident rates (accidents per million vehicle kilometres) gives (100, 300, 500):

8.621:2.468:1.632.

These comparisons show that it is not unimportant how safety in curves is measured. To meaningfully synthesise models developed in different countries, it is essential that safety has been measured the same way in all studies. Unfortunately, this is not the case for the studies reviewed in this paper. Most studies report accident rates (accidents per million vehicle kilometres) in curves. The following rules were adopted to make functions based on other estimators as comparable as possible to accident rates:

1. The estimates developed for Canada (Persaud et al.) have been stated as accident rates, applying a uniform AADT of 6.700.
2. The AMF for Great Britain (McBean, 1982) was developed by applying a case–control approach which is quite different from the other studies included. It was assumed that case sites and control sites were matched by traffic volume, so that estimated relative risks can be interpreted as relative accident rates.
3. The predicted number of accidents in the models for Germany was converted to accident rates by assuming that curve length was proportional to curve radius.
4. The AMF for Portugal has traffic volume in the denominator and is therefore interpreted as a relative accident rate.
5. The AMF for the United States was re-estimated as an accident rate; see more details in the section about the United States below.

The available accident modification functions for all other countries included in this study are stated in terms of accident rates.

4. Accident modification functions developed in different countries

This section presents the accident modification functions that have been developed in each of the ten countries included in the study.

4.1. Australia

Jurewicz and Pyta (2010) present a model developed to predict the number of single-vehicle run-off-road accidents to the left. The model was specified as follows:

$$\text{Number of accidents} = e^{(\beta_0+\beta_1 \text{AADT}_{\text{one}}+\beta_2 \text{Radius}+\beta_3 \text{Grade}+\beta_4 \text{TLSS}+\beta_5 \text{CZ}+\varepsilon)} \qquad (3)$$

Here e denotes the exponential function, the βs are coefficients estimated by means of negative binomial regression, AADT_{one} is annual average daily traffic in one direction only, radius is horizontal curve radius in metres, grade refers to whether the road is flat or on a slope, TLSS is the width of the traffic lane plus sealed shoulder, CZ is clear zone width category and ε is the error term. Horizontal curve radius was included as a categorical variable with three values: less than 600 m, between 600 and 1500 m and more