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Investigation of models for relating roundabout safety to predicted speed

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ABSTRACT

Despite widespread recognition of operating speed as a key safety-related variable for roundabouts, there is no consensus on the best models for capturing the relationship between crashes and speed, or, for that matter, on how speed can be estimated in situations where it cannot be observed (such as when a roundabout is being designed or redesigned). This paper uses US and Italian roundabout approach-level data to investigate models relating safety to various measures of predicted speed. This is an indirect approach for developing safety models for estimating the effects of design features, the premise being that these features can better predict speed, which, in turn, can be used as a predictor of crash frequency. After exploring various possibilities, the approach average speed (AAS) – defined as the average of entry, upstream circulating and exiting speeds in this study – was found to be the speed measure that best predicts safety. US data were used to develop a Bayesian Poisson-gamma safety model based on predicted AAS with random coefficients and varying dispersion parameter. This model structure was not appropriate for the Italian data used to examine whether the approach could be generalized to data for another country. For that data, a zero-inflated Poisson (ZIP) model was found to be suitable. Notwithstanding the heterogeneity of the model structure, the investigation suggests that the indirect approach for evaluating the safety of a roundabout is a sound one in that it can preserve model parsimony while capturing the effects of design changes that affect safety.

1. Introduction

There is now substantial evidence indicating that modern roundabouts can significantly reduce traffic crashes (Federal Highway Administration, 2008) and that the safety benefit results largely from the fact that they are designed to control traffic speeds. It stands to reason, therefore, that safety performance of a roundabout can be related to some measure of its operating speeds.

Recent research presented in NCHRP Report 572 (Rodegerdts et al., 2007) did attempt to establish a speed-based approach-level safety performance function (SPF) for US roundabouts, with the following structure:

$$\text{Crashes/year} = \exp(\text{intercept}) \cdot \text{AADT}^{b} \cdot \exp(cX) \quad (1)$$

where AADT is the average annual daily traffic, X is the independent speed-related variable, and b and c are the calibration parameters.

However, the estimated model was deemed inadequate on the basis of the weak effects of the speed variables (Rodegerdts et al., 2007), so no speed-based SPF could be recommended. By contrast, there were a number of successful non speed-based SPFs estimated for US roundabouts in that research. These models were estimated at both roundabout and approach levels. Some of the approach level models did contain geometric variables, but for the roundabout level models, the sum of entering AADTs from all approaches was typically the only variable.

Researchers have also developed SPFs for roundabouts in Great Britain, Australia, New Zealand and Sweden (Federal Highway Administration, 2000; Turner et al., 2006; Brude and Larsson, 2000; Maycock and Hall, 1984). Some of these efforts included, in addition to traffic exposure, variables reflecting geometric features, configuration of vehicles, and speed features (85th percentile speed, speed limits or relative speed difference). Research from New Zealand (Federal Highway Administration, 2000) also introduced a model relating speed features and factors such as diameter and visibility.

NCHRP Report 572 (Rodegerdts et al., 2007) also quoted and tested the following speed prediction models documented in the Federal Highway Administration Roundabout Guide (Federal Highway Administration, 2000):

$$V = 8.7602R^{0.3861}, \quad \text{for} \quad e = +0.02$$

$$V = 8.6164R^{0.3673}, \quad \text{for} \quad e = -0.02 \quad (2)$$

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where V is the predicted speed for left-turn circulating, through circulating, exit or entry movements (km/h), R is the radius of vehicle path (m), and e is the super-elevation (m/m) (inner edge of curve is lower than the outer when e is positive).

Recent research by Bassani and Sacchi (2011) developed a multiple linear regression model for Italian roundabouts shown in Eq. (3).

$$V_{85} = 0.4433 \cdot D_{\text{INT}} + 0.8367 \cdot W_{\text{CR}} + 3.2272 \cdot W_{\text{ENL}} \tag{3}$$

where V_{85} is the 85-percentile operating speed at circulating roadway (km/h), D_{INT} is the diameter of the central island (m), W_{CR} is the width of the circulatory roadway (m), and W_{ENL} is the width of the entry lane (m).

The two speed prediction models above are different in key aspects. Eq. (2) was fitted based on fundamental functions of vehicle dynamics, while Eq. (3) is an empirically derived function. In this last case, according to the authors, it was developed without a constant term to logically force an estimate of zero speed when there is a value of zero for all covariates. Moreover, Eq. (3) pertains to 85-percentile circulating speed while Eq. (2) is presumed to pertain to predicted circulating design speed.

In summary, international research does suggest that speed can be related to safety performance of roundabouts. However, there is a wide spectrum of definitions for the speed variables, especially in the European literature, with no clear indication of the best variable specification.

This paper aims to address this issue by investigating and comparing possible choices of speed variables, and making a recommendation for the optimal one, with design features as inputs.

The paper further investigates the development of a roundabout SPF with predicted speed as the key input.

2. Sample data

2.1. Summary statistics of raw data

The study used approach-level data for 139 roundabout approaches from eight States in the US, and 34 roundabout approaches from three cities in Italy. US roundabouts are in a mixture of urban, suburban and rural environments, while all Italian roundabouts are in urban and suburban areas. Four observed speeds – approach, entry, upstream (left side of approach) circulating and upstream exiting speeds – and three types of speed differential between each pair of adjacent speeds were available for 34 of the US approaches and 6 of the Italian ones. These are all median speeds. The US sample database is the same one used in the earlier NCHRP study (Rodegerdts et al., 2007). Table 1 shows the summary statistics of the data. These indicate that the US and Italian data are generally comparable.

Fig. 1 depicts the geometric characteristics and the approach locations where speeds were obtained. Location A is for approach speed (measured at least 200 ft upstream of the yield line) (Rodegerdts et al., 2007), B for entry speed, C for upstream circulating speed and D for upstream exiting speed. US speed data were collected by radar guns (Rodegerdts et al., 2007). For the Italian data, the collection of speed and positional data of the vehicles in traffic were acquired with a speed gun and a video camera. The acquisition system was located in positions not visible to drivers and only isolated vehicles were considered, thereby excluding information that could be affected by factors such as those linked to the dynamics of traffic flow. In the case of video measurements, a high-speed digital video camera was employed. From the subsequent analysis of captured frames, and knowing the distance between selected sections, the average speeds of isolated vehicles were calculated.

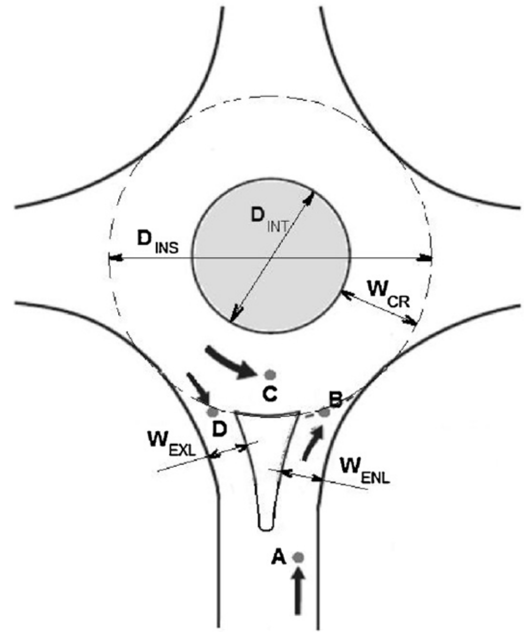

Fig. 1. Geometric characteristics of the approach-level area and locations for speeds.

2.2. Derived data

The average value of measured entry, upstream circulating and upstream exiting speeds was considered as a new speed variable (referred as "approach average speed", AAS). Logically, AAS represents the average operating speed inside or at the periphery of one approach. The sum of absolute values of the three differentials in Table 1 (referred as SDSum) could be used as another measure, representing the overall level of speed gaps. The third derived data item is the speed differential of approach vs. AAS (referred as SDApproachAAS). Table 2 illustrates the summary statistics of the derived speed measures.

In Table 1, speed differential is the arithmetic difference of two adjacent speed measures (e.g., speed differential of approach vs. entry = approach speed − entry speed). The speed differential data were obtained only when both of speed observations were available. As result, the frequency of speed differentials was sometimes smaller than the minimum frequency of two relevant speed measures.

In Table 2, SDSum is the addition of the three speed differentials from Table 1. The sum was obtained only when all three speed differentials were available. Therefore, the frequency of SDSum is less than those of individual speed differentials.

3. Selection and estimation of speed prediction model

For a speed measure to be representative of design features in an approach-based crash prediction model, it must be reflective of speeds in the vicinity of the approach. In earlier research (Chen, 2010; Chen et al., 2011), the authors did try to model individual speeds and individual speed differentials, but that proved fruitless.

The final determination of the most appropriate measure was achieved by running the "effect (variable) selection" procedure within the framework of generalized linear models (GLMSELECT Procedure) in the SAS software (SAS Institute Inc., 2011). Based on a pre-set collection of variables, the procedure of "effect selection" iterates the entry or removal of effects until selection stops at a minimum value of the model optimization criterion (the Schwarz Bayesian information criterion, SBC).