ESTIMATING VEHICLE ROADSIDE ENCROACHMENT FREQUENCY USING ACCIDENT PREDICTION MODELS

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ABSTRACT

The existing data to support the development of roadside encroachment-based accident models are extremely limited and largely outdated. Under the sponsorship of the Federal Highway Administration and Transportation Research Board, several roadside safety projects have attempted to address this issue by providing rather comprehensive data collection plans and conducting pilot data collection efforts. It is clear from the results of these studies that the required field data collection efforts will be expensive. Furthermore, the validity of any field collected encroachment data may be questionable because of the technical difficulty to distinguish intentional from unintentional encroachments. This paper proposes an alternative method for estimating the basic roadside encroachment data without actually field collecting them. The method is developed by exploring the probabilistic relationships between a roadside encroachment event and a run-off-the-road event. With some mild assumptions, the method is capable of providing a wide range of basic encroachment data from conventional accident prediction models. To illustrate the concept and use of such a method, some basic encroachment data are estimated for rural two-lane undivided roads. In addition, the estimated encroachment data are compared with the existing collected data. The illustration shows that the method described in this paper can be a viable approach to estimating basic encroachment data without actually collecting them which can be very costly.

Key Words: Vehicle Roadside Encroachment, Roadside Design, Accident Prediction Model
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1. INTRODUCTION

Past research on the safety of roadside environment has produced more forgiving roadside hardware and improved roadside design practices [Transportation Research Board, 1987]. However, the latest national statistics still indicate that about one-third of the fatal traffic crashes are associated with vehicles running off the road [NHTSA, 1994]. For example, 10,473 out of 34,928 fatal traffic crashes occurred in 1992 were related to collision with roadside fixed objects and, in addition, a large percentage of the 3,281 fatal rollover crashes occurred on sideslopes and ditches. These statistics on run-off-the-road accidents (RORA) continue to indicate the need for more research to develop cost-effective road-, driver-, and vehicle-related countermeasures to reduce the frequency and consequences of such accidents [Viner, 1993; Ray et al., 1995].

To develop cost-effective road-related countermeasures, one needs to have a good understanding of the relationship between roadside safety and roadside design. To date, much of what is known about the roadside safety-design relationships remains to be either qualitative in nature or dependent on subjective engineering guesses [Daily, et al., 1994; Ray et al., 1995]. Recent studies have suggested that new and cost-effective analysis approaches and data collection efforts are essential if a more objective basis of such relationships is to be developed [Mak and Sicking, 1992; Viner, 1995; Mak and Bligh, 1996].

Models used in previous studies to develop the relationships between the RORA frequency, traffic flows, and roadside hazards, such as embankments, utility poles, trees, luminaries, guardrail, median barriers, have been categorized as either an accident-based approach or an encroachment-based approach [Daily, et al., 1994]. The first approach uses statistical regression models to develop the relationships, in which the RORA frequency of hitting a particular or a combination of roadside hazards is the dependent variable, and traffic flows, roadway mainline designs, roadside designs, and other variables are the explanatory variable (or covariates). For example, in one of the models developed in Zegeer et al. [1987], single vehicle (SV) RORA frequencies, including fixed-object and
rollover accidents, were regressed over average annual daily traffic (AADT), lane width, shoulder width, clear roadside recovery distance (CRRD), and terrain type, where CRRD is a summary measure of the width of the flat, unobstructed, and smooth area adjacent to the outside edge of the shoulder within which there is a reasonable opportunity for the safe recovery of an out-of-control vehicle. In another study by Zegeer et al [1990], RORA frequencies hitting various types of roadside fixed objects such as utility poles, trees, guardrails, were regressed over AADT, lane width, and density and lateral offset of the object. The models so developed are typically referred to as accident prediction models. It should be noted, however, that Zegeer et al.'s studies have heavily relied on the use of lognormal regression models. More appropriate accident prediction models based on the Poisson and negative binomial regression models have been advocated and widely used in recent years [e.g., Maycock and Hall, 1984; Miaou and Lum, 1993; Miaou, 1994; Maher and Summersgill, 1996; Miaou, forthcoming]. Data on roadside variables (except shoulder width and shoulder type) were, however, mostly unavailable in these recent studies.

The second approach uses a series of conditional probabilities to describe the sequence of events resulting in a roadside accident. An example sequence of events would be: (1) an errant vehicle leaves the traveled way and encroaches on the shoulder; (2) the location of encroachment is such that the path of travel is directed towards a potentially hazardous object; (3) the hazardous object is sufficiently close to the travel lanes that control is not regained before encounter or collision between vehicle and object; and (4) the collision is sufficiently severe enough to result in an accident of some level of severity. This type of models have traditionally been called roadside encroachment models [Glennon, 1974; Transportation Research Board, 1987; Daily et al., 1994]. The idea of the encroachment-based approach was to formulate and estimate each of these conditional probability based on traffic flow theory, geometry, vehicle dynamics, driver's behavior, and probability theory. The Appendix F of the Transportation Research Board's Special Report 214 (SR214) [1987] provides a good description of the encroachment model and its application on two-lane undivided roads. A recent review of such an approach and its relationship with the accident-based approach is given in Miaou [forthcoming].

In the last 30 years, there has been a constant effort attempting to develop and refine roadside encroachment models, including the National Cooperative Highway Research Program (NCHRP) Report 77 [1969], NCHRP Report 148 [1974], and the model included in American Association of State Highway and Transportation Officials' (AASHTO) Roadside Design Guide [1988], known as
the ROADSIDE model. More recent plans and efforts to further improve roadside encroachment models include Mak and Sicking [1992] and NCHRP Project 22-9 that is currently being conducted by Texas Transportation Institute (TTI), Texas A&M University.

Despite of these efforts, the encroachment-based approach has been criticized as being full of wishful assumptions and lack of empirical basis (or supporting data) [Daily et al. 1994]. For example, on each road section, the most basic data required by an encroachment model is the vehicle roadside encroachment frequency and the probability distribution of lateral extent of encroachments when encroachment occurs. The encroachment frequency is expected to vary from one road section to another, depending on roadway class, AADT, lane width, horizontal curvature, vertical grade, etc. While the probability distribution of lateral extent of encroachments is expected to vary by sideslope and other roadside design factors. At present, the existing data for developing encroachment-based models were largely outdated [Mak and Sicking, 1992; Daily et al., 1994; Mak and Bligh, 1996]. In addition, these data were collected on a small number of road sections and for a limited time period in a year, e.g., during winter or summer months. The Federal Highway Administration (FHWA) and Transportation Research Board (TRB) have been addressing the requirements and collection of such data through their sponsorship of several roadside safety projects. As a result, rather comprehensive data collection plans and pilot data collection efforts have been reported in Mak and Sicking [1992], a recent interim report prepared for the NCHRP Project 17-11 [Mak and Bligh, 1996], and Daily et al. [1994]. A review of these plans and pilot data collection results suggests that the field data collection effort of such data will be difficult and expensive. Furthermore, the validity of any field collected encroachment data may be questionable because of the technical difficulty to distinguish intentional from unintentional encroachments.

The purpose of this paper is to propose an alternative method for estimating the basic roadside encroachment data without actually field collecting the data. The method is developed by exploring the probabilistic relationships between a roadside encroachment event and a RORA event. With some mild assumptions, the method is capable of providing a wide range of basic encroachment data from conventional accident prediction models. To illustrate the concept and use of such a method, the basic encroachment data are estimated for rural two-lane undivided roads. In addition, the estimated encroachment data are compared with the existing collected data.

This paper is organized as follows. To facilitate the illustration of the proposed method, a rural two-lane road accident prediction model, which was developed in Miaou [1996], is first
presented in Section 2. Since the theory behind the accident-based prediction models have been described quite extensively in many recent publications [e.g., Maycock and Hall, 1984; Miaou and Lum, 1993; Miaou, 1994; Maher and Summersgill, 1996; Miaou 1996], the readers are referred to these publications for a review of the Poisson and NB regression-based accident prediction modeling theories. Section 3 describes the proposed method and its assumptions. Section 4 illustrates the concept and use of the proposed method by utilizing the accident prediction model presented in Section 2. Some discussions on the potential extensions of such a method is provided in the last section.

In the following discussion, a "roadside encroachment" is said to occur when an errant vehicle crosses the outside edges of the travelway and encroaches on the shoulder, including both inside and outside shoulders. Thus, for a two-lane undivided road which has no inside shoulder the total number of roadside encroachments includes departures of vehicles from near-side and far-side edges of the travelway in both directions. It is also important to note that roadside encroachments refer only to "unintentional encroachments." In other words, the "intentional encroachments" as a result of vehicles intentionally driven outside of the travel lane on, e.g., adjacent lane (in the same or opposite direction), shoulders, and traversable medians, are not counted as encroachments.

2. A RUN-OFF-THE-ROAD ACCIDENT PREDICTION MODEL

Run-off-the-road accidents and roadway data for rural two-lane undivided roads from a roadway cross-section design data base [Hummer, 1986], administered by FHWA and TRB, were used by Miaou [forthcoming] to develop an accident prediction model. One of the important feature of this particular data base is that it contains a rather detailed description of key design elements of various roadside obstacles. The roadway data used in this study include traffic and geometric design data of 596 road sections in three States: Alabama, Michigan, and Washington. The total length of these sections is 1,788 mi (2,861 km). About 5 years of SV RORA data from 1980 to 1984 were available for analysis. During the 5-year period, there were 4,632 SV reported to be involved in RORA on these road sections, regardless of vehicle and accident severity type. With the total vehicle miles estimated to be 7,639 million vehicle miles (14, 514 million vehicle kilometers), the overall SV RORA rate was 0.61 SV RORA per million vehicle miles (0.38 SV RORA per million vehicle...
kilometers). The same data set has been used in Zegeer et al. [1987] to evaluate the effect of sideslope on the rate of SV RORA. Detailed description and statistics of these road sections can be found in Hummer [1986] and Zegeer et al. [1987].

In addition to vehicle miles traveled, the covariates considered for individual road sections are presented in Table 1. They include (1) dummy variables for Michigan and Washington to capture the overall difference in SV RORA rate among States, due to differences in omitted variables such as weather, socioeconomic and geographic variables, accident reporting threshold, and underreporting rate; (2) AADT per lane, used as a surrogate measure for traffic density; (3) lane width, (4) median clear roadside recovery distance, measured from the right edge of the shoulder, (5) paved shoulder width, (6) earth, grass, gravel, or stabilized shoulder width, (7) median sideslope; (8) terrain type, used as a surrogate measures for horizontal curvature and vertical grade; (9) posted speed limit, (10) number of intersections per mile, (11) number of driveways per mile, and (12) number of bridges per mile. Many of these covariates were also considered by Zegeer et al. [1987]. Horizontal curvature and vertical grade data were not used in this exercise because 147 sections (about 25%) were found to have no curvature data and 341 sections (about 57%) did not have grade information.

The NB regression model, as described in Miaou [1994] and Miaou [forthcoming], was employed and the estimated parameters as well as their associated standard deviations and t-statistics are presented in Table 1. All covariates in the model have the expected effects. Discussions on the choice of covariates and the model's goodness-of-fit can be found in Miaou [forthcoming]. About 62% of the "explainable variance" were explained by the covariates included in this model. It was suggested that a higher explanatory power may be achieved if horizontal curvature and vertical grade were available. Note that there is an ongoing research effort attempting to enhance this model.

Posted speed limit was not found to be significant because of the lack of variation; 530 out of the 596 sections had a posted speed limit of 55 mph. Although the number of intersections per mile had the expected effect, it was not found to be statistically significant (at a 20% \( \alpha \) level) and was removed from the final model.

Major findings from the model can be summarized as follows:

- If all considered variables have the same values, Michigan has the highest SV RORA rate and Alabama has the lowest rate. Michigan's rate is about 20 percent higher than
Washington because of the difference in weather and socioeconomic conditions; while Alabama is about 34 percent lower than Washington mainly because of the incomplete Alabama accident data and differences in weather and other factors.

- AADT per lane shows a negative effect. Although many explanations have been offered in the literature, one plausible explanation is that, all else being equal, higher vehicle density results in higher multiple-vehicle (MV) accident rate and lower SV accident rate.

- All else being equal, increasing lane width is expected to reduce SV RORA rate. Figure 1 gives an illustration of the SV RORA rates for various lane widths and sideslopes. In addition, this figure shows the same rates derived by Zegeer et al. [1987]. It can be seen that the rates from this study are much higher than those from Zegeer et al.'s study. The main reason is that there is a fundamental problem in the method used by Zegeer et al. to compute the mean rate. This problem is one of overlooking an important adjustment factor pertaining to the use of lognormal distributional assumption, which has been pointed out in Miaou and Lum [1993].

- The effect of paved shoulder width was not found to be significantly different from the effect of stabilized shoulder width. All else being equal, increasing shoulder width by 1 ft is expected to reduce SV RORA rate by about 9%.

- Steeper sideslope is associated with higher SV RORA rate. Figure 2 shows the relative rates for various sideslope ratios when compared to the rate of a sideslope of 7:1. This figure also shows that the same relative rates derived from Zegeer et al's model. It can be seen that this study shows lower relative rates than those from Zegeer et al's study. The t-statistic of the estimated parameter in Table 1 shows that the sideslope was not as well determined as other variables. One possible reason is that for each road section the median (i.e., 50th percentile) sideslope measurement was used as the most representative sideslope, but the actual sideslope may vary considerably within a given section [Zegeer et al. [1987].

- As expected, all else being the same, higher numbers of driveways and bridges per mile result in higher SV RORA rates as expected.

In the next section, this model will be used to illustrate how an accident prediction model can be used to estimate roadside encroachment frequency and to derive the probability distribution of lateral extent of encroachment when encroachment occurs.
3. THE PROPOSED METHOD

The relationship between SV RORA probability and SV roadside encroachment probability for a vehicle traveling through a 1-mi or 1-km road section can be mathematically expressed as follow:

\[
P(SV \text{ RORA}|\text{Mainline}, \text{Rdsde Design}) \cdot P(\text{Rdside Encro}|\text{Mainline}, \text{Rdsde Design}) \cdot P(SV \text{ RORA}|\text{Rdside Encro, Mainline, Rdsde Design})\]

(1)

where

- **Mainline** = Mainline traffic and geometric design variables;
- **Rdsde Design** = Rdside design variables;
- \(P(SV \text{ RORA}|\text{Mainline}, \text{Rdsde Design})\) = conditional probability of being involved in a SV RORA when a vehicle travels through a 1-mi or 1-km road section that has a given geometric design and traffic characteristics as described in **Mainline** and **Rdsde Design**; (Note that it is assumed here that the probability of having more than one SV RORA by a vehicle is zero);
- \(P(\text{Rdside Encro}|\text{Mainline, Rdsde Design})\) = conditional probability of having an SV roadside encroachment when a vehicle travels through a 1-mi or 1-km road section that has a given geometric design and traffic characteristics as described in **Mainline** and **Rdsde Design**; (Note that it is assumed here that the probability of having more than one SV roadside encroachment by a vehicle is zero);
- \(P(SV \text{ RORA}|\text{Rdside Encro, Mainline, Rdsde Design})\) = conditional probability of being involved in an SV RORA when a vehicle travels on a 1-mi or 1-km road section that has a given geometric design and traffic characteristics as described in **Mainline** and **Rdsde Design** and has encroached on the roadside.

By assuming that **Rdsde Design** has a very small and negligible effect on roadside encroachment probability, Eq. (1) can be rewritten as:
Now, let's picture a condition where there exists an extremely bad roadside design such that when a vehicle encroaches on the roadside at any point on the road section it is 100 percent sure that the vehicle will result in a RORA. For example, one can picture a road section which has no shoulders and a ditch with a 1:1 sideslope ratio built right next to the traveled lane. Note that very dense point objects, such as trees and utility poles, alone the roadside would also be good examples. Of course, a road section with such a bad roadside design may not exist in the sample. Thus, in practice, extrapolations beyond the range provided by the sample may be required. The reasonableness of the extrapolations depend the extent of the extrapolation and functional relationship in question (e.g., whether it is linear or nonlinear). Note that some engineering and statistical judgements are required if a rather far-out extrapolation is required and the functional relationship appears to be nonlinear.

Under such a bad roadside design condition, \( P(SV 	ext{ RORA} | \text{ Rdside Encro, Mainline, "extremely bad" Rdside Design}) = 1 \), and therefore Eq. (2) can be reexpressed as:

\[
P( SV \text{ RORA} | \text{ Mainline, "extremely bad" Rdside Design}) \times P(\text{ Rdside Encro} | \text{ Mainline})
\]

(3)

To estimate the expected annual number of RORA on a road section with \( t \) miles, one can simply multiply Eq. (3) with \( V \times t \), where \( V \) is the total number of vehicles traveling through the section per year (=365 \times \text{AADT}). That is,

\[
P( SV \text{ RORA} | \text{ Mainline, "extremely bad" Rdside Design}) \times V \times t - P(\text{ Rdside Encro} | \text{ Mainline}) \times V \times t
\]

(4)

In Eq. (4), the right hand side is the annual roadside encroachment frequency of interest, and the left hand side is the expected number of SV RORA per year, which can be estimated using a conventional accident prediction model such as the model presented in the last section.

4. ILLUSTRATIONS

To estimate the roadside encroachment frequency using the model presented in Table 1, an extremely bad roadside design condition can be created by setting shoulder width = 0, median clear roadside recovery distance = 0, and median sideslope = 1. (Note that sideslope ratio of 1:1 is the maximum median sideslope observed in the sample sections.) Except lane width and AADT, other
variables were set equal to their average values. Also, because Alabama has incomplete accident data, only Michigan and Washington models are used. Figure 3 shows the estimated roadside encroachment frequencies per mile per year by various lane widths and AADT's using Eq. (4) under the described bad roadside conditions. The encroachment frequencies collected by Kennedy and Hutchinson [1966] and Cooper [1980], and the estimates given in SR214 based on an encroachment model are also presented in the figure for comparison.

One important observation can be made from Figure 3 is that the estimated encroachment frequencies are very compatible with the encroachment data collected by others. Note that the encroachment frequencies reported in SR214 are higher than they should be for the following reason: An ad hoc ordinary least squares procedure was used for parameter estimation after log-transformation have been taken. Essentially, same as in Zegeer et al.'s study, the procedure overlooked an important adjustment factor as pointed in Miaou and Lum [1993]. In addition, a validation test results provided in the SR214 indicated that the predicted accident rate from the model developed in SR214 exceeded actual rates by up to 160 percent.

Several comments can be made about this particular approach of estimating roadside encroachment frequency:

- One advantage of such an approach is that the encroachment frequency can be estimated for all kind of mainline design and traffic conditions. For example, if horizontal curvature and vertical grade were included in the accident prediction model presented in Section 2, the encroachment frequencies could be estimated for various horizontal curvatures and vertical grades as well. To actually collect such detailed encroachment data will be very expensive and maybe impractical.

- It has been suggested that "The encroachment frequency estimated in this manner can only be as accurate as the accident data used as input" [Daily et al., 1994]. The suggestion is mainly related to the concern about the underreporting of minor accidents. This author would like to point out that this concern is not particularly serious for the approach proposed in this paper. The reason is that under the "extremely bad" roadside design condition stated above, the resulting RORA is expected to be very severe and underreporting of such accidents is very unlikely. Therefore, provided a flexible mean functional form is used in developing accident prediction models, the encroachment frequency estimated from such an approach is relatively unaffected by the underreporting of accidents.
Another advantage of such an approach is that the estimated encroachment frequency is relatively uncontaminated by intentional encroachments. Again, the reason is that intentional encroachments are not likely to occur under such a bad roadside design condition.

It is important to point out that indeed a small extrapolation is used in the estimation (because of the assumed extreme roadside conditions where shoulder width = 0, median clear roadside recovery distance = 0, and median sideslope = 1). It is this author's judgement that the estimated encroachment frequency represents only potentially harmful and unintentional encroachments (which are what the encroachment model need). In addition, the estimate is expected to be lower than what would actually happen on the roads, especially for those roads with wide shoulders where drivers tend to be more relaxed and harmless and unintentional roadside encroachments do occur quite often.

Another possible use of such an approach is to estimate the probability of the lateral extent of encroachment when a roadside encroachment occurs. That is, given a roadside encroachment has occurred, the approach can be used to estimate the probability that the encroached vehicle, in the absence of roadside obstacles, will leave the traveled lane by at least a distance of, say, L. Conceptually, this estimate can be achieved by a simple extension of the approach described above. Specifically, it can be achieved by setting shoulder width = L, median clear roadside recovery distance = 0, and median sideslope = 1. The other variables can be set in exactly the same way. Figure 4 shows a derived probability distribution of the lateral extent of encroachments using such approach. Since shoulder width is used to estimate the probability, the distribution is good for leveled or flat roadside conditions (with no slopes). This estimated distribution can be seen to be quite consistent with AASHTO's distributions for roads with a design speed of 50-60 mi/h (80-96 km/h). On the other hand, it is very different from the distributions derived from Hutchinson and Kennedy's encroachment data. Note that the basis of AASHTO's distributions is not clear from its Roadside Design Guide [Daily et al., 1994]. In addition, the estimation of a single distribution for a design speed has been controversial; it has been suggested that multiple distributions for different sideslope ratios are necessary. In theory, this distribution could be conditional on sideslope,
shoulder type (e.g., paved vs. unpaved, with or without rumble strips), density of roadside hazards, traveled path, or even encroached angle. The readers are referred to Daily et al. [1994] and Mak and Bligh [1996] for more discussion. The derived probability distribution of the lateral extent of encroachments from the proposed method can serve as a basis to obtain more elaborated distributions under different roadside conditions.

5. DISCUSSIONS
The illustration above shows that the method described in this paper can be a viable approach to estimating encroachment frequency without actually collecting the encroachment data that can be very costly. Most importantly, it is straightforward using such an approach to estimating encroachment frequencies for various mainline traffic and design conditions, e.g., AADT, lane width, horizontal curvature, and vertical grade. The only premise is that a sound accident prediction model be developed. The better the accident prediction model, the better the estimate of roadside encroachment frequency can be expected.

In theory, the proposed method can be used for roadway classes other than the two-lane undivided roads illustrated in this paper. It is, however, not clear whether the extension of the proposed method to RORA at intersections is straightforward.

More research to explore the interrelationship between the accident-based approach and encroachment-based approach can help develop viable and cost-effective ways of quantifying roadside safety. The illustration provided in this paper is a good example.

ACKNOWLEDGEMENTS
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Table 1. Estimated regression coefficients of some tested negative binomial regression models and associated statistics for single-vehicle run-off-the-road accidents.

<table>
<thead>
<tr>
<th>Covariate and Parameter</th>
<th>Estimated Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_1$ Dummy intercept (=1)</td>
<td>1.20043 ($\pm0.46;2.62$)</td>
</tr>
<tr>
<td>$\beta_2$ Dummy variable for Michigan (1=Micigan; 0=otherwise)</td>
<td>0.6076 ($\pm0.12;4.92$)</td>
</tr>
<tr>
<td>$\beta_3$ Dummy variable for Washington (1=Washington; 0=otherwise)</td>
<td>0.4218 ($\pm0.13;3.16$)</td>
</tr>
<tr>
<td>$\beta_4$ AADT per lane (in $10^3$)</td>
<td>-0.1783 ($\pm0.04;-4.57$)</td>
</tr>
<tr>
<td>$\beta_5$ Lane width (in ft)</td>
<td>-0.1411 ($\pm0.04;-3.43$)</td>
</tr>
<tr>
<td>$\beta_6$ Median clear roadside recovery distance (in ft)</td>
<td>-0.01375 ($\pm0.007;-1.97$)</td>
</tr>
<tr>
<td>$\beta_7$ Paved shoulder width (in ft)</td>
<td>-0.0881 ($\pm0.014;-6.38$)</td>
</tr>
<tr>
<td>$\beta_8$ Earth, grass, gravel, or stabilized shoulder width (in ft)</td>
<td></td>
</tr>
<tr>
<td>$\beta_9$ Median sideslope (e.g., 3:1 and 7:1 slopes are recorded as 1/3=0.33 &amp; 1/7=0.14, respectively.)</td>
<td>0.6920 ($\pm0.45;1.54$)</td>
</tr>
<tr>
<td>$\beta_{10}$ Terrain type (0=flat; 1=mountainous+rolling)</td>
<td>0.2939 ($\pm0.09;3.35$)</td>
</tr>
<tr>
<td>$\beta_{11}$ Posted speed limit (in mph)</td>
<td></td>
</tr>
<tr>
<td>$\beta_{12}$ Number of intersections per mile</td>
<td></td>
</tr>
<tr>
<td>$\beta_{13}$ Number of driveways per mile</td>
<td>0.0129 ($\pm0.006;2.33$)</td>
</tr>
<tr>
<td>$\beta_{14}$ Number of bridges per mile</td>
<td>0.2016 ($\pm0.095;2.13$)</td>
</tr>
<tr>
<td>Dispersion parameter of the NB model ($\alpha$)</td>
<td>0.3988 ($\pm0.036;11.0$)</td>
</tr>
<tr>
<td>$L(\alpha, \beta)$ (=loglikelihood function)</td>
<td>-1646.8</td>
</tr>
<tr>
<td>Akaike Information Criterion Value</td>
<td>3317.5</td>
</tr>
<tr>
<td>Expected vs. observed total number of accidents</td>
<td>4,709.0 vs 4,632.0</td>
</tr>
</tbody>
</table>

Notes: (1) 596 rural 2-lane undivided road sections; total length=1,788 mi; about 5 years of accident data (1980-1984).
(2) Values in parentheses are asymptotic standard deviation and t-statistics of the coefficients above.
(3) ——— indicates "not included in the model."
(4) 1 mile = 1.61 km. 1 ft = 0.3048 m.
Figure 1. Illustration of single-vehicle run-off-the-road accident rates for various lane widths and sideslopes.

- Solid Line: This study
- Dashed Line: Zegeer et al. [1987]

AADT=1,000
Shoulder Width = 4 ft
Roadside Recovery Distance = 10 ft

Lane Width (in ft)

No. of accidents/100 Million Vehicle Miles

(1 mi = 1.61 km; 1 ft = 0.3048 m)
Figure 2. Single-vehicle run-off-the-road accident rates for a given sideslope versus single-vehicle run-off-the-road accident rate for a sideslope of 7:1
Figure 3. Comparison of the derived roadside encroachment frequency from the accident prediction model developed in this study and observed frequencies from earlier studies.
Figure 4. Comparison of various probability distributions of the lateral extent of encroachments.