Development of Accident Modification Factors for Rural Frontage Road Segments in Texas

Dominique Lord*
Zachry Department of Civil Engineering &
Center for Transportation Safety
Texas Transportation Institute
Texas A&M University System
3135 TAMU, College Station, TX, 77843-3135
Tel. (979) 458-3949
Fax: (979) 845-6481
d-lord@tamu.edu

James A. Bonneson, P.E.
Texas Transportation Institute
Texas A&M University System
3135 TAMU, College Station, TX, 77843-3135
Tel. (979) 845-9906
Fax: (979) 845-6254
j-bonneson@tamu.edu

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* Corresponding author
ABSTRACT

Frontage roads are most frequently used in rural and urban environments along freeway and full-controlled principal arterial corridors. Their primary function is to distribute and collect traffic between local streets and interchanges. They have been the primary design solution for providing access along Texas rural freeways and full-controlled principal arterials. With the growing public demand for safer streets and highways, state and national transportation agencies have developed safety programs that emphasize public education, accelerated highway renewal, community-sensitive street systems, and innovative technology to facilitate safe highway design practices. Unfortunately, there currently exist no reliable tools, including the ones proposed in the upcoming Highway Safety Manual, that specifically address the safety performance of rural frontage roads. The original research on which this paper is based is aimed at developing a safety performance function (SPF) for rural one- and two-way frontage roads in Texas and, through the modeling effort, estimate accident modification factors (AMFs) for quantifying the relationship between changes in highway geometric design characteristics and frontage road safety. To accomplish the objectives of this study, an SPF was estimated using data collected on frontage roads located along rural freeways in central Texas. The findings from this research show that wider lane and shoulder widths are associated with a reduction in segment-related collisions. In addition, the data suggest that edge marking presence has a significant impact on the safety performance of rural two-way frontage roads. However, the magnitude of the crash reduction due to marking presence was significant and believed to overstate the true benefit of such markings. The results also show that the SPF developed for this research indicates that rural frontage road segments experience about the same number of severe crashes as typical rural two-lane highways for the same traffic volume. Differences in turning volume and weaving activity on these two facility types may explain the subtle differences noted in the SPF estimates for the two facility types.
INTRODUCTION

Frontage roads are most frequently used in rural and urban environments along freeway and full-controlled principal arterial corridors. Their primary function is to distribute and collect traffic between local streets and interchanges. They also serve other purposes depending on the type of facilities they serve and the characteristics of the surrounding areas. For instance, frontage roads can be used to control access, provide access to adjacent properties, and maintain circulation on each side of the arterial (1). In general, they usually run parallel to the main traveled way, and may be provided on both sides of the principal arterial. Depending on the characteristics of the adjacent land, frontage roads can operate as a one-way or two-way facility.

Frontage roads have been the primary design solution for providing access along Texas rural freeways and full-controlled principal arterials. As of 2000, the State of Texas had more than 4,510 miles of urban and rural frontage roads (2). The Texas Department of Transportation (TxDOT) has developed several guidelines for designing rural frontage roads (3). The guidelines address various important design elements, such as selecting the design speed, lane and shoulder widths, and the type of operation (i.e., one-way or two-way).

With the growing public demand for safer streets and highways, state and national transportation agencies have developed safety programs that emphasize public education, accelerated highway renewal, community-sensitive street systems, and innovative technology to facilitate safe highway design practices. Recent effort has been devoted to incorporate safety in a quantitative manner within the highway design process (4,5). In fact, the forthcoming Highway Safety Manual (HSM) (6) will specifically provide tools for estimating the safety performance of several types of highway facilities. Unfortunately, the first edition of the HSM will not be addressing the safety performance of rural frontage roads.

This paper describes the development of quantitative tools for estimating the safety of rural frontage road segments on Texas highways. These tools include a safety performance function (SPF) and several accident modification factors (AMFs). The SPF quantifies the relationship between the crash frequency on a frontage road segment and its length and average daily traffic volume (ADT). An AMF quantifies the relationship between a change in a specific highway geometric design element (e.g., lane width) and safety.

The focus of this research is the geometric design factors that influence the safety of two-way and one-way frontage road segments in rural areas. The tools described herein are intended to help the designer evaluate alternative geometric design element dimensions, such as a lane width of 11 ft versus 12 ft, in terms of their impact on safety. These tools do not address the safety of ramp/frontage-road terminals or the safety of frontage-road/crossroad intersections. Moreover, they are not intended to be used to directly address questions related to the safety impact of one-way frontage-road operation versus two-way frontage road operation.

The remainder of this paper is divided into six parts. The first part summarizes the literature on the safety performance of frontage roads. The second part describes the segment selection and data collection activities. The third part explains the statistical analysis procedure used to develop the SPF. The fourth part describes the frontage road AMFs derived from the
data. The fifth part describes the frontage road SPF that was calibrated using the data. A summary of the work is provided in the last part.

BACKGROUND

There has been little research into the safety performance of rural or urban frontage roads. Only two research projects could be identified that specifically evaluated the safety performance of frontage roads. The first project was conducted by Woods and Chang (7). They evaluated the change in safety at nine frontage road sites following their conversion from two-way to one-way operation. These authors found a reduction of about 20 percent in crash frequency following the frontage road conversion.

Jacobson et al. (8) analyzed crash data occurring near frontage-road entrance ramps at several locations in Texas. They used this data to determine the distance necessary to minimize the speed differential between vehicles entering the entrance ramp and those continuing on the frontage road. Their objective was to develop guidelines for determining the minimum distance between ramp terminals and commercial driveways when located on one-way frontage roads.

Jacobson et al. collected data at five sites in Austin and San Antonio. They reported that segments with driveways located within 100 ft of the ramp terminal had significantly higher crash rates than segments with driveways located further away from the terminal. They recommended an absolute minimum of 100 ft upstream (200 ft is more desirable) of the ramp terminal where no driveways should be located. They also recommended maintaining a driveway-free section equal to 50 ft downstream from the ramp terminal.

No frontage-road-based AMFs were specifically identified in the literature. AMFs that have been developed for rural two-lane highways could arguably be used to for rural frontage-roads given their similar area-type, high-speed character, and two-lane cross section. AMFs for rural two-lane highways have been documented in several reports (5, 6). However, the frontage road is different from the two-lane highway because it has restricted access along at least one side of the road, a higher percentage of turning traffic, and periodic ramp-frontage-road terminals with yield control. As a result of these differences, a given design element is likely to have a different effect on frontage-road safety than on two-lane highway safety. For this reason, there is a need to develop AMFs for rural frontage roads.

DATA COLLECTION ACTIVITIES

This section describes the data collection activities undertaken to assemble a database suitable for developing a frontage road SPF and associated AMFs. The first sub-section outlines the criteria used in the segment selection process. The second sub-section describes the characteristics of the crash data. The third sub-section describes the process used to collect traffic flow and geometry data. The last sub-section explains how the data were assembled and analyzed.
Selection Process

Figure 1 shows the frontage road segment that formed the basis for the analysis. All frontage road segments considered for inclusion in the database were located between successive interchanges. Also, each segment selected was required to have at least one ramp terminal along its length (however, the ramp terminal area was not considered to be part of the segment).

![Figure 1. Frontage Road Analysis Segment.](image)

Four Texas highway corridors were considered for segment selection. In all cases, only those frontage-road segments in rural areas were considered for inclusion in the database. The first corridor was located along I-35 between the City of Georgetown and the location where I-35 splits between I-35E and I-35W north of Waco (segments in the vicinity of the Cities of Temple and Waco were excluded). The second corridor was located along S.H. 6/S.H. 190 near the Cities of Bryan/College Station. The third study corridor was located on I-10 between the Cities of Glidden and Brookshire. The last study corridor was located on I-45 between the Cities of Willis and Centerville. The study corridors collectively contained a mix of one-way and two-way frontage roads.

A total of 141 segments were ultimately identified from a review of various maps and aerial photos. Each segment was subsequently visited to collect additional data not available from other sources. A distance measuring instrument (DMI) was used to measure segment length and the location of driveways and ramp terminals. After screening the initial 141 segments for data availability and construction activity, the sample size was reduced to 123 segments. The characteristics of these segments are summarized in Table 1.

Crash Data

Crash data for each frontage road segment were extracted from the Department of Public Safety (DPS) electronic database. A total of five years of crash data (1997 to 2001) were used. Only crashes that were “segment-related” were included in the database assembled for this research. Crashes that were related to the ramp/frontage-road terminals or that were related to the frontage-road/crossroad intersections are referred to as “non-segment-related crashes” and were excluded. These crashes were rationalized to be strongly influenced by the design of the
terminal, or intersection, and would not be helpful in identifying correlation between segment design and segment crash frequency. Non-segment-related crashes were defined to be those crashes identified as “At-Intersection” or “Intersection Related” in the DPS database.

<table>
<thead>
<tr>
<th>Highway</th>
<th>Operation</th>
<th>Number of Segments</th>
<th>ADT, veh/day</th>
<th>Percent Segments with Edge Delineation</th>
<th>Segment Length, miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.H. 6/ S.H. 190</td>
<td>Two-way</td>
<td>11</td>
<td>2,360</td>
<td>110</td>
<td>6,168</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>20</td>
<td>2,550</td>
<td>140</td>
<td>5,270</td>
</tr>
<tr>
<td>I-10</td>
<td>Two-way</td>
<td>16</td>
<td>675</td>
<td>168</td>
<td>1,585</td>
</tr>
<tr>
<td>I-35</td>
<td>Two-way</td>
<td>57</td>
<td>575</td>
<td>125</td>
<td>2,199</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>6</td>
<td>790</td>
<td>361</td>
<td>1,046</td>
</tr>
<tr>
<td>I-45</td>
<td>Two-way</td>
<td>10</td>
<td>1,990</td>
<td>218</td>
<td>1,988</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>3</td>
<td>4,470</td>
<td>3,093</td>
<td>5,766</td>
</tr>
<tr>
<td>Summary</td>
<td>Two-way</td>
<td>94</td>
<td>2,385</td>
<td>110</td>
<td>6,168</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>29</td>
<td>940</td>
<td>140</td>
<td>5,766</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>123</td>
<td>1,230</td>
<td>110</td>
<td>6,168</td>
</tr>
</tbody>
</table>

Crashes for all types of severity were extracted from the Department of Public Safety (DPS) database. The severity classes considered include: fatal (K), incapacitating-injury (A), non-incapacitating injury (B) and minor injury (C) and property damage only (O). A summary of the crash data characteristics is presented in Table 2. The data in this table correspond to crashes that were reported to have occurred on the frontage-road segment and that were determined to be segment-related crashes. The numbers listed in Table 2 are based on crashes that occurred during a five-year period.
Table 2. Frontage-Road Segment Crash Characteristics.\(^1\)

<table>
<thead>
<tr>
<th>Highway</th>
<th>Operation</th>
<th>Severe (KABC) Crash Freq.,(^2)</th>
<th>Total (KABCO) Crash Freq.,(^2)</th>
<th>Total Crashes Per Segment(^2)</th>
<th>Total Crash Rate,(^3) cr/mvm</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.H. 6/ S.H. 190</td>
<td>Two-way</td>
<td>11</td>
<td>19</td>
<td>1.73</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>23</td>
<td>33</td>
<td>1.65</td>
<td>0</td>
</tr>
<tr>
<td>I-10</td>
<td>Two-way</td>
<td>8</td>
<td>15</td>
<td>0.94</td>
<td>0</td>
</tr>
<tr>
<td>I-35</td>
<td>Two-way</td>
<td>44</td>
<td>72</td>
<td>1.26</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>8</td>
<td>9</td>
<td>1.50</td>
<td>0</td>
</tr>
<tr>
<td>I-45</td>
<td>Two-way</td>
<td>17</td>
<td>21</td>
<td>2.10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>13</td>
<td>17</td>
<td>5.67</td>
<td>4</td>
</tr>
<tr>
<td>Summary</td>
<td>Two-way</td>
<td>80</td>
<td>127</td>
<td>1.35</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>44</td>
<td>59</td>
<td>2.03</td>
<td>0</td>
</tr>
<tr>
<td>Overall</td>
<td>124</td>
<td>186</td>
<td>1.51</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

Notes:
1 – Crash data apply to frontage-road segments and do not include crashes that may have occurred at ramp/frontage-road terminals or at frontage-road/crossroad intersections.
2 – Crash frequencies listed in columns 3 through 7 are based on a five-year period.
3 – Crash rate has units of total crashes per million vehicle miles (cr/mvm).

As indicated in Table 2, there were 186 total crashes that occurred on the 123 frontage-road segments during the five years for which crash data were available. Many of the segments experienced no crashes during this time period. One segment experienced eight crashes during this period. Severe crashes accounted for 124 of the 186 crashes, or about 67 percent of all crashes (note: PDO collisions are probably under reported, but the magnitude is unknown). Although not shown in the table, the severe crash rate for frontage road segments is 0.28 cr/mvm. This rate is slightly higher than the severe crash rate of 0.20 cr/mvm found for the typical rural two-lane highway (\(\frac{5}{2}\)). The slight increase may be due to the more complicated environment of the rural frontage road (i.e., ramp terminals, concentrated weaving).

Supplemental Data Collection

Supplemental data were collected to facilitate the statistical examination of factors that may influence segment crashes. The data collected include: traffic counts, lane width, paved shoulder width, presence of pavement edge line markings (no raised pavement markers), presence of curb, and the number of private and commercial driveways. The characteristics for some of the data are summarized in Table 3. The physical characteristics of the highway sections were shown in Table 1.
### Table 3. Frontage-Road Segment Supplementary Data.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Private Driveways (dr/mile)</th>
<th>Commercial Driveways (dr/mile)</th>
<th>Lane Width, ft</th>
<th>Paved Right-Shoulder Width, ft</th>
<th>Paved Left-Shoulder Width, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave. Two-Way 1.44 One-Way 2.10</td>
<td>Ave. Two-Way 2.55 One-Way 5.50</td>
<td>Ave. Two-Way 10.5 One-Way 11.7</td>
<td>Ave. Two-Way 1.3 One-Way 1.3</td>
<td>Ave. Two-Way 1.1 One-Way 2.4</td>
</tr>
<tr>
<td>Min</td>
<td>0 0</td>
<td>0 0.53</td>
<td>9 10</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Max</td>
<td>9.34 12.33</td>
<td>10.63 21.04</td>
<td>13 13</td>
<td>9 8</td>
<td>9 7</td>
</tr>
<tr>
<td>Sum</td>
<td>421 54</td>
<td>466 207</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Traffic counts were extracted from TxDOT’s Road-Highway Inventory Network (RHiNo) database for the years 1997 to 2001. RHiNo counts were available for most of the 123 segments. Automatic traffic counters were used to obtain counts for those frontage roads not in the RHiNo database. All traffic counts were collected for a 24-hour time period. They were then adjusted to yield an estimate of the annual average daily traffic for the midpoint year of the 5-year period corresponding to 1997 to 2001.

**Database Assembly**

Once the crash and the supplemental data were collected for each site located along the study corridors, the data were combined into one database. The database was formatted to be imported in Genstat (9), the statistical software program used to develop the statistical models.

**STATISTICAL MODEL DEVELOPMENT**

The statistical analysis of the database consisted of developing a safety performance function relating the reported crash frequency to the measured site characteristics. Several alternative model forms were tested. However, only the model that provided the best combination of good fit to the data and a logical relationship between the independent and dependent variables is described in this section.

The number of crashes at the i-th rural frontage road segment, \( Y_i \), when conditional on its mean \( \mu_i \), is assumed to be Poisson distributed and independent over all segments as:

\[
Y_i \mid \mu_i \sim Po(\mu_i) \quad i = 1, 2, \ldots, I \text{ and } t = 1, 2, \ldots, T
\]  

(1)

The mean of the Poisson is structured as:

\[
\mu_i = f(X_i; \beta) \exp(e_{it})
\]  

(2)

where,

- \( f(\cdot) \) is the predictive model represented as a function of the variables \( X \);
- \( \beta \) is a vector of unknown coefficients; and,
- \( e_{it} \) is the random error.
It is usually assumed that \( \exp(e_i) \) is independent and Gamma distributed with a mean equal to \( 1 \) and a variance equal to \( 1/\phi \) for all \( i \) (with \( \phi > 0 \)). With this characteristic, it can be shown that \( Y_i \), conditional on \( f(.) \) and \( \phi \), is distributed as a Negative Binomial (NB) (or Poisson-gamma) random variable with a mean \( f(.) \) and a variance \( f(.)(1+f(.)/\phi) \), respectively. The term \( \phi \) is usually defined as the "inverse dispersion parameter" for the NB distribution. If \( \phi \to \infty \), then the distribution converges to a full Poisson distribution and a Poisson regression model was used for estimating the predictive model.

An important characteristic associated with the development of statistical relationships is the choice of the functional form linking the crashes to the variables. For this work, the selected functional form for the predictive model is:

\[
\mu_i = \beta_0 L_i F_i^{\beta_1} e^{x_i\beta_2} \tag{3}
\]

where,

- \( \mu_i \) = the estimated number of crashes per year for segment \( i \);
- \( F_i \) = vehicles per day (both ways for two-way operations) (ADT) for segment \( i \);
- \( L_i \) = length of segment \( i \) in miles;
- \( x_i \) = a series of variables; and,
- \( \beta_0, \beta_1, \ldots, \beta_n \) = coefficients to be estimated.

It was decided to use the segment length variable as an offset variable in Equation 3, as opposed to a variable associated with an exponential regression coefficient (e.g., as is the case for the flow variable \( F \)). This approach was taken because segment length is considered to be directly related to segment crash frequency (i.e., the number of crashes on a segment increases in direct proportion to the increase in its length). Hence, no empirical adjustment is believed to be needed for the length variable.

The coefficients in the model were estimated using Genstat (9). At the start of the modeling effort, several NB regression models were attempted using one-way and two-way frontage roads together in one model, and then in separate models. Due to the low sample mean values and small sample size, some models did not provide reasonable results. As explained by Lord (10), models developed using datasets subjected to these characteristics can show significant signs of instability during the model estimation process. In fact, the data may exhibit over-dispersion, but this characteristic cannot be captured by a NB regression model (see [10] for additional information). Based on these considerations, it was decided to use a Poisson regression model for fitting the frontage road data, since the model output of the NB regression model showed an inverse dispersion parameter equal to infinity.

During the model development, each variable was added to the model one at the time. Initially, predictive models were developed separately for the one-way and two-way frontage road types. However, it was found that the regression coefficients for common variables in these
two models were not significantly different from one another. For this reason, the data were combined and one predictive model was developed. Indicator variables were used in this model whenever the effect of a specific variable was found to be correlated with frontage road type.

Table 4 summarizes the coefficient values associated with the calibrated model. These coefficients correspond to a model that predicts total (i.e., KABCO) crashes on rural frontage road segments. An additional model was fit to the severe crash data; however, the elimination of property-damage-only crashes from the database contributed further to the low sample mean and small sample size problems noted previously. For this reason, further efforts to calibrate a model using severe crash frequency were abandoned.

The coefficient values listed in Table 4 indicate the nature of the correlation between the corresponding variable and crash frequency. Specifically, positive coefficient values indicate that an increase in the variable value correlates with an increase in crash frequency (and negative values correlate with a decrease in crashes). For example, the coefficient of -0.188 associated with the Lane Width variable indicates that an increase in lane width is associated with a decrease in the number of crashes. The interaction variable (Edge Marking Presence x Two-Way Operation) shows that the presence of a pavement edge line is negatively associated with the number of crashes for two-way frontage roads. It suggests that the addition of edge lines to a two-lane frontage road reduces crash frequency. A similar effect was not found for one-way frontage road segments in the assembled database; however, intuition would suggest it is likely to exist.

<table>
<thead>
<tr>
<th>Model Variables</th>
<th>Coefficient Value (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (\ln{\beta_0})</td>
<td>-3.85 (1.11)</td>
</tr>
<tr>
<td>Log(ADT) (\beta_1)</td>
<td>0.641 (0.0857)</td>
</tr>
<tr>
<td>Lane Width (\beta_2), ft</td>
<td>-0.188 (0.104)</td>
</tr>
<tr>
<td>Combined Shoulder Width* (\beta_3), ft</td>
<td>-0.035 (0.028)</td>
</tr>
<tr>
<td>Edge Marking Presence x Two-Way Operationb (\beta_4)</td>
<td>-0.518 (0.203)</td>
</tr>
</tbody>
</table>

Summary Statistics
Scaled Deviance = 143.0 (F=15.26)

* Combined Shoulder Width = paved left shoulder width + paved right shoulder width
b Edge Marking Presence = Left edge marking (0.5 = yes, 0 = no) + right edge marking (0.5 = yes, 0 = no)
b Two-Way Operation (1 = yes, 0 = no)

The coefficient values listed in Table 4 can be substituted into Equation 3 to yield the following calibrated model:
\[ \mu_i = 0.021 \times L_i F_i^{0.641} e^{(-0.188 LW - 0.035 SW - 0.518 EM \times I_2)} \]  

where,
- \( LW \) = average lane width, ft;
- \( SW \) = combined paved shoulder width (left + right shoulder), ft;
- \( EM \) = proportion of segment with pavement edge markings (both directions); and
- \( I_2 \) = indicator variable (= 1.0 for two-way operation, 0.0 for one-way operation).

The variable \( EM \) used in Equation 4 is a proportion that varies from 0 to 1.0. It represents the length of edge line on the right side of the roadway plus the length of edge line on the left side of the roadway, all of which is divided by twice the segment length. Thus, a 1.0 mile frontage road with edge lines only on the right side would have \( EM = 0.5 \) (= \([1.0 + 0.0]/[2 \times 1.0]\)).

**ACCIDENT MODIFICATION FACTORS**

Three AMFs were derived from the frontage-road segment database. Alternative approaches for developing AMFs from cross section data, such as that proposed by Washington et al. (11), were examined and ruled out due to the small number of crashes in the database. Consequently, the AMFs were estimated directly from the coefficients of the model, as listed in Table 4. This approach for AMF development assumes that each model variable is independent and, thus, not influenced by the value of any other variable. It also assumes that the relationship between the change in the variable value and the change in crash frequency is exponential (as suggested by Equations 3 or 4). A more rigorous study design and a larger database (i.e., one with more segments) would be needed to test the validity of these assumptions. However, experience in deriving AMFs in this manner indicates that the assumptions are reasonable and, with thoughtful model development, the resulting AMFs can yield useful information about the first-order effect of a given variable on safety.

**AMF – Lane Width**

The recommended AMF for lane width is:

\[ AMF_{LW} = e^{(-0.188 \times [LW - 12.0])} \]  

where,
- \( LW \) = average lane width, ft.

The average lane width used in Equation 5 represents the total width of all through traffic lanes on the frontage road divided by the number of through lanes. The value of 12.0 in Equation 5 reflects the base, or typical, lane width condition. By definition, it is associated with an AMF value of 1.0.

The graphical representation of \( AMF_{LW} \) is shown in Figure 2. The relationship between lane width and AMF value shown in this figure suggests that crash frequency is reduced about 17
percent (i.e., $1 - e^{-0.188}$) for a 1-ft increase in lane width. Based on the range of lane widths in the database, the lane width AMF is applicable to lane widths ranging from 9 to 13 ft.

![Figure 2. AMF for Lane Width.](image)

Also shown in Figure 2 is the lane width AMF for rural two-lane highways. A comparison of this AMF with the lane width AMF for frontage roads suggests that lane width on a frontage road has a greater impact on crash frequency than it does on a two-lane highway. It is possible that this trend stems from the relatively high percentage of turning traffic and the considerable weaving activity that occurs on frontage roads (between the ramp terminals and the crossroad intersection), relative to a two-lane highway. Wider lanes on frontage road segments may provide some additional room for recovery when these turning and weaving-related conflicts occur.

**AMF – Shoulder Width**

The recommended AMF for shoulder width is:

$$AMF_{SW} = e^{(-0.070 \cdot (ASW - 1.5))}$$  \hspace{1cm} (6)

where,

$ASW =$ average paved shoulder width \((\text{left shoulder width + right shoulder width})/2\), ft.

This AMF is derived from Equation 4; however, the associated regression coefficient (i.e., -0.035) has been doubled such that the resulting AMF is based on the average paved shoulder width. This average is computed as the sum of the left and right shoulder widths divided by 2.0. The value of 1.5 in Equation 6 reflects the base, or typical, average paved shoulder width condition.
The graphical representation of $AMF_{SW}$ is shown in Figure 3. The relationship between shoulder width and AMF value shown in this figure suggests that crash frequency is reduced 7.0 percent for a 1-ft increase in shoulder width. Based on the range of shoulder widths in the database, the shoulder width AMF is applicable to average shoulder widths ranging from 0 to 9 ft.

![Figure 3. AMF for Paved Shoulder Width.](image)

Also shown in Figure 3 is the shoulder width AMF for rural two-lane highways developed by Bonneson et al. (5). The base condition for this AMF has been changed to a shoulder width of 1.5 ft to facilitate comparison with Equation 6. As suggested by the trend lines in this figure, shoulder width has a slightly lower impact on frontage road safety than on rural two-lane highways. However, the difference is somewhat subtle and may only be a result of random variation in the database.

**AMF – Edge Marking Presence on Two-Way Frontage Roads**

The AMF that was derived from variables associated with the presence of edge line delineation is:

$$AMF_{EM} = e^{-0.518EM}$$

(7)

where,

$EM = \text{proportion of segment with pavement edge markings (both directions)}$.

This AMF was derived using data for two-way frontage roads. An equivalent AMF for one-way frontage roads could not be derived. The AMF likely explains the effect of edge line
delineation and other traffic control devices that are used to highlight the two-way operation (relative to the more common one-way operation) and to ensure correct driving behavior.

Equation 7 reflects a base, or typical, frontage road condition where there are no pavement edge lines. A graphical representation of the $AMF_{EM}$ is shown in Figure 4.

![Figure 4. AMF for Presence of Edge Line Delineation on Two-Way Rural Frontage Roads.](image_url)

The trend shown in Figure 4 suggests that edge markings can reduce crashes on two-way frontage roads by 40 percent if placed fully along both sides of the frontage road. This reduction is relatively large and suggests that this AMF is explaining more than just the effect of pavement edge marking presence on crash frequency. The presence of pavement edge markings is also likely to be accompanied by additional warning signs that denote two-way operation. Hence, the 40 percent reduction noted previously is likely a reflection of the effectiveness of the full complement of traffic control devices often deployed on two-way frontage roads to mitigate the increased potential for wrong way driving. Given this speculation and the lack of corroborating evidence from other research projects, this AMF cannot be recommended for evaluating edge marking presence. However, it does provide some validation to the belief that a full complement of traffic control devices on two-way frontage roads will reduce crashes, although the amount of reduction is uncertain at this time.

SAFETY PERFORMANCE FUNCTION

The SPF developed from the analysis is based on the regression model in Equation 4, after adjustment such that it can be used to obtain an estimate of severe crash frequency. This adjustment entailed multiplying the constant 0.021 in Equation 4 by 0.67, where the multiplier
0.67 reflects the fact that 67 percent of the crashes in the database correspond to severe crashes (as noted previously in the discussion of Table 2).

\[ \mu_i = 0.00134L_i F_i^{0.641} \]  

where,

- \( \mu_i \) = the estimated number of severe crashes per year for segment \( i \);
- \( F_i \) = vehicles per day (both ways for two-way operations) (ADT) for segment \( i \); and
- \( L_i \) = length of segment \( i \) in miles.

Equation 8 predicts the severe crash frequency that would be estimated for a frontage road segment with 12 ft lanes and a combined paved shoulder width of 3.0 ft. In application, the crash frequency predicted by Equation 8 would be multiplied by the AMFs for lane width and shoulder width (provided in the previous section) to estimate the severe crash frequency for a given segment with a specified lane and shoulder width.

The estimate obtained from Equation 8 does not include the crashes that would be attributed to the ramp/frontage-road terminal or the frontage-road/crossroad intersection. It also does not include any crashes that may occur on the main lanes that may indirectly be attributed to the frontage road operation or its ramp design.

Equation 8 is compared in Figure 5 with the rural two-lane highway SPF included in the *Interim Roadway Safety Design Workbook* (5). The *Workbook* SPF is based on a severe crash rate of 0.20 cr/mvm. The trend lines in the figure indicate that a frontage road experiences slightly more severe crashes than a rural two-lane highway for ADTs that are less than 3500 veh/d. The reverse trend applies for ADTs greater than 3500 veh/d. It is possible that the increased turning and weaving activity associated with the frontage road (relative to the two-lane highway) may explain the slightly higher severe crash frequency on frontage roads for ADTs less than 3500 veh/d. As ADT exceeds 3500 veh/d, there may be less opportunity for turning (i.e., fewer gaps) and the weaving activity may be more constrained (i.e., lower speed) on the frontage road, such that frontage road crash frequency is lower than that found on two-lane highways.

The predicted values from the two SPFs shown in Figure 5 are not statistically different from each other when a 95th percentile confidence interval is used. Hence, there is a small chance that the trend shown in Figure 5 is a result only of random variation in the data and that the two facility types actually have a similar severe crash frequency for segments.
SUMMARY AND CONCLUSIONS

This paper examined the safety performance of rural frontage road segments. A SPF and three AMFs were derived from a statistical model that was estimated using data collected on rural frontage road segments. The variables that were found to have significant correlation with crash frequency include lane width, paved shoulder width, and for two-lane frontage roads, edge marking delineation. The SPF and AMFs do not consider crashes that would be attributed to the ramp/frontage-road terminal or the frontage-road/crossroad intersection. Moreover, they do not consider crashes that occur on the main lanes that may indirectly be related to wrong-way travel down an exit ramp.

The findings from this research have shown that wider lane and shoulder widths are associated with a reduction in segment-related collisions. In addition, the data suggest that edge marking presence has a significant impact on the safety performance of rural two-way frontage roads. However, the magnitude of the crash reduction due to marking presence was significant and believed to overstate the true benefit of such markings. Additional research is needed to confirm the safety benefit associated with the pavement markings and related control devices used on frontage roads. The SPF developed for this research indicates that rural frontage road segments experience about the same number of severe crashes as typical rural two-lane highways for the same traffic volume. Differences in turning volume and weaving activity on these two facility types may explain the subtle differences noted in the SPF estimates for the two facility types.
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REFERENCES


