An Attempt to Develop Crash Reduction Factors Using Regression Technique

by

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ABSTRACT

With the constantly growing traffic volumes and limited resources for highway infrastructure extension and management, efficient methods of safety improvement become increasingly important. A crash reduction factor is a measure of the effectiveness of an improvement expressed in the number of crashes reduced at a given location. Due to simple concept and application, crash reduction factors are widely used in the highway management process to estimate users’ benefits and to optimize the use of safety funds.

This study attempts to develop crash reduction factors using the cross-sectional analysis. An example of highway sections is discussed. Regression models of crash frequencies developed for four categories of Indiana highways: rural multilane, rural tow-lane, rural multilane, urban tow-lane highways. Indiana road inventory data and crash data for five years were used. The results were critically evaluated.

The regression parameters that did not involve serious concern about their validity were used to derive corresponding crash reduction factors. Concluding remarks raise several issues critical for the validity of the crash reduction factor estimates using cross-sectional analysis.

Key words: crash reduction factors, regression analysis, highway safety, safety improvements

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1. INTRODUCTION

Traffic safety has become one of the major public concerns in day-to-day life. With the constantly growing traffic volumes and limited resources for road infrastructure, efficient methods of safety improvement become increasingly important. Indiana Department of Transportation with the cooperation of Purdue University is developing a Safety Management System -- a systematic process to assist decision makers in selecting cost-effective strategies to improve the efficiency and safety of highway traffic.

Crash reduction factors are one of the important components of the Safety Management System. Although a previous effort undertaken by the INDOT and a team from Purdue yielded a set of factors (Ermer et al, 1991), the increase of the quality and amount of data has prompted a need for updating the original values and for adding new ones. This paper presents example results of the recent study.

It is widely recognized that the occurrence of crashes results from the complex interaction among a driver, vehicle, and roadway. An alteration of some cross-section and intersection characteristics may positively influence the level of safety on this segment. Prediction of such effect is required where the planned alteration is claimed to improve safety. Typically, crash reduction factors are used to predict the safety effect due to the simple concept and application. The crash reduction factor expresses the percent reduction in the number of crashes attributed to a specific highway improvement.

The objective of this study was to develop crash reduction factors for Indiana road sections using a regression technique. The road sections considered for this study are state and U.S. highways. Data collection and preliminary processing are described in Section 2. This study uses negative binomial regression to model the crash frequency on highway sections -- the method widely used in the safety analyses area. The methodology is described in detail in Eranky et. al., 1997. The developed regression models are presented in Section 3 and discussed in Section 4. Section 5 presents derivation of example crash reduction factors from the regression models presented in Section 3. A comparison of the results obtained in this study with the results obtained by other authors follows. Final remarks (Section 6) close the presentation.
2. DATA COLLECTION AND PRELIMINARY PROCESSING

The quality of data is critical for the quality of results. The authors make an effort to ensure that the data prepared for the statistical analysis are of the highest quality available at the time of the research. Three sources of data were used for this project.

1. *INDOT Road Inventory Database* consists of records with various geometric and traffic characteristics of homogenous highway section. The variables used in the regression models have either been taken directly from this file or obtained through relevant transformations.

2. *Indiana State Police Crash Database* contains location information and other data describing crashes reported to the Indiana Police Department. Data files for the five-year period (1991-1995) were used. These files will henceforth be referred to as Crash Database.

3. Integration Files (Weiss, 1996) were used to link the Road Inventory Database and Crash Database. The Inventory and Crash Databases use different systems of coding information of crash locations.

Indiana counties can be classified with regard to topography as mountainous, rolling, and level. Eight counties have been selected for analysis so that all the types of terrain are represented in the sample. The selected counties are Bartholomew, Brown, Clark, Jefferson, Marion, Montgomery, Switzerland, and Tippecanoe. All U.S. and state highways in the selected eight counties were included in the analysis. They are represented in the Road Inventory Database by 994 highways segments. Due to substantial differences between two-lane roads and multilane roads and between rural roads and urban roads, the highway segments were grouped into four categories.

1. Rural multilane roads (47 segments)
2. Rural two-lane roads (434 segments)
3. Urban multilane roads (331 segments)
4. Urban two-lane roads (182 segments)
Separate regression models were developed for each highway category. Three types of crashes were considered: all crashes, fatal/injury crashes, and property-damage-only crashes. Only results obtained for the all-crashes category are presented in this paper. The complete results can be found in the Joint Transportation Research Program report (Erantry et al., 1997).

There are two reasons for restricting the analysis to the U.S. and state roads: (1) the road inventory database had incomplete data for county and local roads, (2) INDOT is particularly interested in the roads under its jurisdiction.

Software was developed as a part of this research to extract crashes from the crash database. In some cases, the data was incomplete and determination of the location of crashes was not possible. If one assumes that there is no association between the lack of location data and some highway characteristics, neglecting the observations with missing data should not cause any systematic bias on the regression parameters coupled with the highway characteristics.

3. STATISTICAL ANALYSIS

As was already mentioned, the methodology used in this investigation is well established and many authors have reported its use. The form of the model widely used is as follows:

$$A = kLQ^\beta \exp(\sum \gamma_i X_i)$$

(1)

where:  
$A =$ frequency of crashes (acc/5 years),  
$L =$ length of the section,  
$Q =$ AADT on the section (1000 veh/24 h),  
$k =$ slope parameter,  
$X_i =$ explanatory variable of factor $i$,  
$\beta =$ coefficient of AADT, and  
$\gamma =$ coefficient of the factor $i$.  

The safety effects of various geometric and pavement characteristics can be investigated by incorporating appropriate variables $X_i$ into Equation 1. The regression coefficient $\gamma_i$ associated with the variable $X_i$ for their potential safety impact:

1. SL - Segment length (expressed in meters),
2. AADT – Annual Average Daily Traffic (veh/day),
3. NL - Number of lanes,
4. LW - Lane width (m),
5. MT - Median type (barrier type or not),
6. MW - Median width (m),
7. OSW - Outside inside shoulder widths (m),
8. ISW - inside shoulder widths (m),
9. POS – Paved outside shoulder (0 = no, 1 = yes); other variables represent shoulder types (earth, stabilized, paved) and conditions (good, poor),
10. Presence of auxiliary lanes (LT - left, RT – right, and CLT - continuous left turn lanes),
11. SI - Pavement serviceability index (PSI),
12. NC - Number of curbs (0 = no curb, 1 = one side, 2 = two sides),
13. AC - Access control (three levels: 0 = no access control, 1= partial access control, and 2= full access control),
14. PM – pavement material (0 = bituminous, 1 = Portland cement),
15. NPL – number of parking lanes.

The basic descriptive statistics have been computed and histograms were plotted for all the explanatory variables in order to evaluate their variability in the sample. The variables that did not show a significant distribution were removed from the sample. Correlation matrices were calculated for all the independent variables as well as with the dependent variable. A weak multicollinearity was detected among the explanatory variables.

The validity of the results requires that the highway segments do not experience crashes caused by the presence of intersections. This condition has been addressed in a somewhat arbitrary manner following the present practice of collecting crash data in Indiana. Thirty-meter
sections on each side of intersections located on the investigated segments have been excluded from the analysis. A total segment length adjusted for the presence of intersections was included in the regression equation as an offset variable i.e. its coefficient was restricted to 1. This decision is easily defendable by noting that a segment twice longer should experience twice more crashes if all other characteristics are the same. The same claim regarding AADT is not defendable so easily, thus a coefficient for AADT is kept in the equation.

LIMDEP is the software used in the step-wise regression analysis. The analysis started with basic models that included only AADT and the section length. Then, the explanatory variables were added to the model starting from the most significant ones. The final model includes only these factors that are significant at the 20-percent level. It should be noted that the outcome of the regression models is the accident frequency for a five-year period.

Example models of crash frequency for all crashes (fatal + injury + PDO) are presented for all four classes of highways in Tables 1-4. The overdispersion factor $\alpha$ is highly significant indicating the Negative Binomial model as a good choice. Further, such strong overdispersion indicates the presence of other factors not included in the regression equation. The errors of measurement may be among the missing factors. The significance of the first model is much weaker than the other three models. This is caused by the small size of the sample of multilane highways (only 47).

An example comparison of the predicted crash frequencies with the observed frequencies is given in Figure 1 for rural two-lane highways. The growing dispersion of the points around the regression line with the increase in the crash counts (heteroscedasticity) is accounted for through the assumption of the Negative Binomial distribution of the counts.
4. DISCUSSION OF THE RESULTS

As it could be expected, traffic volumes turned out to be a safety factor in all the roads’ categories. The regression parameter $\beta$ associated with AADT is significantly higher than one for urban multilane streets and takes values closer to the value of 1 for other roads. Thus, the same increase in the number of vehicles causes on average more additional crashes on urban multilane roads than elsewhere.

Lane width was found to be significant for two-lane highways in rural and urban areas. Although the estimates differ between the two areas, the magnitude of the estimation errors is large enough to claim that there is no statistical evidence that the true values are different. Thus a single crash reduction factor could be proposed for these two types of highways.

Access control is defined in the road inventory database at three levels: no access control, partial access control, and full access control. The sign of the coefficient is in accordance with the expectations. The higher the level of access control the less crashes on the highway. Regardless of its plausibility, the result is rather difficult to apply since the definitions of levels of service are vague. Most vague is the definition of the second level since it can range from almost no access control to almost full access control. For the present, there is no good method of precise determination of the level of access control implemented in Indiana. Since the two other levels (no control and full control) are more meaningful, the presented analysis can give a rather clear answer to the question about the expected safety effect of converting no access control to full access control. Although the case is quite theoretical, it gives an estimation of the maximum benefit that can be achieved. The actual effect will be lower than the estimated effect. The Purdue University team is carrying out parallel research addressing exclusively the impact of access control on traffic safety and delays. In that project, the access control is measured through the density of access points and their structure (signalized/unsignalized, channelized/ unchannelized, etc.).
Median's width is considered an important safety measure. The results obtained in our analysis support this claim in regard to rural highways. The effect turned out to be strong and positive, as expected. The lack of the effect on the urban highways is difficult to explain. One plausible explanation is that urban conditions impose on traffic more risk factors than rural areas. Frequent median openings, parking vehicles, bus stops, etc. obscure or even reduce the benefit provided by a wide median. Also, typically lower speeds and streetlights on urban streets may reduce the safety effect of wider medians. The lack of safety impact of medians with openings at intersections has been confirmed by another study aimed to evaluate the safety effect of access control on urban arterial streets (Brown and Tarko, 1999). The other study used quite different empirical material collected from video tapes.

The continuous left-turn lanes appeared to be an efficient safety measure. They separate directions, and provide storage and deceleration distance for left-turning vehicles. The urban roads with continuous left-turn lanes appeared to be safer than the segments with traditional treatment of left turning movements. The safety effect of continuous left-turn lanes is similar for two-lane and multilane highways.

Number of lanes significantly affect safety on urban multilane highways. Detecting this effect for rural highway was not possible since the highways wider than four lanes were not present in the sample. The result conforms to the expectations. Adding more lanes increase safety by reducing the level of congestion and interaction between vehicles. It must be emphasized that the effect associated with the number of lanes does not incorporate an increase in the traffic volume that typically follows street widening. The effect of the increased traffic can, however, be easily incorporated using the volume adjustment factor. This factor can be derived and used similarly as crash reduction factors. The method of derivation is explained in the next section.

Pavement serviceability is measured in the inventory database with PSI values ranging between 3.0 and 4.5. The smoother the pavement the higher PSI. The analysis results indicate
that rural highways with smoother surface seem to experience fewer crashes. This result could be expected. Rural roads carry long-distance traffic with considerable number of drivers unfamiliar with the road. Drivers unfamiliar with a road that has a rough pavement may be prone to crashes, particularly during night where the road illumination is lacking. According to the obtained models, urban highways with smoother surface experience more crashes. This result should be taken with reservation. Although, drivers’ familiarity with the road and the road illumination prompt for a weaker safety impact than on rural roads, the reverse effect is difficult to explained.

The effect of pavement material appears significant only in one category of rural two-lane highways. The results indicate that the highway segments with concrete pavement are safer than the highways with bituminous pavement. This result needs further analysis and discussion with the INDOT experts. One plausible explanation could be the policy of using the concrete pavement that promotes selection of highways that are safer anyway.

Two other variables found significant for urban multilane highways are presence of paved outside shoulders and presence of parking lanes. Presence of these cross-sectional components improves safety. The first impact is confirmed by the study already mentioned (Brown and Tarko, 1999). The second impact is rather surprising. The presence of parking vehicles creates additional risk of collision unless the parking lanes are not used and remain empty. That the regression coefficients associated with the variables are rather high would indicate a strong safety impact. On the other hand, the estimation errors are also high indicating low accuracy of the estimates. This situation is apparently caused by the small size of the sample and is discussed in the final remarks in Section 6.

The last variable included in the equations is the presence of traditional (short) left-turn lanes on the segment. The segments that have left-turn lanes appear to be more dangerous than those without. The result is in conflict with the expectation. Nobody would claim that installation of auxiliary left-turn lanes increases the number of crashes. The only possible interpretation of the results is that the left-turn lanes indicate the presence of busy intersections
whose effect on safety has not been fully eliminated from the observations. This case is a good example of misleading results that may be produced by the regression analysis.

5. DERIVATION OF CRASH REDUCTION FACTORS

Regression models like the ones presented in the previous section can be used to derive crash reduction factors. A crash reduction factor is defined as the percentage reduction in the number of crashes caused by the improvement:

\[
CRF = \left(1 - \frac{A'}{A}\right) \cdot 100
\]

where:

\[A = \text{expected number of crashes before the improvement and} \]
\[A' = \text{expected number of crashes after the improvement.} \]

The improvement \(k\) is represented in the regression model (1) through the change in \(X_k\). The expected number of crashes before the improvement \((A)\) and after the improvement \((A')\) are estimated using the regression model \(A = kLQ^\beta \exp(\sum_i \gamma_i X_i)\), thus

\[
CRF_k = \left(1 - \frac{A'}{A}\right) \cdot 100
\]
\[
= \left(1 - \exp(\gamma_k X_k - \gamma_k X'_k)\right) \cdot 100
\]
\[
= \left(1 - \exp(\gamma_k \Delta X_k)\right) \cdot 100
\]

where \(\gamma_k = \text{coefficient of variable } X_k \text{ in the calibrated model,} \)
\(\Delta X_k = \text{change in the value of the variable which represents the highway improvement } k.\)

The example crash reduction factors have been derived for the change of lane width and for the installation of the continuous two-way left-turn lane.

**Widening of Lanes**
The lane widening is significant for two-lane rural and urban highways. The corresponding coefficients are -0.453 (0.251) and -0.701 (0.436), respectively. The values taken in parentheses are the standard errors of estimation. The expected reduction in the number of crashes associated with the widening of traffic lanes by 0.25 meters is (Equation 3):

- two-lane rural highways
  \[ [1 - \exp(-0.453 \times 0.25)] \times 100 = 11 \%
  \]
- two-lane urban highways
  \[ [1 - \exp(-0.701 \times 0.25)] \times 100 = 16 \%
  \]

The errors of estimation of the crash reduction factor for improvement \( k \) can be approximated using the following equation:

\[
e_k = \sqrt{\text{var} f(\gamma_k)} = \sqrt{\left[ \frac{\partial f(\gamma_k)}{\partial \gamma_k} \right]_{\gamma_k}^2 \cdot \text{var} \gamma_k}
\]

where \( f(\gamma_k) \) is the function in equation (3) used to estimate the crash reduction factors and \( \gamma_k \) is the regression parameter associated with a given improvement \( k \). Since

\[
\frac{\partial f(\gamma_k)}{\partial \gamma_k} = -100 \cdot \Delta X_k \cdot \exp(\bar{\gamma}_k \cdot \Delta X_k),
\]

thus

\[
e_k = 100 \cdot \Delta X_k \cdot \exp(\bar{\gamma}_k \cdot \Delta X_k) \cdot \sqrt{\text{var} \gamma_k}.
\]

The estimation errors for the two crash reduction factors are:

- two-lane rural highways
  \[ 100 \times 0.25 \times \exp(-0.453 \times 0.25) \times 0.251 = 5.6 \%
  \]
- two-lane urban highways
  \[ 100 \times 0.25 \times \exp(-0.701 \times 0.25) \times 0.436 = 9.1 \%
  \]

The two crash reduction factors take similar values. A single value can be obtained by combining the two results using the Bayesian method. The estimation error would decrease since a larger combined sample is used. This operation is out of the scope of this presentation.
Example crash reduction factors for widening lanes of two-lane rural roads is presented below in Table 5. The values apply to traffic lanes of width between 2.7-3.6 meters.

The report by Creasey and Agent (1985) is used as a primary source of information about crash reduction factors for other states. The report includes an extensive literature review of available crash reduction factors. The selected crash reduction factors obtained in our study are compared with the ones reported by Creasey and Agent (see Table 6).

The comparison clearly indicates that the obtained results match well the crash reduction factors obtained by other authors. The lack of error estimation reported by other sources does not allow for combining the results to improve the final estimate.

**Continuous Left-turn Lane**

Installation of a continuous left-turn lane is represented by a binary variable (0 = no left-turn lane, 1 = there is a left-turn lane). The calculation of the crash reduction factor and its estimation error are the same as for the lane widening with this difference that the change in variable X takes only one value – one. The results are presented in Table 7. The comparison with the results obtained for other states is in Table 8. Apparently, the Indiana values are consistent between themselves but much higher than for other states. This discrepancy calls for more study to confirm the results obtained for Indiana. An alternative study (Brown and Tarko, 1999) indicates a lower value of this factor (53 % with the estimation error of 16.2 %).

6. **CONCLUDING REMARKS**

This study presents a method of developing crash reduction factors based on the regression technique and direct use of the definition of crash reduction factor. Indiana road inventory data and crash data for five years were used in this research to develop Negative Binomial regression models of crash frequency. The total number of crashes, injury type crashes and PDO type crashes were modeled. Only models for the first category were presented.
Crash reduction factors for various improvement types have been developed. Example crash reduction factors were presented to illustrate the calculation procedure. These factors have been evaluated by comparing them to the ones obtained by other authors. The evaluation has brought rather inconclusive results.

The cross-sectional analysis was found promising in developing crash reduction factors, a careful consideration has to be exercised to avoid false conclusions. The most serious reservation towards the method is the incompleteness of the data. It is hardly known whether the sample includes all significant variables. It may happen that the left out variable represents an actual safety factor and is correlated with another variable included in the analysis. In such cases, the substitute variable may be interpreted as representing the actual crash cause. The conclusions regarding safety countermeasures may be entirely incorrect. Such cases are easily detectable where conclusions derived from regression results contradict common sense.

The small size of the sample is a typical problem faced in statistical analyses of highway safety. A large error of estimation or regression parameters and crash reduction factors is a direct effect of utilizing too small a sample. Further, some safety factors although practically significant, cannot be identified since they appear as statistically insignificant.

Small samples used by researchers can lead to the overestimation of safety impacts. For illustration, let us consider an investigation of some roadway improvement that is believed to improve safety but in fact it does not. The true crash reduction factor is zero. Since the estimate of the crash reduction factor is a random variable, various studies of the same impact will yield different results. If the significance level is 10%, then in 10% of studies the investigated impact will be reported as significant and plausible. In the remaining 90% of studies, the results will be found insignificant or contradicting the expectations. No crash reduction factors will be estimated in these cases. This filtering mechanism in reporting crash reduction factor estimates apparently promotes overestimation. Paradoxically, the weaker impact and smaller sample the bigger overestimation. Indeed, some of the results presented in this paper indicate surprisingly strong safety impacts.
In light of the previous remark, strong safety impacts of even minor improvements reported by various authors should not be a surprise. This presentation is not an exception. The mitigation of this problem is in reporting not only factors found to be significant, but also all other factors that were investigated. It is highly desirable to use large samples and to analyze all the variables that are considered potential safety factors. Recent advancements in technologies and techniques applicable to data collection, storage, and maintenance give hope that large and complete databases will be available in the predictable future.

LITERATURE


Figure 1. Predicted vs. observed total number of accidents for rural two-lane highways
Table 1  Regression Model for Rural Multilane Highways

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>Std.Err.</th>
<th>t-ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(k)</td>
<td>-0.598</td>
<td>0.509</td>
<td>-1.174</td>
<td>0.241</td>
</tr>
<tr>
<td>SL</td>
<td>1.000</td>
<td>Fixed Parameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AADT</td>
<td>1.156</td>
<td>0.851</td>
<td>1.359</td>
<td>0.174</td>
</tr>
<tr>
<td>MW</td>
<td>-0.175</td>
<td>0.052</td>
<td>-3.370</td>
<td>0.001</td>
</tr>
<tr>
<td>AC</td>
<td>-0.995</td>
<td>0.475</td>
<td>-2.095</td>
<td>0.036</td>
</tr>
<tr>
<td>Alpha</td>
<td>1.744</td>
<td>0.552</td>
<td>3.158</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Table 2  Regression Model for Rural Two-lane Highways

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>Std.Err.</th>
<th>t-ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(k)</td>
<td>-0.458</td>
<td>0.123</td>
<td>-9.860</td>
<td>0.000</td>
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<tr>
<td>SL</td>
<td>1.000</td>
<td>Fixed Parameter</td>
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<tr>
<td>AADT</td>
<td>1.019</td>
<td>0.079</td>
<td>12.929</td>
<td>0.000</td>
</tr>
<tr>
<td>LW</td>
<td>-0.453</td>
<td>0.251</td>
<td>-1.805</td>
<td>0.071</td>
</tr>
<tr>
<td>SI</td>
<td>-0.027</td>
<td>0.013</td>
<td>-2.072</td>
<td>0.038</td>
</tr>
<tr>
<td>PM</td>
<td>-0.973</td>
<td>0.231</td>
<td>-4.205</td>
<td>0.000</td>
</tr>
<tr>
<td>Alpha</td>
<td>1.032</td>
<td>0.096</td>
<td>10.716</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 3  Regression Model for Urban Multilane Highways

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>Std Err.</th>
<th>t-ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(k)</td>
<td>-0.861</td>
<td>0.225</td>
<td>-3.539</td>
<td>0.000</td>
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<td>SL</td>
<td>1.000</td>
<td>Fixed Parameter</td>
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<td></td>
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<tr>
<td>AADT</td>
<td>1.745</td>
<td>0.412</td>
<td>4.234</td>
<td>0.000</td>
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<td>NL</td>
<td>-1.104</td>
<td>0.213</td>
<td>-5.184</td>
<td>0.000</td>
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<tr>
<td>SI</td>
<td>0.084</td>
<td>0.027</td>
<td>3.171</td>
<td>0.002</td>
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<tr>
<td>CLT</td>
<td>-2.255</td>
<td>0.841</td>
<td>-2.680</td>
<td>0.007</td>
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<tr>
<td>AC</td>
<td>-1.303</td>
<td>0.429</td>
<td>-3.033</td>
<td>0.002</td>
</tr>
<tr>
<td>POS</td>
<td>-0.831</td>
<td>0.325</td>
<td>-2.555</td>
<td>0.011</td>
</tr>
<tr>
<td>NPL</td>
<td>-1.290</td>
<td>0.502</td>
<td>-2.570</td>
<td>0.010</td>
</tr>
<tr>
<td>Alpha</td>
<td>3.833</td>
<td>0.400</td>
<td>9.594</td>
<td>0.000</td>
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### Table 4  Regression Model for Urban Two-lane Highways

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>Std. Err.</th>
<th>t-ratio</th>
<th>P-value</th>
</tr>
</thead>
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<tr>
<td>( \ln(k) )</td>
<td>-0.592</td>
<td>0.514</td>
<td>-3.041</td>
<td>0.002</td>
</tr>
<tr>
<td>SL</td>
<td>1.000</td>
<td>Fixed Parameter</td>
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<td></td>
</tr>
<tr>
<td>AADT</td>
<td>1.220</td>
<td>0.317</td>
<td>3.847</td>
<td>0.000</td>
</tr>
<tr>
<td>LW</td>
<td>-0.701</td>
<td>0.436</td>
<td>-1.609</td>
<td>0.108</td>
</tr>
<tr>
<td>LT</td>
<td>1.182</td>
<td>0.513</td>
<td>2.303</td>
<td>0.021</td>
</tr>
<tr>
<td>CLT</td>
<td>-1.544</td>
<td>1.186</td>
<td>-1.302</td>
<td>0.193</td>
</tr>
<tr>
<td>Alpha</td>
<td>1.525</td>
<td>0.260</td>
<td>5.872</td>
<td>0.000</td>
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</table>

### Table 5  Crash Reduction Factors for Lane Widening (total number of crashes)

<table>
<thead>
<tr>
<th>Lane Widening (m)</th>
<th>Rural two-lane highways</th>
<th>Urban two-lane highways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor (%)</td>
<td>Error (%)</td>
</tr>
<tr>
<td>0.25</td>
<td>11</td>
<td>5.6</td>
</tr>
<tr>
<td>0.50</td>
<td>20</td>
<td>10.0</td>
</tr>
<tr>
<td>0.75</td>
<td>29</td>
<td>13.4</td>
</tr>
<tr>
<td>1.00</td>
<td>36</td>
<td>16.0</td>
</tr>
</tbody>
</table>

### Table 6  Comparison of Results for Lane Widening

<table>
<thead>
<tr>
<th>State</th>
<th>Crash Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indiana</td>
<td>11 – 50(^{\dagger})</td>
</tr>
<tr>
<td>Kansas</td>
<td>38</td>
</tr>
<tr>
<td>California, New York</td>
<td>30</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: \(^{\dagger}\)Value depends on the lane widening and highway location
Table 7  Crash Reduction Factors for Installing Continuous Left-turn Lane  
(total number of crashes)

<table>
<thead>
<tr>
<th>Urban multilane highways</th>
<th>Urban two-lane highways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor (%)</td>
<td>Error (%)</td>
</tr>
<tr>
<td>90</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Table 8 Comparison of Crash Reduction Factors for Continuous Left-Turn Lane

<table>
<thead>
<tr>
<th>State</th>
<th>Crash Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indiana</td>
<td>79, 90(^1)</td>
</tr>
<tr>
<td>Kansas</td>
<td>30</td>
</tr>
<tr>
<td>Montana</td>
<td>35</td>
</tr>
</tbody>
</table>

Note: \(^1\)Value depends on the highway location