The Effects of Access Control on Safety on Urban Arterial Streets

by

Henry C. Brown
Graduate Research Assistant
(765) 494-2206
hbrown@ecn.purdue.edu

Andrzej P. Tarko
Assistant Professor
(765) 494-5027
tarko@ecn.purdue.edu

Purdue University
1284 Civil Engineering Building
West Lafayette, Indiana 47907
USA
Fax: (765) 496-1105

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ABSTRACT

Access control techniques are used to improve traffic performance and safety on highways. One important benefit of access control is improved safety. For a quantitative assessment of the benefits of access control on safety, impact models are needed to predict crash frequencies based on the geometric and access control characteristics of the segments.

The objective of the presented research was to develop regression models to predict crash frequencies on urban multi-lane arterial segments. In order to develop these models, data were collected regarding geometric and access control characteristics of the segments and the number of crashes on the segments by severity type.

Negative binomial regression models were developed to predict the total number of crashes, number of property-damage-only crashes, and number of fatal and injury crashes. The three models have a similar structure. The exposure-to-risk variables include segment length, number of years, and AADT. The significant factors include density of access points, proportion of signalized access points, presence of an outside shoulder, presence of a two-way left-turn lane, and presence of a median with no openings between signals. The results indicate that access control has a beneficial impact on safety.

KEY WORDS: access control, safety, multi-lane streets

ACKNOWLEDGMENTS

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INTRODUCTION

The functions of a highway system include providing motorists with mobility on highways and enabling access to surrounding lands. These two functions often conflict with each other. Because arterial streets can be designed to provide some levels of both accessibility and mobility, a variety of access control levels are possible. An arterial can be designed with infrequent access points and with other access control measures such as barrier medians to prevent left-turn and crossing maneuvers. An arterial can also be designed with a low level of access control with many commercial and residential driveways having direct access to the arterial.

In deciding what level of access control to implement, decision-makers need to consider the impacts of access control on traffic performance and safety. Improved safety is one important benefit of proper access management. A reduction in the number of individual access points or improvements to access points such as the addition of a two-way left-turn lane may help reduce the number of crashes on the arterial. In order to evaluate the possible benefits of access control, impact models to predict crashes based on road geometric and access control characteristics need to be developed. The presented research is a part of a project aimed at developing a procedure for evaluating alternative access control solutions on existing and new arterial streets for Indiana Department of Transportation (INDOT). The impact models, such as the one presented in this paper, are important components of the project.

Several previous studies have indicated that access control has a positive effect on safety. Lall et al. (1996), studying a 29-mile corridor of the Oregon Coast Highway 9 (US 101), found a relationship between access density and the number of accidents for both rural and urban locations. Gattis (1996), in a study of 3 segments in a small Oklahoma city, found that the segment with the highest access control had accident rates approximately 40 percent lower than the other two segments. Garber and White (1996), in a study of 30 sections in Virginia, found that ADT per lane, average speed, number of accesses, left-turn lane availability, average driveway spacing, and average difference in driveway spacing influenced the accident rate for urban principal arterials. Li et al. (1994), using a database of 163 sections of rural roads in British Columbia, studied the
effects of geometric characteristics and access control on accidents. They classified access points into four major categories: unsignalized public road intersection, business access, residential access, and roadside pullout. They found a correlation between access density and accidents for all four categories with public road intersection density having the greatest influence on accidents. The results of these studies indicate that access control can help reduce the number of crashes. However, crash models based on sections in Indiana are desirable since local factors can influence safety.

One common access control technique involves the use of medians to reduce the influence of left-turning vehicles on through vehicles. Some research has focused on the effects of various median treatments on safety. McCoy and Malone (1989) analyzed urban four-lane roadways in Nebraska to determine if the presence of left-turn lanes at signalized and uncontrolled approaches influenced crash rates. They found that the presence of left-turn lanes led to a reduction in rear-end, sideswipe, and left-turn accident rates for both signalized and uncontrolled approaches. However, they also found that left-turn lanes led to an increase in right-angle accidents for uncontrolled approaches on urban undivided roadways. Squires and Parsonson (1989), studying four-lane and six-lane roadways in Georgia, developed regression equations to predict accidents for raised median and two-way left-turn lane sections. They found that raised medians generally had lower accident rates than two-way left-turn lanes except in cases where left turns were concentrated in a few areas on the road segment. McCoy et al. (1988) found that the accident rate on sections with a two-way left-turn lane was 34 percent lower than that on four-lane undivided sections.

Some studies have been undertaken to investigate the impacts of access control on safety in Indiana. McGuirk (1973) studied a total of 100 segments from 10 cities in Indiana. He found that the total number of driveways per mile and the number of commercial driveways per mile influenced the number of driveway accidents per mile. He reported that driveway accidents represented approximately 14 percent of all accidents on the sections. Uckotter (1974) studied 14 urban arterial segments from 5 cities in Indiana. He found that the driveway accident rate increased as the average daily driveway volume and average daily roadway volume increased. He also reported that 33
percent of the accidents on these sections were driveway accidents. The results of these studies indicate some of the factors that may influence driveway accidents in Indiana. However, models are needed to predict all types of crashes that may occur on arterial segments. In addition, driving conditions and drivers’ behavior may have changed since these studies were undertaken.

In the most recent research by Eranky et al. (1997), crash reduction factors were developed for Indiana roads based on cross-sectional characteristics described in the Road Inventory Database. Separate negative binomial regression models were developed for rural two-lane, rural multi-lane, urban two-lane, and urban multi-lane highways. The model for urban multi-lane highways included the following variables: number of lanes, skid resistance factor, median width, median type-mountable, left-turn lane, presence of continuous left-turn lanes, outside shoulder width, inside shoulder width, and access control. A barrier type median was found to increase the number of accidents. The level of access control was described by a qualitative variable with three levels.

Based on the initial results of the study by Eranky et al. (1997), it was decided to further investigate the effects of access control on the number of accidents in Indiana. It was decided to incorporate variables such as the density of access points into a safety analysis. The results of this analysis allow for predicting crash frequencies on Indiana road segments from the geometric and access control characteristics.

DATA COLLECTION

In order to develop regression models, two types of data were needed: road segment data and crash data. The multi-lane road sections for analysis were selected in cooperation with INDOT to represent a wide array of geographic locations and levels of access control. Table 1 summarizes the sections used for analysis. These sections were subdivided into 155 segments that were homogeneous with respect to cross section and traffic volume.

A Road Inventory Database (RIDB) maintained by INDOT contains traffic and geometric data for the selected road segments. The RIDB classifies each segment based on access control into three qualitative levels. For the purpose of this study, more detailed
access control data regarding the number and type of access points were needed. These data were obtained from the INDOT videolog database. The segments were viewed on the videolog database to obtain data regarding access points and cross section.

The crash counts for the selected segments were obtained from the INDOT Crash Database. In order to obtain the crash data, a software package was developed because the method for coding crash location in the INDOT Crash Database is not compatible with the RIDB. The software extracts crashes for a given county and given year during each run. The output of the program includes the crash data for each segment and summary statistics regarding the number of crashes located and the number of crashes missed for various reasons. The crash data output includes a table containing the following information for each segment: total crashes, fatal crashes, injury crashes, property-damage-only (pdo) crashes, and number of crashes for which severity information is missing. The summary statistics for the program run include

- total number of crashes in Indiana for a given year,
- number of crashes in the county that was run,
- number of crashes that were missed for various reasons,
- number of crashes located near the segment endpoints, and
- number of crashes located on segments.

The information regarding the number of crashes with missing data was used to develop an adjustment factor to account for missing crashes.

The developed software was used to obtain the crash data for the segments in this study. In most cases, crash data for the five-year period from 1991 to 1995 were used. For a few segments that underwent improvements during the period from 1991 to 1995, crash data for three years were used to ensure that the segments had consistent cross-section characteristics.

**STATISTICAL MODELS**

Once the crash and segment data were collected, statistical models were developed to predict the number of total crashes, number of fatal and injury crashes, and
number of pdo crashes. A negative binomial regression model was used with the following form:

\[ Y = k \cdot LEN \cdot YRS \cdot AADT^\gamma \cdot \exp \left( \sum_i \beta_i \cdot X_i \right) \]  

where:
- \( Y \) = expected number of total, fatal/injury, or pdo crashes,
- \( k \) = intercept coefficient,
- \( LEN \) = length of the segment,
- \( YRS \) = number of years,
- \( AADT \) = Annual Average Daily Traffic,
- \( \gamma, \beta_i \) = model parameters,
- \( X_i \) = variables representing segment characteristics.

Many authors have successfully used the form of the model previously. Although the proportionality of crashes to the segment length and the number of years is obvious, it was tested. The hypothesis of proportionality for \( LEN \) and \( YRS \) has been confirmed. Also, \( AADT \) has appeared to influence \( Y \) in the proportional manner (\( \gamma = 1 \)).

The statistical analysis was done using LIMDEP v7.0. The following is a list of names of the variables that were investigated. A brief description and units are added where applicable:

- **CRASH**: Total number of crashes on the segment.
- **PDO**: Number of pdo crashes on the segment.
- **FATINJ**: Number of fatal and injury crashes on the segment.
- **LEN**: Length of the segment (km).
- **YRS**: Number of years.
- **AADT**: Annual Average Daily Traffic (thousands of vehicles/day).
- **ACCESS**: Access density (number of access points per km). An access point is defined as an intersection between arterial street and local street or driveway (commercial or residential). Such an intersection does not lead
to a substantial change in traffic volume and cross-section characteristics of the arterial.

**SHLDR**
Dummy variable to indicate presence of outside shoulder (1 if outside shoulder is present, 0 otherwise).

**SL**
Speed limit on the segment (km/hr).

**LANES**
Number of lanes on the segment.

**COMM**
Dummy variable to indicate segment in commercial area (1 if area type is commercial, 0 otherwise).

**PS**
Proportion of access points that are signalized.

**TWLTL**
Dummy variable to indicate presence of two-way left-turn lane on segment (1 if two-way left-turn lane is present, 0 otherwise).

**NOMED**
Dummy variable to indicate segment without median or two-way left-turn lane (1 if segment has no median, 0 otherwise).

**NOMEDO**
Dummy variable to indicate segment with median (excluding two-way left-turn lane) with no openings between signalized intersections (1 if segment has median with no openings between signals, 0 otherwise).

**PC**
Proportion of access points that are channelized.

**PR**
Proportion of access points with right-turn lane.

**LNLEN**
Natural logarithm of LEN.

**LNYRS**
Natural logarithm of YRS.

**LNAADT**
Natural logarithm of AADT.

The AADT data were obtained from the RIDB. The segment lengths were calculated from the RIDB using a spreadsheet macro developed by Eranky et al. (1997). The segment lengths as calculated by the macro were adjusted by subtracting approximately 60 m because crashes near the segment endpoints were arbitrarily excluded from the analysis as being associated with intersections or changes in cross section. The natural logarithms of LEN, YRS, and AADT were used as input to LIMDEP v7.0 to transform the model to the form of Equation 1.
The access density was calculated as the total number of access points divided by
the segment length. The total number of access points includes both signalized and
unsignalized access points. Since side streets or driveways may access the arterial at a
given location from one side or from both sides, the question has arisen whether one-
sided and two-sided access points should be treated alike. After several trials, the
following manner of counting access points has been applied as providing the most
effective prediction of crashes. For unsignalized intersections, a T-intersection (one-sided
access point) was considered as one access point, while a four-leg intersection (two-sided
access point) was considered as two access points. Signalized intersections were
considered as two access points regardless of the number of legs, probably because
signals stop traffic in either direction on the segment. Access points within 30 m of the
segment endpoints were not considered.

The proportion of signalized access points was calculated as the number of
signalized access points divided by the total number of access points. The proportion of
channelized access points was calculated as the number of channelized access points
divided by the total number of access points. The proportion of access points with a right-
turn lane was calculated as the number of access points with a right-turn lane divided by
the total number of access points. These proportion values were defined to be zero for a
segment with no access points.

Separate models were developed using stepwise regression to predict the total
number of crashes, number of pdo crashes, and number of fatal/injury crashes. A
significance level of 0.10 was used. Tables 2 to 4 provide a summary of the regression
output. Residual plots for the three models are given in Figures 1 to 3. The residual plots
indicate that the variance appears to be increasing as the predicted values increase.

The goodness of the models is measured with the standard error $e$ of expected
count estimate $Y$. The variance of expected count estimate $Y$ is the variance of crash
counts at $Y$ reduced by the Poisson variance. In the Negative Binomial this variance is
equal $\alpha \cdot Y^2$, where $\alpha$ is the overdispersion estimated in the model calibration. Thus, the
estimation error of $Y$ is:

$$e = \alpha^{1/2} Y,$$  \hspace{1cm} (2)
where \( Y \) is the expected crash count calculated with Equation (2).

The relative error of estimation expressed in percents is \( 100\alpha^{1/2} \). The relative error of estimation for the developed models varies between 102\% and 107\% depending on the model. Although the estimation error seems to be rather large, the \( R^2 \) value slightly below 0.5 indicates that the model goodness is comparable to the results obtained is similar studies. The unexplained portion of the sample variance is attributed to the safety factors not included into the models. It should be noted that the missing factors not necessary must be related to access control.

Adjusting the models to account for missing crashes was the last step of models development. The models summary statistics generated from the crash extraction software were used to determine the proportion of missing crashes. Crashes could be missed for several reasons. First, a crash record may contain missing pseudo numbers, distance, or direction. Crashes may also be missed if the pseudo number pair in the crash record corresponds to more than one physical location in the County File. Finally, the crash direction or distance may be coded incorrectly. It was assumed that the loss of a given crash under given circumstances could happen to any crash in the Crash Database with the same likelihood. Thus, a single adjustment factor was developed to account for missing crashes. The adjustment factor was determined based on the 12 counties in this study and 5 years of crash data. Table 5 summarizes the proportion of crashes lost. Based on these results, an adjustment factor of 1.61 = \( 1/((1-0.311) \times (1-0.083) \times (1-0.018)) \) was applied to account for missing crashes.

The final equations after adjustment for missing crashes are as follows:

\[
CRASH = 0.494 \cdot LEN \cdot YRS \cdot AADT \cdot \exp(0.0285 \cdot ACCESS - 0.631 \cdot SHLDR + 2.520 \cdot PS - 0.748 \cdot TWLTL - 0.604 \cdot NOMEDO) \quad (3)
\]

\[
PDO = 0.374 \cdot LEN \cdot YRS \cdot AADT \cdot \exp(0.0261 \cdot ACCESS - 0.669 \cdot SHLDR + 2.627 \cdot PS - 0.686 \cdot TWLTL - 0.684 \cdot NOMEDO) \quad (4)
\]
Equations (3), (4), and (5) can be used to predict the expected number of crashes on new and existing arterial streets. The access density must be calculated in the same way as for the model calibration. The length of the segment may include intersections with local streets only. Intersections with streets more important than local ones (collectors and arterial streets) determine the ends of the analyzed segment. The segments should be homogeneous in regard to the traffic volumes and level of access control.

The use of the equations requires caution. The equations can be used to compare safety of various design alternatives involving different levels of access control. The alternatives must first be developed in accordance with the design rules, traffic management principles, and local policy, then evaluated. The equations cannot be considered in this process with the violation of the design rules. For example, it would be inappropriate to neglect the need for traffic signals where they are warranted in order to obtain a lower estimate of number of crashes.

**DISCUSSION OF RESULTS**

The three final models have the same structure and contain the following variables: ACCESS, SHLDR, PS, TWLTL, NOMEDO. Based on the model results, the power value $\gamma$ associated with AADT does not appear to differ significantly from one. It was decided to fix this parameter at one, which means that the crash frequencies are proportional to traffic volume. Models with unrestricted coefficients for LEN and YRS were also tested; these coefficients do not appear to differ significantly from one.

The coefficient of ACCESS is positive, indicating that segments with more frequent access points experience more crashes. This result is expected since the introduction of more access points creates more conflict points.

The coefficient of SHLDR is negative, indicating that the presence of an outside shoulder leads to a reduction in crashes. An outside shoulder may increase drivers’ comfort by increasing the traveled way width. In addition, the introduction of an outside shoulder...
shoulder may lead to longer turning radii and thus eases the ingress of vehicles onto the arterial street.

The coefficient of $PS$ is positive, indicating that the presence of signals can lead to higher crash rates. This result may be due to the higher likelihood of rear-end collisions when vehicles are stopped at signals. The presence of a two-way left-turn lane leads to a reduction in crashes by separating through vehicles from stopped left-turning vehicles.

The presence of a median with no openings between signalized intersections also leads to a reduction in crashes. In this case, there are no left-turn or crossing maneuvers permitted at unsignalized access points. It should be noted that the analysis has not detected any significant difference in safety between the urban highways with and without median if the median has openings at intersections. This finding has been confirmed with another ongoing study for Indiana (results are not published yet).

The variables $PC$ and $PR$ were tested to determine if the type of access point had an impact on crashes. The variables $PC$ and $PR$ were individually significant but were not significant when both were introduced into the model simultaneously. In addition, the signs of the coefficients for $PC$ and $PR$ were positive. This result indicates that the presence of high-type access points is associated with higher frequencies of crashes. This result contradicts the expectations and requires careful consideration. Channelization and right-turn lanes are more likely to be installed at high-volume access points. When $PC$ and $PR$ are large, the proportion of high-volume access points would also typically be large. More crashes would be expected due to high-volume access points than low-volume access points. Thus, the variables $PC$ and $PR$ substitute for traffic volume from cross streets – the variable not incorporated into the model due to the lack of data. Thus, the model results for $PC$ and $PR$ seem to indicate the effect of high-volume access points. It was decided not to incorporate the two variables into the models.
For the illustration purpose, the developed models have been used to investigate the effect of access density in two extreme cases:

(a) Suburban arterial streets with shoulders and access onto arterial facilitated only through unsignalized right turns,

(b) Urban arterial streets without turning restrictions and with some access points signalized (typical proportion of 8% was assumed).

The safety effect is measured with the number of reported crashes per million kilometers traveled and with the proportion of crashes that involve injuries or fatalities.

The increasing trends in the crash frequency are observed (Figure 4). Ten additional access points are associated with the 32-percent increase in the number of crashes. Further, the crash ratio for urban streets is over four times higher than for the suburban streets. This should be expected given the restrictions on turning movements, presence of shoulders, and the absence of signals at minor intersections.

The percentage of injury and fatality crashes increases with the increase in the access density (Figure 5). The effect of access control on crash severity is weaker than on the crash frequency. Thirty two percent of crashes reported on suburban streets with full access control involve injury or death. Allowing 50 access points with right turns increases this proportion to nearly 40%. The urban streets with no access points experience one injury/fatal crash per four reported crashes. The urban sections with 50 access points with unrestricted movements and some traffic signals experience 31% injury/fatal crashes. The difference in the crashes’ severity between the suburban and urban streets can be attributed to the generally lower speeds on urban streets.

**CONCLUSIONS**

Models were developed in this study to predict crash rates on multi-lane arterial segments based on geometric and access control characteristics. The models for total number of crashes, property-damage-only crashes, and fatal/injury crashes all have the same structure. The exposure-to-risk variables include segment length, AADT, and number of years. The significant factors include access density, proportion of signalized access points, presence of an outside shoulder, presence of a two-way left-turn lane, and
presence of a median with no openings between signalized intersections. The number of crashes increases as the access density and proportion of signalized access points increase. An outside shoulder, two-way left-turn lane, or median without openings between signals leads to a reduction in the number of crashes. These models can be used to estimate crash rates on multi-lane arterial segments between intersections. The results of the statistical analyses indicate that access control has a beneficial impact on safety.

REFERENCES


Table 1 List of sections used in safety analysis

<table>
<thead>
<tr>
<th>County</th>
<th>Route</th>
<th>Section</th>
</tr>
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<tbody>
<tr>
<td>Allen</td>
<td>Old US 24/30</td>
<td>Goshen Av. to Anthony Blvd.</td>
</tr>
<tr>
<td>Bartholomew</td>
<td>SR 46</td>
<td>I-65 to SR 11</td>
</tr>
<tr>
<td>Clark</td>
<td>SR 131</td>
<td>SR 62 to I-65</td>
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<tr>
<td>Clark</td>
<td>SR 62</td>
<td>Conrail #308 to Springdale Dr.</td>
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<td>Howard</td>
<td>US 31</td>
<td>Alto Rd. to Sycamore St.</td>
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<tr>
<td>Jefferson</td>
<td>SR 62</td>
<td>SR 7 to US 421</td>
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<td>Lake</td>
<td>US 30</td>
<td>SR 55 to SR 53</td>
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<tr>
<td>Lake</td>
<td>US 30</td>
<td>Mississippi St. to SR 51</td>
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<td>Lake</td>
<td>US 41</td>
<td>US 30 to I-80</td>
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<td>SR 236 to SR 32</td>
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<td>SR 135</td>
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<td>Marion</td>
<td>SR 37</td>
<td>US 31 to Fall Creek Pkwy.</td>
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<td>US 31</td>
<td>Kessler Blvd. To 86th St.</td>
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<td>County Line Rd. to Thompson Rd.</td>
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<td>US 36</td>
<td>Raceway Rd. to High School Rd.</td>
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<td>US 40</td>
<td>I-465 to German Church Rd.</td>
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<td>St. Joseph</td>
<td>US 33</td>
<td>I/80-90 connector to Glendale Av.</td>
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<td>Tippecanoe</td>
<td>SR 26</td>
<td>US 52 to I-65</td>
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<td>SR 66</td>
<td>US 41 to I-164</td>
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<tr>
<td>Vigo</td>
<td>US 41</td>
<td>I-70 to US 40</td>
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Table 2 Summary of regression output for total number of crashes

| Variable | Coefficient | Standard Error | b/St.Er. | P[|Z|>z] | Mean of X |
|----------|-------------|----------------|----------|---------|-----------|
| Constant | -1.182      | 0.298          | -3.972   | 0.0001  |           |
| LNLEN    | 1           | (Fixed Parameter) | -0.538   |          | -0.538    |
| LNYRS    | 1           | (Fixed Parameter) | 1.583    |          | 1.583     |
| LNAADT   | 1           | (Fixed Parameter) | 3.431    |          | 3.431     |
| ACCESS   | 0.0285      | 0.00843        | 3.379    | 0.0007  | 22.644    |
| SHLDR    | -0.631      | 0.257          | -2.455   | 0.0141  | 0.481     |
| PS       | 2.520       | 0.913          | 2.761    | 0.0058  | 0.0804    |
| TWLTL    | -0.748      | 0.343          | -2.179   | 0.0293  | 0.150     |
| NOMEDO   | -0.604      | 0.228          | -2.649   | 0.0081  | 0.293     |

Overdispersion parameter for negative binomial model

Alpha 1.147 0.131 8.780 0.0000

Table 3 Summary of regression output for property-damage-only crashes

| Variable | Coefficient | Standard Error | b/St.Er. | P[|Z|>z] | Mean of X |
|----------|-------------|----------------|----------|---------|-----------|
| Constant | -1.459      | 0.277          | -5.272   | 0.0000  |           |
| LNLEN    | 1           | (Fixed Parameter) | -0.538   |          | -0.538    |
| LNYRS    | 1           | (Fixed Parameter) | 1.583    |          | 1.583     |
| LNAADT   | 1           | (Fixed Parameter) | 3.431    |          | 3.431     |
| ACCESS   | 0.0261      | 0.00814        | 3.210    | 0.0013  | 22.644    |
| SHLDR    | -0.669      | 0.250          | -2.680   | 0.0074  | 0.481     |
| PS       | 2.627       | 0.861          | 3.050    | 0.0023  | 0.0804    |
| TWLTL    | -0.686      | 0.321          | -2.134   | 0.0329  | 0.150     |
| NOMEDO   | -0.684      | 0.212          | -3.234   | 0.0012  | 0.293     |

Overdispersion parameter for negative binomial model

Alpha 1.105 0.134 8.260 0.0000
Table 4 Summary of regression output for fatal/injury crashes

| Variable  | Coefficient | Standard Error | b/St.Er. | P[|Z|>z] | Mean of X |
|-----------|-------------|----------------|----------|---------|-----------|
| Constant  | -2.540      | 0.312          | -8.141   | 0.0000  |           |
| LNLEN     | -0.538      |                |          |         | -0.538    |
| LNYRS     | 1.583       |                |          |         | 1.583     |
| LNAADT    | 3.431       |                |          |         | 3.431     |
| ACCESS    | 0.0325      | 0.00779        | 4.166    | 0.0000  | 22.644    |
| SHLDR     | -0.525      | 0.252          | -2.081   | 0.0374  | 0.481     |
| PS        | 2.280       | 0.870          | 2.620    | 0.0088  | 0.0804    |
| TWLTL     | -0.865      | 0.356          | -2.432   | 0.0150  | 0.150     |
| NOMEDO    | -0.493      | 0.252          | -1.956   | 0.0505  | 0.293     |

Overdispersion parameter for negative binomial model
Alpha 1.041 0.138 7.540 0.0000

Table 5 Percent of crashes lost

<table>
<thead>
<tr>
<th>Reason for missing crashes</th>
<th>Percent missed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing data</td>
<td>31.1</td>
</tr>
<tr>
<td>Multiple locations</td>
<td>8.3</td>
</tr>
<tr>
<td>Incorrect distance or direction</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Figure 1 Residual plot for dependent variable CRASH

Figure 2 Residual plot for dependent variable PDO
Figure 3 Residual plot for dependent variable FATINJ

Figure 4 Effect of access density on crash frequency
Figure 5  Effect of access density on crash severity