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Crash Causal Factors and Countermeasures for High-Risk Locations on Multilane Primary Highways in Virginia

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16. Abstract:

In 2004, a total of 95,020 vehicle crashes occurred on highways under the jurisdiction of the Virginia Department of Transportation (VDOT). Of these, 39,847 crashes occurred on primary highways, and 345 of these were fatal crashes. VDOT's traffic engineers continue to place increasing emphasis on identifying causal factors for crashes to enhance the selection of appropriate and effective countermeasures. The purpose of this study was to identify causal factors and appropriate countermeasures for crashes occurring at high-risk locations on multilane primary highways from 2001 through 2006. These high-risk locations were identified by Fontaine and Reed (2006) in a VDOT safety corridor study.

A total of 365 sites, 1 to 2 mi in length, were used in the study. The statewide sites were located on rural and urban highways with divided, undivided, and traversable medians, with about 40 sites per VDOT district. Crash data were extracted from police crash reports, and geometric data were collected through site visits. Operational data were collected using VDOT's resources.

The analysis involved more than 34,000 crashes and was conducted using fault tree analysis and generalized linear modeling. The fault tree analysis was used to determine the critical fault path based on the probability of an event occurring. Individual fault trees were constructed for each collision type and for each highway classification. The generalized linear models were developed for different highway classifications: urban divided, urban undivided, urban traversable (central lanes that can be used for left turns in both directions), and rural divided highways. Models were developed for rear-end crashes and total crashes, and separate models were developed for injury crashes, property damage only (PDO) crashes, and injury + PDO crashes. Appropriate potential countermeasures were then identified based on the significant causal factors identified in the models.

The results indicated that rear-end crashes were the predominant type of crash, representing 56% of all PDO crashes on urban divided highways and 37% of all PDO crashes on rural divided highways. Implementing the recommended countermeasures for total, rear-end, and angle crashes for different assumed levels of rehabilitation is expected to result in a crash reduction of up to about 40% depending on the site and level of rehabilitation undertaken. A benefit/cost analysis showed that the benefit/cost ratios were higher than 1 for all levels of countermeasure implementation.

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FINAL REPORT

CRASH CAUSAL FACTORS AND COUNTERMEASURES FOR HIGH-RISK LOCATIONS ON MULTILANE PRIMARY HIGHWAYS IN VIRGINIA

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ABSTRACT

In 2004, a total of 95,020 vehicle crashes occurred on highways under the jurisdiction of the Virginia Department of Transportation (VDOT). Of these, 39,847 crashes occurred on primary highways, and 345 of these were fatal crashes. VDOT's traffic engineers continue to place increasing emphasis on identifying causal factors for crashes to enhance the selection of appropriate and effective countermeasures. The purpose of this study was to identify causal factors and appropriate countermeasures for crashes occurring at high-risk locations on multilane primary highways from 2001 through 2006. These high-risk locations were identified by Fontaine and Reed (2006) in a VDOT safety corridor study.

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The analysis involved more than 34,000 crashes and was conducted using fault tree analysis and generalized linear modeling. The fault tree analysis was used to determine the critical fault path based on the probability of an event occurring. Individual fault trees were constructed for each collision type and for each highway classification. The generalized linear models were developed for different highway classifications: urban divided, urban undivided, urban traversable (central lanes that can be used for left turns in both directions), and rural divided highways. Models were developed for rear-end crashes and total crashes, and separate models were developed for injury crashes, property damage only (PDO) crashes, and injury + PDO crashes. Appropriate potential countermeasures were then identified based on the significant causal factors identified in the models.

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INTRODUCTION

The current safety goal for Virginia is to reduce the annual number of injuries and deaths attributable to motor vehicle crashes by 100 deaths and 4,000 injuries from the 2005 levels by the year 2010 (Virginia's Surface Transportation Safety Executive Committee, 2006). Thus, the emphasis placed on identifying causal factors for crashes on all types of highways is increasing every year, as the identification of suitable countermeasures for different types of crashes will enhance the achievement of Virginia's safety goal.

In 2006, there was a total of 151,692 crashes in Virginia, including 865 fatal crashes and 52,083 injury crashes. Included in these were 39,646 that occurred on primary highways, of which 356 were fatal crashes and 14,272 were injury crashes (Virginia Department of Transportation [VDOT], 2007). Figures 1 and 2 show that over the past several years (2001 through 2006), neither injury nor fatal crash rates for multilane primary highways have decreased significantly. Crash rates were calculated as the number of crashes per million vehicle miles traveled (VMT). Although multilane primary highways with four or more lanes comprise 3,514 centerline miles, and two-lane primary highways comprise 5,912 centerline miles, in 2006, there were 25,312 total crashes on the multilane highways and 11,594 total crashes on the two-lane highways. These figures indicate that to improve overall safety on Virginia's highways, the causal factors for crashes on two-lane and multilane primary highways should be identified.

Crash causal factors were identified for two-lane primary roads in a recent study by Garber and Kassebaum (2008). A similar study for multilane primary roads is needed so that plans can be developed for implementing feasible countermeasures for Virginia's two-lane and multilane primary roads. This will enhance the achievement of Virginia's safety goals.

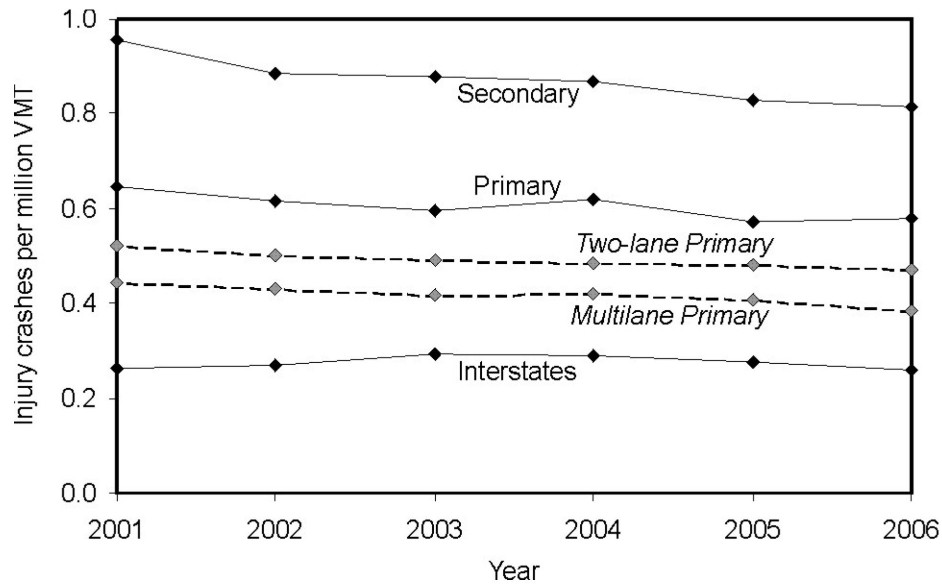

Figure 1. Injury Crash Rates for Virginia Highways (2001-2006). Crash rates were calculated as the number of crashes per million vehicle miles traveled (VMT).

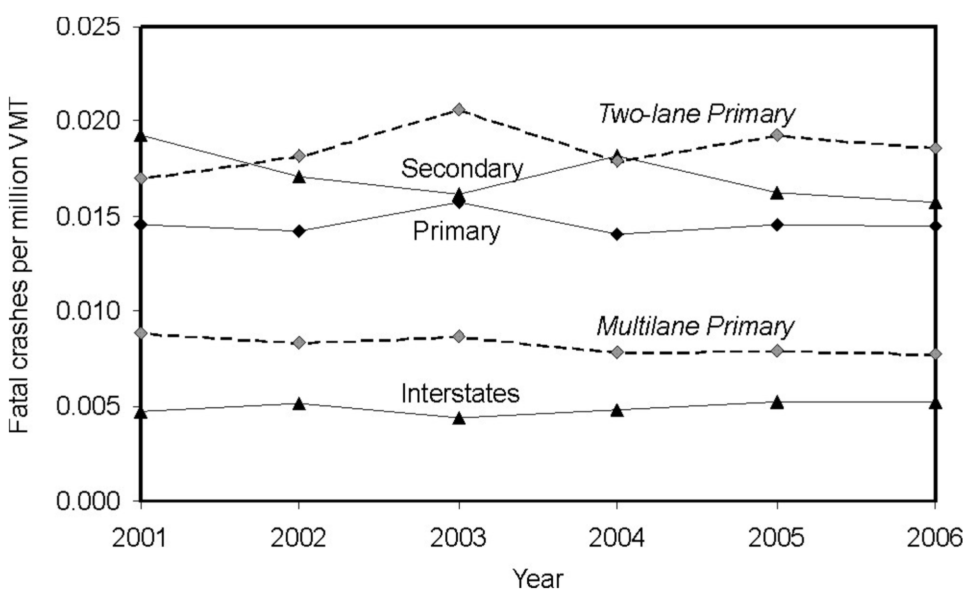

Figure 2. Fatal Crash Rates for Virginia Highways (2001-2006). Crash rates were calculated as the number of crashes per million vehicle miles traveled (VMT).

PURPOSE AND SCOPE

The purpose of this study was to identify causal factors and appropriate countermeasures for crashes occurring from 2001 through 2006 at the sites on multilane primary highways that were identified as high-risk locations in a VDOT safety corridor study (Fontaine and Read, 2006).

The specific objectives of the study were (1) to develop appropriate models relating crashes to the causal factors identified and (2) to determine appropriate countermeasures.

The scope of this study was limited to the sites identified.

METHODS

The following tasks were conducted to achieve the study objectives:

1. literature review
2. selection of study sites
3. collection of crash data
4. collection of operational and geometric data
5. analysis of crash data
6. analysis of operational and geometric data
7. fault tree analysis
8. generalized linear modeling.

Literature Review

The literature review focused on roadway environmental factors. Recent publications and studies on multilane crashes were identified using the Transportation Research Information Service (TRIS), the VDOT Research Library, libraries at the University of Virginia, and Internet search engines. The materials identified were critically reviewed and summarized to identify results relevant to this study.

Site Selection

The starting point for selecting the study sites was the set of high-crash corridors identified by Fontaine and Read (2006) in their VDOT safety corridor study. Fontaine and Read used crash data for the years 2001 through 2003 to identify all roadway segments on Virginia's primary and interstate highways with a high crash rate. For the current study, in order to obtain a manageable number of sites, the identified sites were reduced by discarding those with fewer than 25 crashes over the study period. The sites selected were then separated by VDOT district. A random selection process was then used for each of the nine districts to select approximately 60 sites per district for the study. Sixty sites for each district were deemed adequate to account for the probability that some selected sites would be discarded because of a lack of accurate data.

A total of 365 sites were used for the study, with about 40 sites on average per district. The lengths of the sites ranged from 1 to 2 mi, with sites located on rural, urban, divided, undivided, and traversable median highways. By using the selected high-crash locations as the study sites, the study enhanced identification of the major causal factors of crashes on multilane primary highways in Virginia. Table A-1 of Appendix A lists the sites used for the study.

Collection of Crash Data

Crash data for each site were extracted from VDOT's crash database for the years 2001 through 2006. A 2-mi segment of the site was used for the extraction of the crash data to take account of the varying site lengths; this included up to 0.5 mi on each side of the designated start and end mile markers for each site. Thus, the length of each site used in the study was 2 mi. Crashes occurring within 150 ft of a signalized intersection were excluded from the study because of the differing characteristics of signalized intersection crashes and highway segment crashes. The signalized intersections were identified during the field data collection process. Crashes at unsignalized intersections were included in the analysis, and the impact of these intersections is reflected in the number of cross routes per mile used as an independent variable in the generalized linear models (GLMs).

The database for the study was compiled from police crash reports (FR 300s), which include the officer's indication of the driver's actions and maneuvers leading to each crash, severity, number of vehicles involved, collision type, day and time, and environmental conditions at the time of the crash. Other information obtained consisted of the gender and age of the driver, lighting conditions, and the major factors contributing to the occurrence of the crash. The crash data were extracted by executing a query in VDOT's crash database that specified the route location (construction district, county, and mile marker) and inventory information (functional class, number of lanes, etc.) desired. Each crash was given a document and a node (plus offset) number, which is an identification number used to designate a specific intersection and to determine the corresponding route mile marker.

Collection of Operational and Geometric Data

For each site identified, operational and geometric data were collected, including average annual daily traffic (AADT), speed, truck percentage, speed limit, median type, cross-route density, driveway density, median crossover density, commercial entrance density, signal density, ramp density, shoulder width, lane width, school zones, curb and gutter, turn lanes, latitude and longitude, elevation, and number of advisory signs.

AADT and truck percentage data were extracted from VDOT 2006 traffic data. To account for traffic traveling in each direction, the available AADT for each site was divided by 2 because directional AADT was not available for primary roads. The directional data were needed for divided highways as the crashes for these highways were considered separately for each direction. The truck percentage recorded included all vehicles that were not categorized as a passenger vehicle. The traffic data identified several categories of trucks, but for this study, they were considered as one category.

Continuous speed data were obtained from continuous count station data maintained by VDOT's Traffic Engineering Division. Individual spot speed data were obtained from spot speed studies conducted by the districts and maintained in the individual residency offices. For the continuous speed data, 1 month of data from each season of the most recent year was extracted to account for peak travel time and to give an average value for an entire year. The

85th percentile speed was computed for each site and used as the operational speed. Spot speed samples from each district were requested for the study sites for which continuous count data were not available. The spot speed samples were collected by pneumatic road tubes, usually for multiple days but for at least a 24-hr period. These were also used to compute the 85th percentile speeds.

All geometric data were collected by the research team by driving through each site during the summer of 2007. A global positioning system (GPS) was used to collect the latitude, longitude, and elevation along the length of each site. Each geometric feature along with its distance from the beginning of the site was recorded.

Analysis of Crash Data

The sites were first categorized into the six major highway classifications using the functional classification system:

1. urban divided
2. urban undivided
3. urban traversable
4. rural divided
5. rural undivided
6. rural traversable.

Dividing the sites into these six categories enabled a comparison of crashes while controlling for common, yet unobserved, characteristics of similar highways.

Then the severity of the crashes was identified. For this study, the researchers used two severity categories:

1. property damage only (PDO)
2. injury + fatal crashes.

The injury and fatal crashes were grouped into one category because of the low number of fatal crashes and for consistency with the goals of Virginia's strategic highway safety plan (Virginia's Surface Transportation Safety Executive Committee, 2006).

The next crash characteristic of most interest to the study was collision type, as the causal factor of a crash may be dependent on collision type. For this study, five major collision types were used:

1. angle
2. rear end
3. sideswipe same direction
4. fixed object off road
5. others.

The category of "others" comprised all other crash types that occurred but not as frequently as the first four categories. These crashes consisted of run-off-the-road, sideswipe opposite direction, pedestrian, and animal crashes.

From the crash reports, the weather, lighting, day of week, vehicle type, driver gender, driver age, driver action, and vehicle maneuver were extracted. Each crash characteristic was divided into categories for statistical analysis.

Weather was divided into three categories:

1. dry
2. wet (rain, snow, sleet)
3. fog (mist or smoke).

Lighting was divided into four categories:

1. day
2. night
3. dawn
4. dusk.

Day of week was divided into two categories:

1. weekdays (Tuesday–Thursday)
2. weekend (Friday–Monday).

Driver age was divided into four categories:

1. young (<25)
2. young middle age (25–40)
3. old middle age (41–55)
4. elder (>55).

Vehicle maneuver and driver action were divided into 9 and 15 categories, respectively, as shown in Tables 1 and 2. The reason for the large number of categories was the large number of codes for each vehicle maneuver and driver action.

Table 1. Vehicle Maneuver Categories

New Code	Crash Report Code	Vehicular Maneuver
1	1	Going straight ahead
2	2,3,4	Right, left, and U-turns
3	5	Slowing or stopping
4	6,7	Starting from parked or traffic lane
5	8	Stopped in traffic lane
6	9	Ran off road (right)
7	10	Ran off road (left)
8	13,14	Passing, changing lanes
9	11,12,15,16	Other

Table 2. Driver Action Categories

New Code	Crash Report Code	Driver Action(s)
1	7,13,18,19,24,25,26,27,28,29,30,33,35, 36,37,38,39	Other
2	1	None
3	2	Exceeded speed limit
4	3	Exceeded safe speed but not speed limit
5	4,5,6	Overtaking on hill, curve, or intersection
6	8,9,10,41,42	Cutting in, improper passing, improper or unsafe lane change, wrong side of road
7	11	Did not have right of way
8	12	Following too close
9	14,15,16,17	Improper turning
10	20,21,22	Disregarded officer, stoplight, or stop sign
11	23	Driver inattention
12	31	Avoiding other vehicle
13	32	Avoiding animal
14	34	Hit and run
15	40,43	Failure to maintain control, overcorrection

Analysis of Geometric and Operational Data

The major geometric features considered in this study were related to rural and urban highway characteristics and median type. The majority of the sites were on rural and urban divided highways. Of a total of 365 sites analyzed, 154 were on rural divided highways, 149 on urban divided highways, 28 on urban undivided highways, 20 on urban traversable segments, 12 on rural traversable segments, and 2 on rural undivided highways.

The geometric data were analyzed by separating the data into individual categories. The existence of geometric features such as curb and gutter, curves with chevrons, and school zones were recorded as "yes" or "no" categories. Other characteristics such as commercial entrances, driveways, median crossovers, cross routes, advisory signs, turn lanes, signals, ramps, AADT, operational speed, and truck percentage were separated into three to five categories. For example, based on the distribution of crashes using histograms, AADTs were divided into four categories, as shown in Table 3, for the fault tree analysis, but actual values were used in developing the GLMs, and commercial entrances were divided into five categories based on the number per mile, as shown in Table 4. The tables for the other geometric characteristics are provided in Appendix B.

Based on field observations while operational data were being collected, it was observed that geometric characteristics such as horizontal curves, vertical curves, and grades did not vary

Table 3. Average Annual Daily Traffic (AADT) Categories

Code	AADT
1	0-5,000
2	5,001-9,500
3	9,501-13,000
4	>13,000

Table 4. Commercial Entrance Categories

Code	No. of Commercial Entrances/Mi
1	0
2	1-3
3	4-7
4	8-12
5	>12

greatly within any site and, therefore, had no influence on the operational characteristics of the site; thus, they were not included in the study. This was due to the similar alignment of the highway segments used in each classification.

Fault Tree Analysis

A fault tree analysis is a hierarchical model used to analyze risk. It provides a graphical representation of component failures and describes all interactions of the components. All events throughout a fault tree are determined by some combination of basic events. The top event, also known as the root of the tree, is the event that represents the most general statement of risk. For this study, the top event was the occurrence of a crash. A fault tree analysis allows an understanding about the nature of crashes through the identification of potential failures, the quantification of those failures, the identification of cause and effect relationships, and informed judgment about how, why, and with what frequency the systems fail (Garber and Joshua, 1990).

The symbols used in a fault tree analysis are shown in Figure 3. They represent the events and logic gates used in that they describe the possible outcomes of the top event. Two types of logic gates are used in a fault tree analysis: the "And" gate is a logical operation that requires all input events to be true in order to produce the top event; the "Or" gate allows for the situation where the top event is true if one or more of the basic events are true. Since this study sought to identify any variables that influenced the occurrence of crashes, Or gates were primarily used in a fault tree construction. A binary event is a basic variable for the fault tree. A collapsed symbol indicates that the tree is collapsed and could be continued, as shown in Figure 4.

A fault tree allows the researcher to determine the minimum cut set, which is the shortest chain of events that leads to a failure. Therefore, the minimum cut set would provide the sequence of variables that is most likely to lead to a crash. The researchers used the fault tree analysis to determine the probability of the existence of a sequence of factors leading to a specific crash type. By determining these probabilities for different crash types, the most probable associated causal factors that led to a specific crash type could be identified. These associated causal factors were used to develop the GLMs for that crash type.

Figure 3. Symbols Used in Fault Tree Analysis

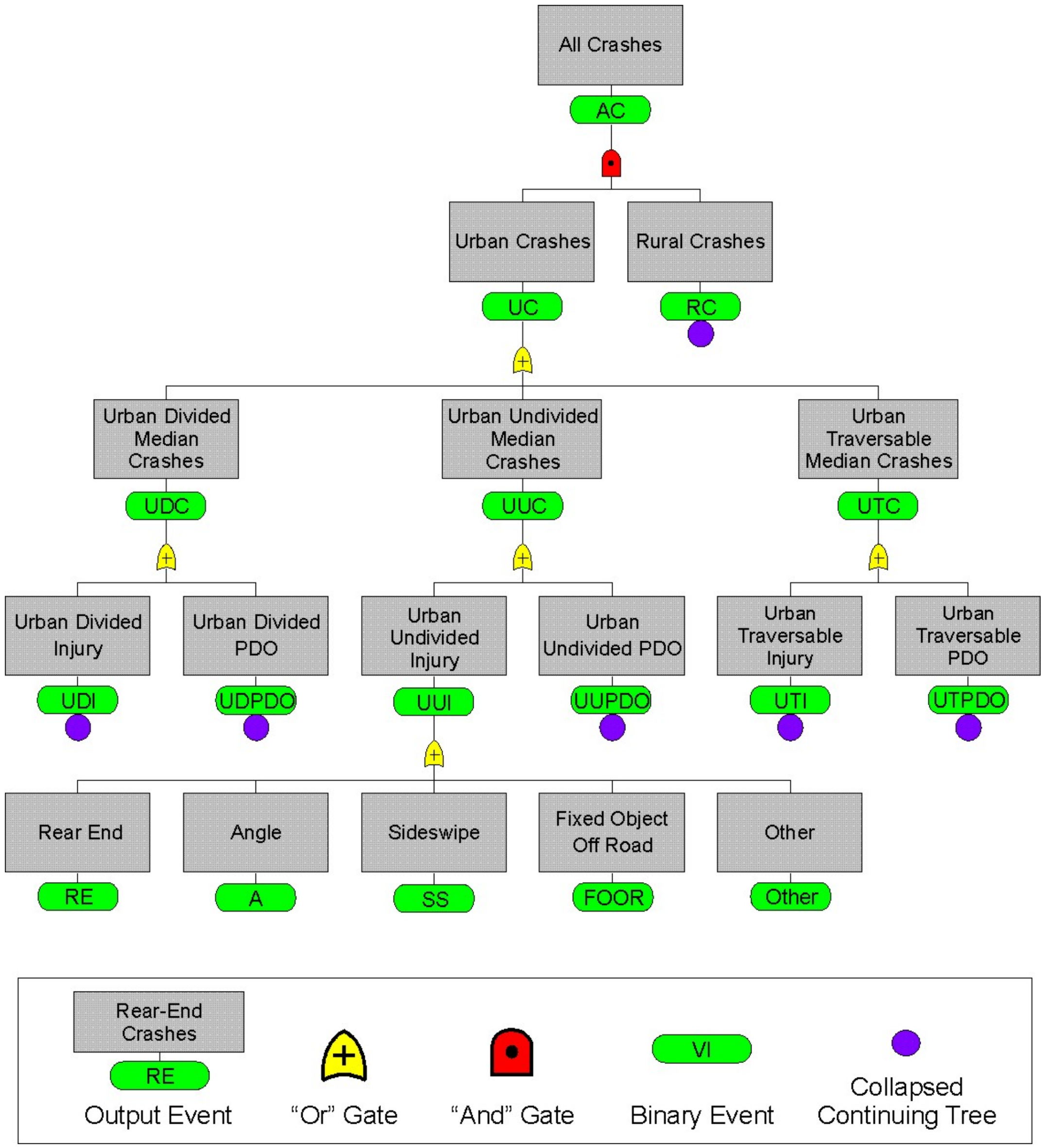

Figure 4. General Fault Tree. PDO = property damage only.

In developing the fault tree, a top event is first designated, then subevents are determined. Each variable was divided into categories for analysis. This process allowed the researchers to determine how the variation in a variable affected crash occurrence. In many cases, the categories were self-evident, such as whether passing was allowed or not. Other variables including AADT and lane width were more challenging to classify. For these variables, a histogram was used to determine the distributions of the values. The researchers used these to determine appropriate categories for each variable. The variables and number of categories used for the fault tree analysis are shown in Table 5. The top event for the fault tree was "All Crashes," and the subevents were "Rural" and "Urban" locations. The subevents from these nodes were the median types "Divided Median," "Undivided Median," and "Traversable Median." The subevents for the median types were "Injury/Fatal Crashes" and "Property Damage Only Crashes (PDO)." Subsequent events were the collision types and crash characteristics.

Table 5. Fault Tree Variables

Variable	Unit	Category Ranges 1	2	3	4	5
Rural/Urban		Rural	Urban			
Weather[1]		1	2 - 4, 8	5-7		
Lighting[2]		1 or 3	2	4		
Day of Week		T-TH	F-M			
Driver Age		<25	25-40	>40-55	>55	
Driver Sex		Male	Female			
Driver Action		See Table 2				
Speed Limit	mph	<45	45	55	>55	
Median Type		Divided	Undivided	Traversable		
Curb and Gutter		Yes	No			
Shoulder Width	ft	0	1-3	>3-6	>6	
No. of Cross Routes	No./mi	0	1-2	3-5	>5	
No. of Signals	No./mi	0	1-2	3-5	>5	
No. of Commercial Entrances	No./mi	0	1-3	4-7	8-12	>12
No. of Driveways	No./mi	0	1-3	4-7	8-12	>12
No. of Crossovers	No./mi	0	1-2	3-5	>5	
Advisory Signs	No./mi	0	1-4	5-8	>8	
Curves with Chevrons		Yes	No			
School Zone		Yes	No			
Right Turn Lanes at U signalized Intersections	No./mi	0	1-2	3-5	>5	
Left Turn Lanes	No./mi	0	1-2	3-5	>5	
Ramps	No./mi	0	1-2	3-5	>5	
AADT		0-5,000	5,001-9,500	9,501-13,000	>13,000	
Operational Speed (85th)	mph	<40	40-49.9	50-54.9	55-65	≥65
Truck Percent	%	0-5	>5-10	>10-15	>15	
Collision Type		Rear End	Angle	Sideswipe	Fixed Object	Other
Severity		Injury/Fatal	PDO			

[1] See Table B-1 in Appendix B for definitions of Weather Codes (2, 4, etc.).
[2] See Table B-4 in Appendix B for definitions of Lighting Codes (1, 2, 3, etc.).

Figure 4 shows a general diagram of the fault tree with the top event being "All Crashes." In Figure 5, a more specific fault tree is shown with the top event of "Collision Type" with additional crash characteristics being the subevents. Figure 6 shows "Collision Type" as the top event with the site characteristics as the subevents. A separate fault tree was developed for each of the six highway classifications used in the study.

Generalized Linear Models

Regression analysis was used to capture the relationships between crash count and causal factors. However, since a normal distribution is not an appropriate assumption for the crash count data used in this study, a typical linear model was not applicable. Because of the nature of the crash count data, non-negative integer and skewed distribution, GLMs were selected for the study. The GLMs allow the dependent variable, in this case the number of crashes per year for a 2-mi segment, to follow any of the distributions in the exponential family. Note that although variables such as *commercial entrances* are given in terms of their density (e.g., number of

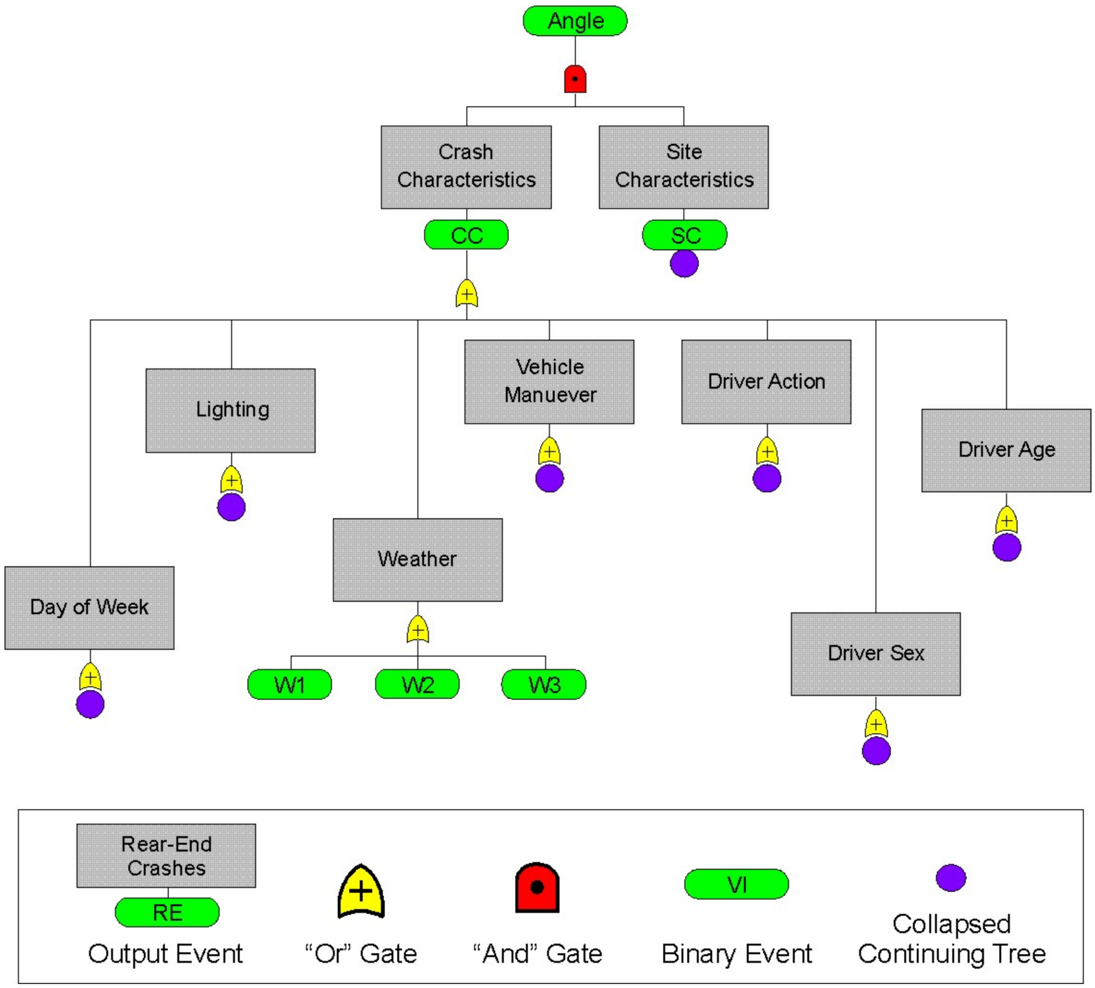

Figure 5. Crash Characteristics Fault Tree

commercial entrances per mile), the number of crashes per year is given for a 2-mi segment. Thus, as noted previously, site lengths were increased to 2 mi to account for the small variation in the lengths of the sites selected for study, thus maintaining the same length for all sites. This was also necessary as an initial analysis using the varying lengths did not give acceptable *p*-values for length for the models because the variation in the lengths was low. Poisson and negative binomial distributions were tested for the crash count data, and the negative binomial distribution was shown to fit the data better. Thus, in developing the models, the negative binomial distribution was assumed. The basic model specification for the relationship between crash count and causal factors is shown in Eq. 1.

$$\begin{aligned} \mathrm{E(Number\ of\ crashes)} = \exp(&\alpha + \beta_1 \times \mathrm{Main\ effect1} + \beta_2 \times \mathrm{Main\ effect2} \\ &+ \beta_3 \times \mathrm{Main\ effect3} + \cdots) \end{aligned} \qquad \text{(Eq. 1)}$$

where
:

E(Number of crashes) = expected number of crashes per year for a 2-mi segment
α = intercept term
$\beta_1, \beta_2, \cdots$ = coefficient parameters for the main effects (e.g., access point density).

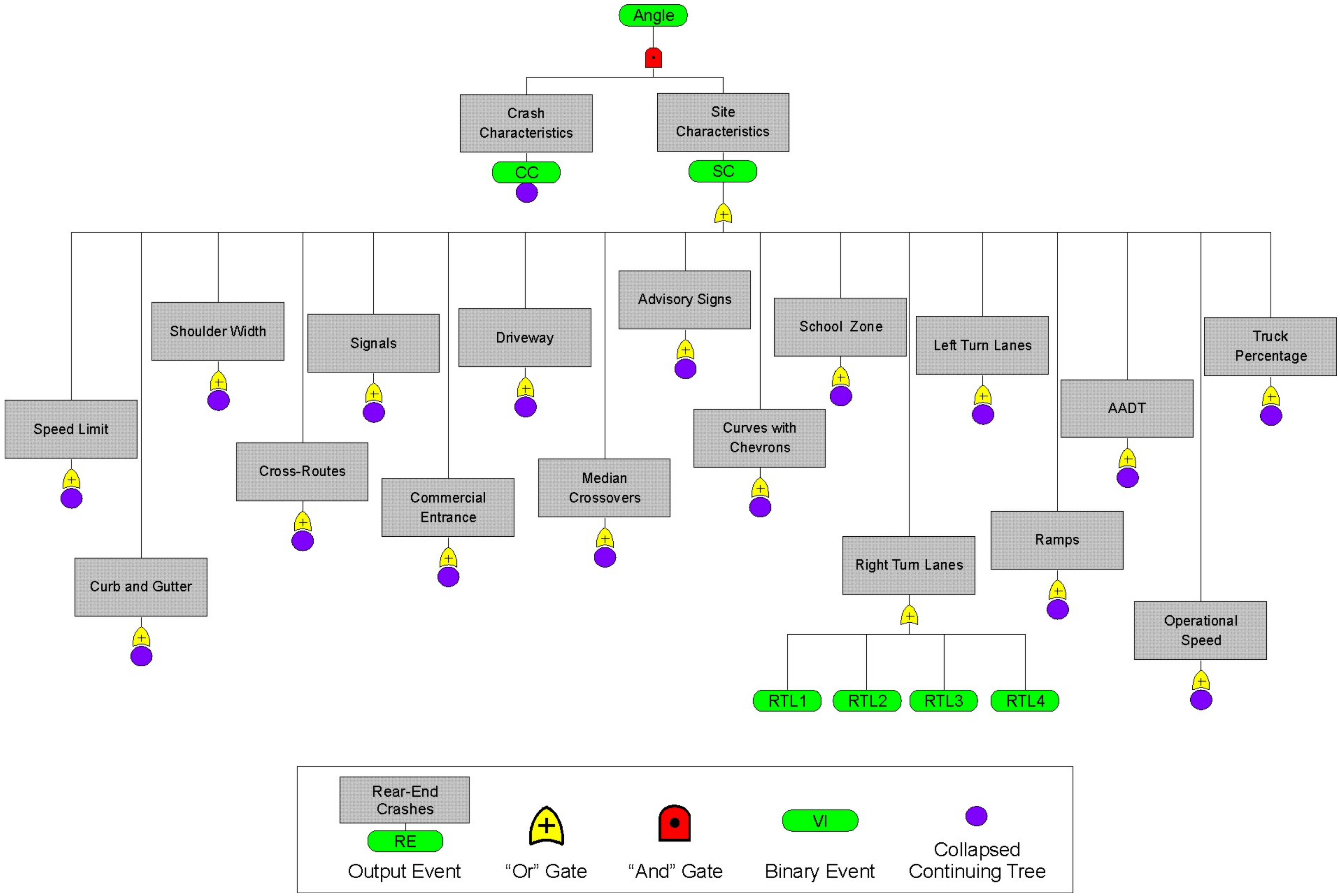

Figure 6. Geometric Characteristics Fault Tree. AADT = average annual daily traffic.

To develop the GLMs, the results from the fault tree analysis were used to assist in determining the causal factors of significance in the crashes. Each highway classification had models developed for injury + fatal, PDO, and total crashes for the specific collision types. A few highway classifications did not have a statistically significant difference between injury + fatal and PDO crashes. Thus, the models were developed for the combined severity levels. In addition, because of the low number of rural undivided and rural traversable sites, GLMs were not developed for these highway classifications. In the end, 20 models were developed for the three collision types on the four highway classifications.

The models were developed with crash causal factors for which appropriate countermeasures could be identified. Therefore, the models did not include causal factors that are beyond the control of traffic engineers and road designers. For example, younger drivers may contribute to the higher occurrence of fixed-object-off-road crashes, but the driver age factor was not included in the model because an engineering crash countermeasure mitigating a safety effect of the age factor was not identified or could not be implemented readily if identified.

For this study, 70% of the sites for each highway classification were randomly selected for estimating the models. The other 30% of the sites were reserved as test sites to evaluate the estimated models. The Mann-Whitney test was used for validating estimated models by testing the difference in the distributions of the actual crash counts and predicted crash counts for the test sites. However, because of the lack of data points, model validation was not performed for all six highway classifications. Because of the low number of sites under the urban traversable median classification, 100% of the sites were used in estimating the models. Urban and rural divided highways had 44 sites each that were used in testing the models, and urban undivided highways had 8 sites.

RESULTS AND DISCUSSION

Literature Review

Based on data from the Federal Highway Administration (FHWA), the U.S. General Accounting Office (2003) reported that fatal crashes were more frequent on rural roads than on urban roads regardless of the road type. A study by Preston et al. (1988) found that the existence of numerous access points on a highway segment is likely to be a major factor in crashes on multilane highways. The access points include residential driveways, public streets, commercial driveways, field access driveways, and other access points, all of which are potential conflict points for vehicles. For the selected sites, the study found that the residential driveways accounted for 38% of access points on rural highways, public streets accounted for 28%, and commercial driveways accounted for only 6%. For urban highways, public streets accounted for 40% and commercial driveways accounted for 34% of all access points. Once the access density was determined, the crash rates for a given number of access points were determined. The results obtained for the crash rates for a four-lane urban conventional roadway with no left turn lanes are shown in Table 6. There is a positive relationship between access density and crash rates. The study concluded that access management is a legitimate public safety issue.

Table 6. Crash Rates for Four-Lane Roadways with No Left Turns

Access Points/Mi	Crash Rates (Crashes/Million Vehicle Miles Traveled)
0-10	2.22
10-30	3.34
30-50	4.74
>50	7.38

Source: Preston, H., Newton, R., Keltner, D., and Albrecht, C. (1988). *Statistical Relationship Between Vehicular Crashes and Highway Access.* Minnesota Department of Transportation, St. Paul.

Brown et al. (1998) focused on access control on high-speed urban arterials. The study examined various aspects of urban arterials such as turning volumes, delays, crash rates, and economic effectiveness, which led to the development of a comprehensive procedure for evaluating access control alternatives. A negative binomial distribution was assumed for crash prediction models, and separate models were developed for total, PDO, and fatal + injury crashes:

$$\begin{aligned}\text{TotalCrashes} = {} & 0.494 \times \text{Length} \times \text{Years} \times \text{AADT} \times \exp(0.285 \times \text{AccessPoint} \\ & - 0.631 \times \text{Shoulder} + 2.520 \times \text{Signals} - 0.748 \times \text{TWLTL} \\ & - 0.604 \times \text{ClosedMedian})\end{aligned} \quad \text{(Eq. 2)}$$

$$\begin{aligned}\text{PDOCrashes} = {} & 0.374 \times \text{Length} \times \text{Years} \times \text{AADT} \times \exp(0.0261 \times \text{AccessPoint} \\ & - 0.669 \times \text{Shoulder} + 2.520 \times \text{Signals} - 0.684 \times \text{ClosedMedian})\end{aligned} \quad \text{(Eq. 3)}$$

$$\begin{aligned}\text{FatalInjuryCrashes} = {} & 0.127 \times \text{Length} \times \text{Years} \times \text{AADT} \times \exp(0.0325 \times \text{AccessPoint} \\ & - 0.525 \times \text{Shoulder} + 2.280 \times \text{Signals} - 0.865 \times \text{TWLTL} \\ & - 0.493 \times \text{ClosedMedian})\end{aligned} \quad \text{(Eq. 4)}$$

where

Length = length of highway segment in kilometers
AADT = average annual daily traffic in thousands of vehicles
Signals = number of signals per kilometer
AccessPoint = number of access points per kilometer
Shoulder = either 1 or 0
TWLTL = two-way left-turn lanes and is either 1 or 0
ClosedMedian = either 1 or 0.

The models indicated that the variables that had a statistically significant effect on crash occurrence were access points, presence of shoulder, number of signals per mile, presence of two-way left-turn lanes (TWLTL), and presence of a median opening between signals. The models also indicated that an increase in the number of access points per kilometer increased crash occurrence. The presence of shoulders decreased crashes, whereas an increase in the number of signals per mile increased crashes. The presence of TWLTL and/or closed medians decreased crashes.

Abdel-Aty and Radwan (2000) conducted a traffic safety study on SR 50 in Central Florida using the negative binomial distribution assumption. SR 50 is a 141-mi principal arterial that varies between four and six lanes. AADT, degree of curvature, lane, shoulder and median widths, urban/rural, and section length were shown to be the predominant factors for crash occurrence. AADT per lane was found to be the most critical factor, with per lane crash frequency increasing as AADT increased. The study also found that narrower lanes, narrower shoulders, more lanes, narrower medians, and speeding increased the probability of crash occurrence.

Crashes resulting from vehicles crossing medians and entering the opposing lanes have been identified as a problem because of the severity of these types of crashes (Shankar et al 1998). Shankar et al. (1998) also determined that median width is a statistically significant factor in median crossover collisions.

Fitzpatrick and Balke (1995) showed no significant difference in crash rates between TWLTL medians and flush medians on rural multilane highways where driveway density is low. Brown et al. (1998) showed that the installation of TWLTLs in place of solid yellow line medians can dramatically improve the traffic safety and flow of a highway if installed in accordance with the recommendation of the American Association of State Highway and Transportation Officials (2004): "In general, continuous left-turn lanes should be used only in an urban setting where operating speeds are relatively low and where there are no more than two through lanes in each direction."

Montello et al. (2008) developed crash prediction models for rural motorways (freeways) in Italy. Although these models were primarily for freeways, the methodology and variables used are applicable to multilane highways. GLMs with a negative binomial distribution were used to fit the data. The researchers focused on total and severe crashes. A base model for each variable was first developed and the statistically significant variables were identified and selected to develop the GLMs. Once the variables were selected, the forward selection, adding one variable at a time, was used to develop the GLMs. The variables used in the model for all crashes were curvature, operating speed reduction, length of tangent proceeding to the curve, year effect, deflection, upgrade, and difference between friction demand and supply. The results indicated that design consistency affects road safety considerably.

Baek and Hummer (2008) conducted a study in North Carolina in which emphasis was placed on the impact of curbs on safety and developed crash prediction models with a negative binomial distribution. The variables used in the total crash model were AADT, access point density, shoulder width, and shoulder type. The same variables with the exclusion of shoulder type were used for injury crashes. The results indicated that routes with curbs had fewer total crashes, yet the presence of curbs had no statistically significant effects on the occurrence of injury crashes.

SafetyAnalyst, Safety Analyst User's Manual (FHWA, 2008) also gives safety performance functions for multilane highway segments in North Carolina, Minnesota, Washington, and Ohio:

$$K = e^{\alpha} \times ADT^{\beta} \times SL^{\gamma} \quad \text{(Eq. 5)}$$

where

K = predicted crash frequency per mile per year
ADT = average daily traffic (veh/day)
SL = segment length.

Although these models are suitable for use in the identification of high-crash locations with promise for improvements, they do not identify all significant crash causal factors and, therefore, cannot be used to identify appropriate countermeasures.

In summary, the literature review provided a better understanding of causal factors, countermeasures, and methodologies used in determining crash causal factors, but inconsistencies were found in these studies. For example, Brown et al. (1998) found that TWLTL reduces crashes whereas Fitzpatrick and Balke (1995) found no significant difference in crash rates between highways with TWLTL and flush medians. This was likely due to the low driveway density for the sites in the Fitzpatrick and Balke study. In addition, although the access points (commercial entrances, driveways, and cross routes) were combined in both the Brown et al. (1998) and Preston et al (1998) studies, the Brown et al. study did not differentiate between signalized and non-signalized access points. Because of these inconsistencies in the data used for analysis in these studies, the models developed for other states are not directly transferable to Virginia's multilane highways.

Fault Tree Analysis

Fault trees were developed using 2001 through 2006 data for total crashes, injury crashes with different collision types, and PDO crashes with different collision types. Although a GLM was not estimated for the rural traversable median highways, a fault tree was developed. The fault trees indicated that the crash causal factors were similar for different highway classifications for a given collision type and median type. The fault trees allowed the researchers to identify crash and driver characteristics associated with different collision types although the GLMs included only design and operational factors. The detailed results from each fault tree are provided in Appendix C.

Figures 7 through 9 are examples of the fault trees developed. Figure 7 is the general fault tree for urban highways, and it reveals that 56% of PDO crashes occurring on urban divided highways were rear-end crashes. Approximately 60% of all crashes on urban undivided highways were PDO crashes, and approximately 40% were injury crashes. Figure 8 shows similar results for rural divided highways, where 57% were PDO and 43% were injury crashes, with 37% of the PDO crashes being rear-end crashes. Figure 9 shows that the highest percentage (46%) of crashes occurred on segments with three or more median crossovers per mile.

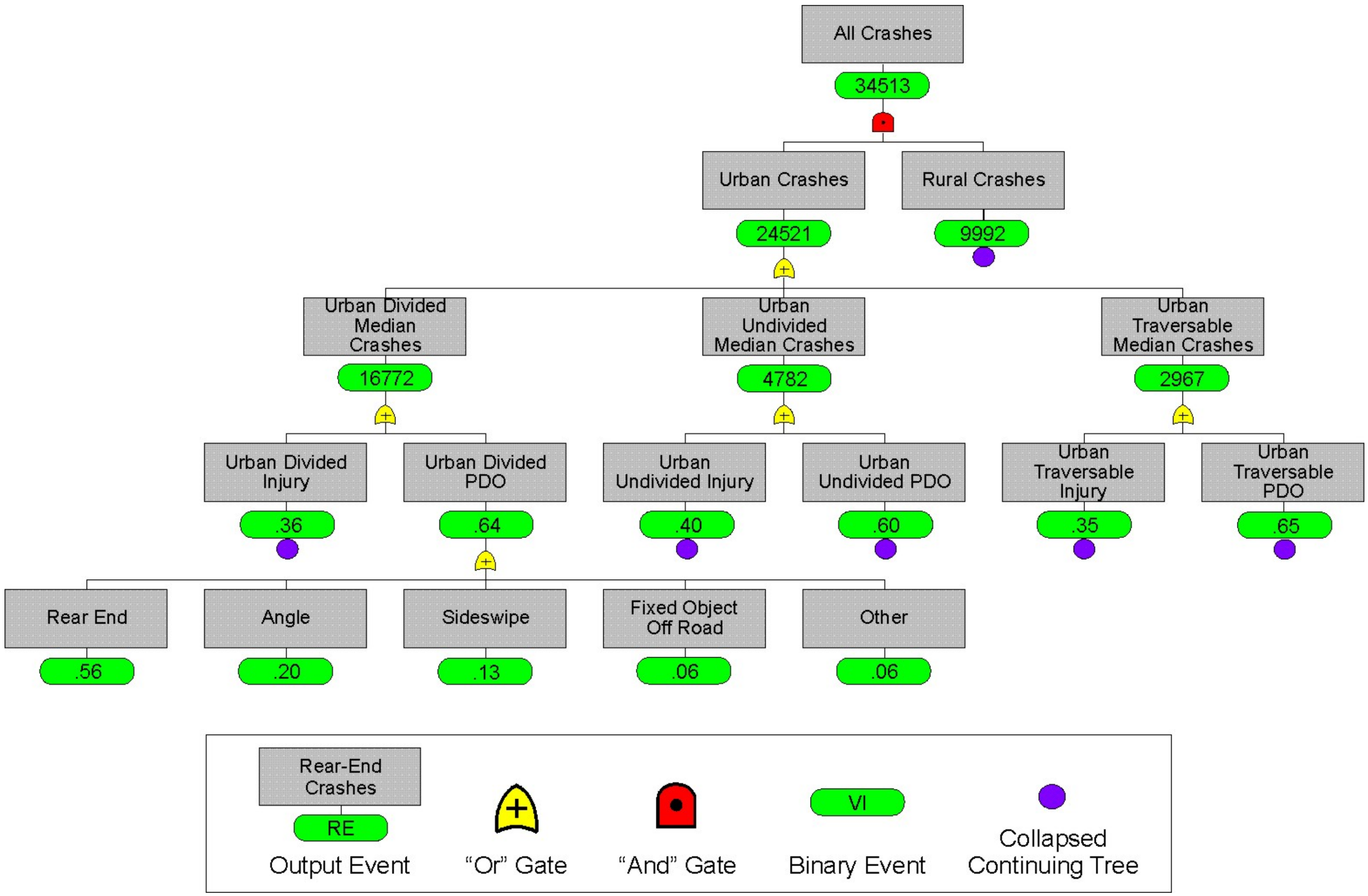

Figure 7. Fault Tree for Urban Crashes. PDO = property damage only.

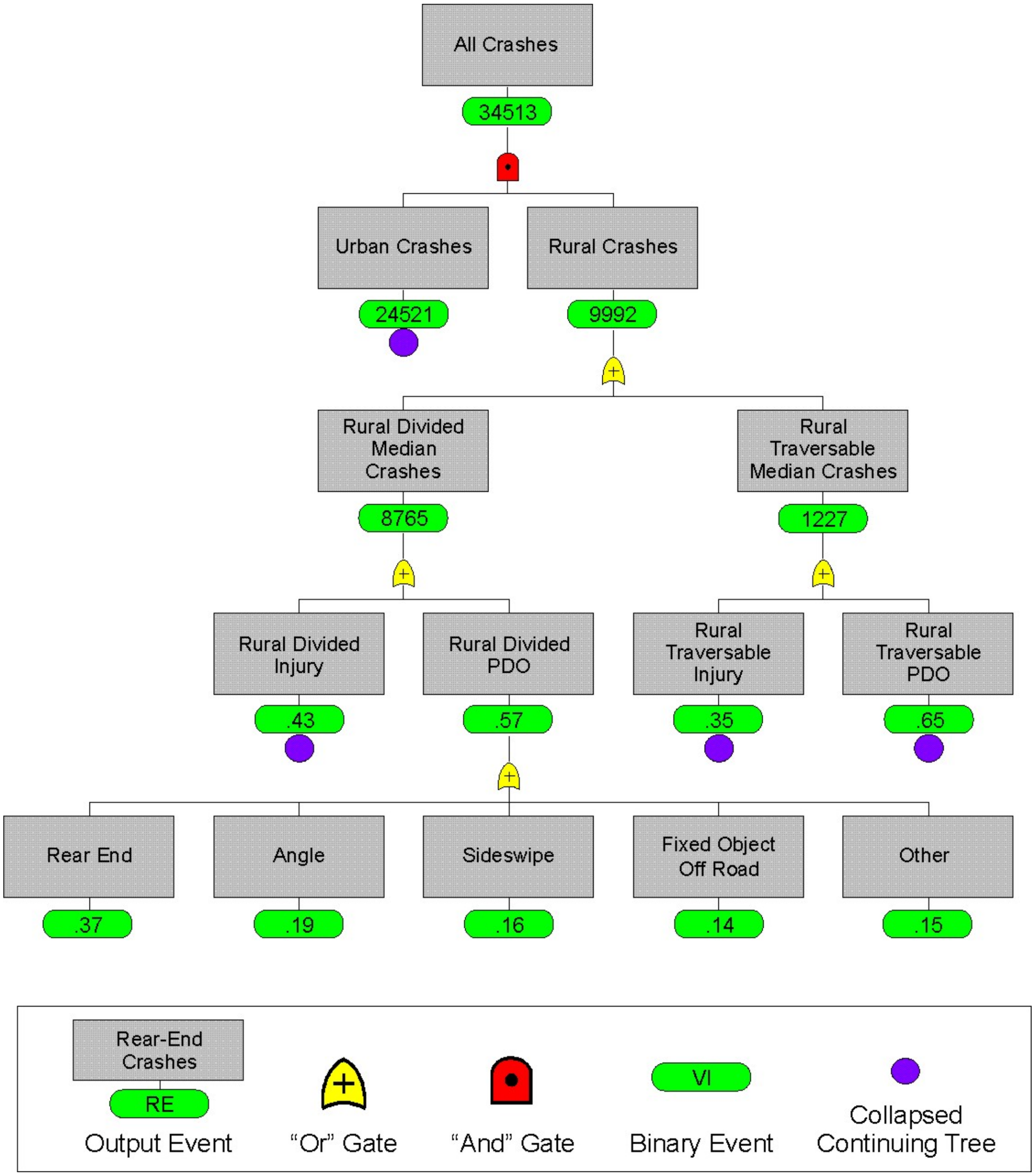

Figure 8. Fault Tree for Rural Crashes. PDO = property damage only.

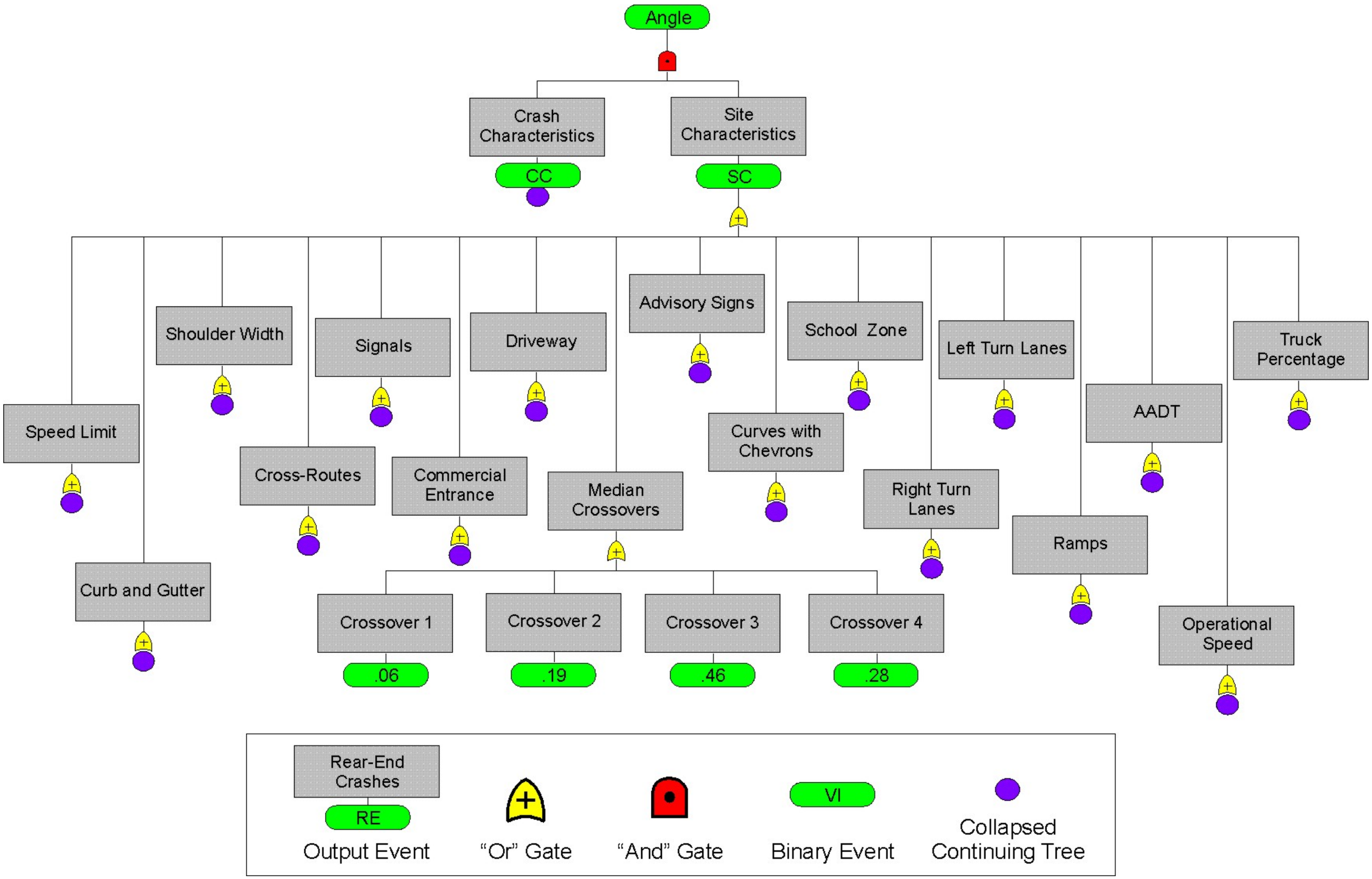

Figure 9. Fault Tree for Site Characteristics for Rural Divided Injury Angle Crashes. AADT = average annual daily traffic.

Generalized Linear Models

GLMs were developed for each collision type and specific highway classification using crash data over the 6 years of 2001 through 2006 and geometric/operational data for specific sites. It should be noted again that the crashes at signalized intersections were not used in the datasets for developing the models. However, a preliminary analysis indicated that the number of signals per mile had an impact on crashes outside the zone of 150 ft from the intersection. This variable was, therefore, included in developing the models. Other variables used in the models were based on a per mile basis, such as commercial entrances per mile, cross routes per mile, etc.

The GLMs for a specific collision type and highway classification are provided in Appendix D. Although models were initially estimated for all collision types (angle, rear- end, sideswipe same direction, fixed object off road and others), only 20 models were developed, as shown in Appendix D. This was due to an insufficient number of sites for some collision types. An example of the models developed is given in Equation 6, which is the model for total crashes on urban divided highways.

$$\text{Total crashes} = \exp(1.9806 + 0.0440 \times \text{Commercial entrances} + 0.00004 \times \text{AADT}) \quad \text{(Eq. 6)}$$

where

Total crashes = expected number of all crashes per year for a 2-mi segment
AADT = AADT for a given site on an urban divided multilane highway.

A positive value for the estimate coefficient indicates the variable was associated with increased crashes, and a negative value indicates the variable was associated with reduced crashes. Some variables such as curb and gutter are indicator variables and have values of 1 for *yes* if the variable occurs at the site or 0 if it does not occur. Table 7 shows an example calculation of the expected number of crashes for a site on an urban divided highway. The example site for calculation in Table 8 is Site 218 S, which is on SR 419 southbound in Roanoke County in VDOT's Salem District.

The Mann-Whitney test was performed to assess the validity of the models based on the model predictions. The test was not performed for urban traversable sites because of an insufficient number of test sites. According to the test results, all models except for three (urban divided injury rear-end crashes, urban divided PDO total crashes, and urban divided injury + PDO total crashes) were shown to satisfy the null hypothesis (i.e., no statistical difference

Table 7. GLM Results for Total Crashes on Urban Divided Highways for Site 218 S

Variable	Coefficient	Value for Site 218 S	Coefficient × Value
Intercept	1.9806	1	1.9806
Commercial entrances/mi	0.0440	12/mi	0.528
Average annual daily traffic	0.00004	14,000 veh/day	0.56
		Sum	3.0686
		Predicted crashes	exp(3.0686) = 21.51
		Observed crashes	22

Table 8. R^2 Values for Developed Models

Highway Type	Severity	Collision Type	R^2 Correlation Based
Rural Divided	Injury	Rear end	0.34
	PDO	Rear end	0.27
		Total	0.36
	Injury + PDO	Rear end	0.47
		Total	0.35
Urban Divided	Injury	Rear end	0.48
		Total	0.39
	PDO	Rear end	0.60
		Total	0.58
	Injury + PDO	Angle	0.36
		Rear end	0.62
		Total	0.55
Urban Undivided	Injury + PDO	Total	0.14
Urban Traversable Median	Injury	Rear end	0.35
		Total	0.35
	PDO	Rear end	0.49
		Total	0.54
	Injury + PDO	Angle	0.53
		Rear end	0.53
		Total	0.46

between the observed and expected crash counts distributions). Although these three models did not satisfy the null hypothesis, the *p*-values of the significant causal factors were much less than 0.1 as shown in Tables D-1 through D-3 in Appendix D. The R^2 values of all models developed are given in Table 8.

The significant major causal factors for different collision types and highway classifications are shown in Tables 9 through 11. Also listed in these tables are potential countermeasures, which are discussed in detail later.

Although crashes within150 ft of signalized intersections were eliminated from the data, the models indicated that the number of signals per mile is a major crash causal factor for rear-end crashes on some highway classifications. This indicates that the presence of signals affects crash occurrence outside the region of 150 ft from the intersection. For example, the number of signals per mile is a significant causal factor for rural and urban divided rear-end PDO crashes and for rural divided injury crashes but not for urban divided injury crashes. This indicates that the number of signals per mile is a factor that influences the occurrence of injury crashes on rural multilane highways but not on urban multilane highways. This most probably is due to the fact that speeds on rural highways are usually higher than those on urban highways. In addition, although the number of signals per mile is shown to increase rear-end PDO crashes for rural and urban divided highways, it is not a significant factor for urban traversable sites. This is probably because traversable sites do not usually have signals. This difference emphasizes the importance of developing different models for different geometric characteristics, as exemplified by the different characteristics of divided highways and traversable highways. Most of the causal factors used in the models had a *p*-value of less than 0.05, although a few had a *p*-value up to 0.15. Tables D-1 through D-3 in Appendix D show the main causal factors for each model and their respective *p*-value.

Table 9. Potential Countermeasures for Injury Crashes

Collision Type	Highway Classification	Statistically Significant Causal/Associated Factors		Potential Countermeasures
		Detrimental	Beneficial	
Rear End	Urban Divided	Commercial Entrances, AADT	N/A	• Combine commercial entrances if feasible. • Consider controlled access for commercial entrances.
	Rural Divided	AADT, Signals	Left Turn Lanes	• Install left turn lanes at signals if feasible. • Check signal head visibility, alignment, and clearance intervals for 85% speeds (and lower left turn speeds). • Install "Signal Ahead" signs where sight distance is limited.
	Urban Traversable	AADT	N/A	N/A
	Urban Divided	Commercial Entrances, AADT	N/A	• Combine commercial entrances if available. • Consider controlled access for commercial entrances.
	Urban Traversable	AADT	N/A	N/A

Table 10. Potential Countermeasures for Property Damage Only (PDO) Crashes

Collision Type	Highway Classification	Statistically Significant Causal/Associated Factors		Potential Countermeasures
		Detrimental	Beneficial	
Rear End	Urban Divided	Signals, Commercial Entrances, AADT	N/A	• Combine commercial entrances if feasible. • Consider controlled access for commercial entrances. • Consider signal coordination, advance signing, and warning. • Check clearance intervals.
	Rural Divided	AADT, Signals, Ramps	N/A	• Lengthen acceleration and deceleration lanes if feasible. • Consider providing exclusive left and right turn lanes. • Install "Signal Ahead" signs and/or controller actuated beacons where sight distance is limited. • Check clearance intervals.
	Urban Traversable	AADT	N/A	N/A
Total PDO Crashes	Urban Divided	Cross Routes, Commercial Entrances, AADT	N/A	• Combine commercial entrances if feasible. • Consider controlled access for commercial entrances.
	Rural Divided	AADT, Signals, Ramps	Curb and Cutter	• Lengthen acceleration and deceleration lanes if feasible. • Consider providing exclusive left and right turn lanes. • Check signal head visibility, alignment, and clearance intervals for 85% speeds (and lower left-turn speeds)
	Urban Traversable	AADT, Truck Percentage	N/A	N/A

Table 11. Potential Countermeasures for Total (Injury + PDO) Crashes

Collision Type	Highway Classification	Causal Factors: Detrimental	Causal Factors: Beneficial	Potential Countermeasures
Angle	Urban Divided	AADT, Median Crossovers	Shoulder Width	• Increase shoulder width. • Install signs warning of presence of median crossovers where sight distance is limited. • Close crossover; provide larger turn radius for U-turns.
	Urban Traversable	AADT, Ramps	NA	
Rear End	Urban Divided	AADT, Commercial Entrances	N/A	• Combine commercial entrances if available. • Consider controlled access for commercial entrances.
	Rural Divided	AADT, Signals, Ramps	Left Turn Lanes, Curb and Gutter	• Install left turn lanes at signals if feasible. • Lengthen acceleration and deceleration lanes when feasible. • Check signal head visibility, alignment, and clearance intervals for 85% speeds (and lower left turn speeds). • Install curb and gutter.
	Urban Traversable	AADT	N/A	N/A
Total (Injury + PDO) Crashes	Urban Divided	Commercial Entrances, AADT	N/A	• Combine commercial entrances if available. • Consider controlled access for commercial entrances.
	Rural Divided	Signals, AADT	Left Turn Lanes, Curb and Gutter	• Install left turn lanes at signals if feasible. • Consider installing curb and gutter.
	Urban Undivided	AADT, Cross Routes	N/A	• Install signs warning of presence of cross routes where sight distance is limited.
	Urban Traversable	AADT	NA	N/A

Potential Countermeasures

Based on the associated crash causal factors identified in the fault tree analysis and GLMs, potential countermeasures were identified. These countermeasures were derived from the literature, including reports from the Transportation Research Board (2003, 2004, 2005). The countermeasures corresponding to statistically significant causal factors, the collision types, and the highway classifications are listed in Tables 9 through 11 for injury, PDO, and total (injury + PDO) crashes, respectively. The recommendations given in Tables 9 through 11 are countermeasures to help alleviate a specific causal factor. Some countermeasures listed, such as adding controlled access and adding turning lanes, could have a greater effect in reducing crashes, but adequate funding or the necessary right of way may not be available.

CONCLUSIONS

- Rear-end crashes are the predominant collision type at high-crash locations on multilane primary highways in Virginia.
- A higher number of signals per mile results in increased rear-end PDO crashes on rural divided and urban highways and increased rear-end injury crashes on rural divided highways.
- Three or more commercial entrances per mile result in a higher number of rear-end crashes on urban divided highways.
- Each causal factor may be associated with several collision types.
- Major causal factors associated with different collision types on different highway classifications can be determined using fault tree analysis.
- GLMs can show a quantitative relationship between causal factors and crashes. This allows engineers to identify what causal factors may have the most effect on the number of crashes for the specific collision type.
- GLMs can be used to estimate percentage reduction in crashes resulting from implementing one or more countermeasures.

RECOMMENDATIONS

The following three recommendations are based on the results of this study. VDOT's Traffic Engineering Division is the audience for Recommendations 1 and 2, and the research community is the audience for Recommendation 3. It should be emphasized again that in developing the models presented here, consideration was given to causal factors that could be changed by engineers. Other factors such as environmental and human factors were not included. The research team recognizes that these factors also have some effect on crash occurrence and, therefore, that implementing Recommendations 1 and 2 will not lead to the elimination of all rear-end and total crashes.

1. *A plan for selecting short-term and long-term safety countermeasures should be developed and implemented for signalized intersections with a high number of rear-end crashes (Tables 12 and 14) based on specific site conditions and the results of this study.* Since the final decision to select a specific countermeasure or set of countermeasures at a particular site depends mainly on the traffic and geometric conditions existing at the site, it is essential that these factors be considered in selecting the most appropriate countermeasure(s) for the site. For example, selecting the provision of turn lanes may be a short-term countermeasure for a signalized rural divided highway with a high number of rear-end crashes but a long-term countermeasure for another intersection.

2. *A plan for selecting short-term and long-term safety countermeasures should be developed and implemented for urban divided highways with a high number of rear-end crashes (Tables 13 and 15) based on specific site conditions and the results of this study.* For example, reducing the number of commercial entrances at an urban divided highway location with a high number of rear-end crashes could be a short-term or long-term countermeasure depending on the specific characteristics of the site.

If a particular countermeasure can improve more than one causal factor, the countermeasure should be considered for implementation first. The final decision to select a specific countermeasure or set of countermeasures depends mainly on the conditions that exist at any given time for a given location. The recommended countermeasures should, therefore, be selected for implementation if engineering judgment fully supports them.

The results of this study show there is a high potential for improving the safety of Virginia multilane highways if Recommendations 1 and 2 are implemented. Although the significant crash causal factors at these high-risk sites have been identified and potential countermeasures suggested, it is not feasible for these recommendations to be implemented at all sites at the same time. A priority list based on the long-term expected reduction of crashes at the sites should, therefore, be developed using the SafetyAnalyst software (FHWA, 2007) and the safety performance functions (SPFs) that are being developed in several studies under way at the Virginia Transportation Research Council for different road types. However, the detailed inventory of the elements in the SPFs developed will first be needed before the SPFs can be used. Recommendations 1 and 2 can then be implemented starting with the highest ranked sites, with the number of sites considered at any given time being dependent on the financial resources available.

3. *A detailed study separating commercial entrances by trip generation should be conducted.* In the current study, access points were divided only into cross routes, driveways, and commercial entrances because of the broad scope of the study. In future research on multilane highways, one might consider dividing the commercial entrances into subcategories based on trip generation. Although the data for

commercial entrances for this study were sufficient, a commercial entrance for a bank cannot be thought of as being the same as a commercial entrance for a grocery store or superstore. If divided into subcategories, the differential effect on crashes among commercial entrances with different trip generation rates can be pinpointed. This also will support the achievement of the requirement of the upcoming *Highway Safety Manual* (HSM) for corridor studies to be conducted that will identify driveway-related crashes and determine if these crashes are greater than those expected from the HSM models.

COSTS AND BENEFITS ASSESSMENT

The costs that will be accrued when implementing any of the identified countermeasures will depend on the type of countermeasure and the specific site characteristics such as the existence of an adequate median width to install a left turn lane and/or the existing land use at the location. However, based on a discussion with VDOT engineers, the researchers determined that the cost for closing a commercial access does not vary as widely as that for installing a left turn lane. For example, the cost for installing a left turn lane could vary from $300,000 to $1,000,000 whereas the cost for closing a commercial entrance is usually between $300,000 and $500,000. The benefits resulting from implementing any of the identified countermeasures can be determined from the appropriate model in terms of the number of crashes reduced.

As an illustration of the benefits that will be accrued, Tables 12 and 13 show examples of the expected benefits in terms of percentage reduction in crashes that are likely for different implementation levels of countermeasures. Examples of implementation of countermeasures for rural divided total crashes and urban divided total crashes were calculated by using the top high-risk sites for each VDOT district based on crash rates. For example, Table 12 shows the expected crash reduction percentages if left turn lanes were implemented at signalized intersections that do not already have left turn lanes on rural divided highways. The table shows the crash reduction percentages likely resulting from implementing 50% and100% of the signals without turn lanes.

Table 13 shows the expected crash reduction percentages for urban divided total crashes if commercial entrances are reduced by 10%, 15%, and 20% by either combining commercial entrances or implementing controlled access. Similar results are shown in Tables 14 and 15 for specific types of crashes.

To estimate the potential monetary benefits and costs of reducing commercial entrances at urban divided highway sites, a sensitivity study of the data for a selected number of sites was conducted as shown in Tables 16 and 17. For each site, the expected number of total crashes was computed from the appropriate model in Appendix D using the existing AADTs (mean of AADTs for years 2001 through 2006) and two levels (10% and 20%) of reduction in commercial

Table 12. Rural Divided Highway Countermeasure Implementation

Site ID	Expected Crash Counts[1]	Number of Signals with Left Turn Lanes		Expected Crash Counts[3]		Crash Reduction (%)	
		50%[2]	100%	50%	100%	50%	100%
104 N	25	4	8	20	16	21.21	37.92
107 N	10	2	3	9	8	8.55	16.37
107 S	9	1	2	9	8	5.79	11.24
204 N	8	1	1	8	8	2.94	5.79
205 N	9	2	3	9	9	2.94	5.79
209 N	10	2	3	9	9	5.79	11.24
209 S	11	2	3	10	9	8.55	16.37
215 N	11	1	2	10	9	8.55	16.37
215 S	8	2	3	8	7	5.79	11.24
314 N	10	1	1	9	8	8.55	16.37
631 S	7	1	2	6	6	2.94	5.79
717 N	9	1	2	9	8	5.79	11.24
717 S	19	1	2	18	17	5.79	11.24
806 N	19	2	3	18	17	5.79	11.24
806 S	5	2	4	5	4	8.55	16.37
807 S	6	1	1	6	5	11.24	21.21
824 N	8	1	1	8	8	2.94	5.79
824 S	8	1	1	8	8	2.94	5.79

[1]Total expected crashes before implementation.
[2]50% implementation means that left turn lanes were installed on 50% of the signalized intersections that did not already have them.
[3]Expected crashes after implementation.

entrances. The mean of the AADTs was used as the crash data spanned years 2001 through 2006. The estimated total rehabilitation cost for each case was then computed assuming an average cost of $40,000 for each commercial entrance closed, which is the average of the range obtained from VDOT engineers. The associated monetary benefits were computed assuming $60,333 for each crash reduced, which is the FHWA estimate for two-vehicle crashes in 2001 dollars. This cost includes medically related costs, emergency services, property damage, lost productivity, and monetized quality-adjusted life years (QALYS), but not the human capital cost.

The benefit/cost (B/C) ratio was then determined using discount rates of 3% and 5% and a time period of 10 years, although it is highly likely that the benefits will continue for a much longer period. The results are shown in Tables 16 and 17. These results indicate that in all cases the B/C ratio is higher than 1.

Table 13. Estimated Crash Reduction for Different Implementation Levels of Countermeasures on Urban Divided Highways

Site ID	Expected Crash Counts[1]	Reduced No. of Commercial Entrances			Expected Crash Counts[3]			Crash Reduction (%)		
		10%[2]	15%	20%	10%	15%	20%	10%	15%	20%
113 N	46	28	26	25	40	37	35	12.75	18.50	23.88
218 N	18	7	7	6	17	17	17	3.46	5.14	6.80
218 S	22	11	10	10	20	20	19	5.14	7.61	10.02
304 S	21	10	9	9	20	20	19	4.72	7.00	9.23
317 N	22	16	15	14	20	19	18	7.61	11.20	14.65
512 N	29	7	7	6	28	28	27	3.46	5.14	6.80
517 N	22	9	9	8	21	20	20	4.30	6.39	8.42
517 S	27	14	13	12	25	25	24	6.39	9.43	12.37
606 S	17	5	4	4	16	16	16	2.18	3.25	4.30
611 N	82	21	20	18	75	71	67	9.62	14.08	18.32
611 S	123	29	27	26	106	99	92	13.13	19.04	24.54
715 N	22	5	4	4	22	21	21	2.18	3.25	4.30
802 N	17	6	6	6	16	16	16	3.03	4.51	5.97
822 N	19	10	9	9	18	17	17	4.72	7.00	9.23
822 S	21	13	12	11	20	19	19	5.97	8.83	11.59
902 N	16	4	3	3	16	16	16	1.74	2.61	3.46
910 N	15	5	5	5	15	15	14	2.61	3.88	5.14
910 S	18	9	9	8	17	17	17	4.30	6.39	8.42
924 N	22	8	8	7	21	21	20	3.88	5.77	7.61
924 S	18	4	3	3	17	17	17	1.74	2.61	3.46
925 N	27	20	19	18	25	24	23	9.23	13.52	17.60

[1]Total expected crashes before implementation.
[2]10% implementation means that the commercial entrances on the site have been reduced by 10%.
[3]Expected crashes after implementation.

Table 14. Estimated Crash Reduction by Collision Type for Implementing Different Countermeasures on Rural Divided Highways

Site ID	AADT	Primary Collision Type	Median Type	Major Causal Factor	Countermeasure	Crash Reduction (%)
107 S	6000	Rear End	Divided	Signals	Add LTL at Signal[1]	20.36
122 N	10000	Rear End	Divided	Signals	Add LTL at Signal	10.76
204 N	9000	Rear End	Divided	Signals	Add LTL at Signal	10.76
209 N	9000	Rear End	Divided	Signals	Add LTL at Signal	28.92
209 S	9000	Rear End	Divided	Signals	Add LTL at Signal	28.92
614 S	15500	Rear End	Divided	Signals	Add LTL at Signal	10.76
631 S	8000	Rear End	Divided	Signals	Add LTL at Signal	20.36
717 N	22500	Rear End	Divided	Signals	Add LTL at Signal	20.36
717 S	22500	Rear End	Divided	Signals	Add LTL at Signal	20.36
721 N	22500	Rear End	Divided	Signals	Add LTL at Signal	20.36
721 S	22500	Rear End	Divided	Signals	Add LTL at Signal	20.36
804 N	13000	Rear End	Divided	Signals	Add LTL at Signal	20.36
806 N	3800	Rear End	Divided	Signals	Add LTL at Signal	28.92
806 S	3800	Rear End	Divided	Signals	Add LTL at Signal	36.57
807 S	3800	Rear End	Divided	Signals	Add LTL at Signal	10.76
809 N	6000	Rear End	Divided	Signals	Add LTL at Signal	10.76
809 S	6000	Rear End	Divided	Signals	Add LTL at Signal	20.36
814 N	6500	Rear End	Divided	Signals	Add LTL at Signal	10.76
825 S	7000	Rear-End	Divided	Signals	Add LTL at Signal	10.76

[1]Apply left turn lanes at all signals that do not already have left turn lanes.

Table 15. Estimated Crash Reduction by Collision Type for Implementing Different Countermeasures on Urban Divided Highways

Site ID	Crash Rates (per MVMT)	AADT	Primary Collision Type	Major Causal Factor	Countermeasure	Crash Reduction (%)
108 N	1.53	7000	Angle	Median Cross	Close 50% of Median Crossovers[1]	12.28
108 S	1.34	7000	Angle	Median Cross	Close 50% of Median Crossovers	6.34
113 N	5.37	12000	Rear End	Commercial Ent	Combine Commercial Ent[2]	25.79
211 S	1.84	12500	Rear End	Commercial Ent	Combine Commercial Ent	8.29
218 N	1.72	14000	Rear End	Commercial Ent	Combine Commercial Ent	7.41
218 S	2.08	14000	Rear End	Commercial Ent	Combine Commercial Ent	10.90
220 N	1.48	14000	Rear End	Commercial Ent	Combine Commercial Ent	4.70
220 S	1.42	14000	Rear End	Commercial Ent	Combine Commercial Ent	3.77
304 S	1.96	15000	Rear End	Commercial Ent	Combine Commercial Ent	10.04
316 S	2.19	5500	Angle	Median Cross	Close 50% of Median Crossovers	9.36
317 N	2.41	7500	Angle	Median Cross	Close 50% of Median Crossovers	25.53
321 S	1.17	11500	Angle	Median Cross	Close 50% of Median Crossovers	12.28
409 N	2.30	13500	Rear End	Commercial Ent	Combine Commercial Ent	12.60
413 S	0.76	10500	Angle	Median Cross	Close 50% of Median Crossovers	6.34
421 N	2.42	10500	Angle	Median Cross	Close 50% of Median Crossovers	15.10
421 S	2.42	10500	Angle	Median Cross	Close 50% of Median Crossovers	15.10
422 N	1.64	10000	Rear End	Commercial Ent	Combine Commercial Ent	4.70
426 N	2.16	34500	Rear End	Commercial Ent	Combine Commercial Ent	5.61
512 N	1.90	26000	Rear End	Commercial Ent	Combine Commercial Ent	7.41
512 S	2.09	26000	Rear End	Commercial Ent	Combine Commercial Ent	9.17
513 N	4.22	16500	Rear End	Commercial Ent	Combine Commercial Ent	22.87
517 N	1.86	16500	Rear End	Commercial Ent	Combine Commercial Ent	9.17
517 S	2.37	16500	Rear End	Commercial Ent	Combine Commercial Ent	13.44
606 S	1.47	15500	Rear End	Commercial Ent	Combine Commercial Ent	4.70
611 N	5.06	35500	Rear End	Commercial Ent	Combine Commercial Ent	19.85
611 S	7.80	35500	Rear End	Commercial Ent	Combine Commercial Ent	26.50
616 S	2.26	18000	Rear End	Commercial Ent	Combine Commercial Ent	12.60
617 N	1.53	22000	Rear End	Commercial Ent	Combine Commercial Ent	4.70
617 S	1.53	22000	Rear End	Commercial Ent	Combine Commercial Ent	4.70
621 S	1.86	17000	Rear End	Commercial Ent	Combine Commercial Ent	9.17
628 N	1.63	19000	Rear End	Commercial Ent	Combine Commercial Ent	6.51
628 S	1.63	19000	Rear End	Commercial Ent	Combine Commercial Ent	6.51
714 S	1.86	17500	Rear End	Commercial Ent	Combine Commercial Ent	9.17
728 N	3.52	11500	Rear End	Commercial Ent	Combine Commercial Ent	19.07
802 N	1.66	13000	Rear End	Commercial Ent	Combine Commercial Ent	6.51
802 S	1.74	13000	Rear End	Commercial Ent	Combine Commercial Ent	7.41

822 N	2.08	11500	Rear End	Commercial Ent	Combine Commercial Ent	10.04
822 S	2.40	11500	Rear End	Commercial Ent	Combine Commercial Ent	12.60
902 S	1.61	16000	Rear End	Commercial Ent	Combine Commercial Ent	6.51
910 N	1.61	12000	Rear End	Commercial Ent	Combine Commercial Ent	5.61
910 S	1.95	12000	Rear End	Commercial Ent	Combine Commercial Ent	9.17
924 N	1.78	18000	Rear End	Commercial Ent	Combine Commercial Ent	8.29
924 S	1.40	18000	Rear End	Commercial Ent	Combine Commercial Ent	3.77
925 N	3.40	9000	Angle	Median Cross	Close 50% of Median Crossovers	23.05
925 S	3.40	9000	Angle	Median Cross	Close 50% of Median Crossovers	23.05
927 N	1.81	12500	Angle	Median Cross	Close 50% of Median Crossovers	9.36

[1]Close 50% of median crossovers on site.
[2]Reduce 20% of commercial entrances on site.

Table 16. Urban Divided Highway Benefit/Cost Analysis for Closure of Commercial Entrances Assuming Interest Rate of 3%

Site ID	Expected Crash Counts[1]	No. of Existing Commercial Entrance	No. of Commercial Entrances Closed		Expected Crash Counts		Benefit/Cost Analysis					
							10%			20%		
			10%[2]	20%	10%[2]	20%	Cost	Benefit	B/C	Cost	Benefit	B/C
113 N	46	31	3	6	40	35	120,000	3,006,415	25.05	240,000	5,629,493	23.46
218 N	18	8	1	2	17	17	40,000	321,126	8.03	80,000	631,146	7.89
218 S	22	12	1	2	20	19	40,000	569,389	14.23	80,000	1,109,494	13.87
304 S	21	11	1	2	20	19	40,000	520,992	13.02	80,000	1,017,368	12.72
317 N	22	18	2	4	20	18	80,000	846,385	10.58	160,000	1,628,322	10.18
512 N	29	8	1	2	28	27	40,000	518,964	12.97	80,000	1,019,978	12.75
517 N	22	10	1	2	21	20	40,000	482,320	12.06	80,000	943,877	11.80
517 S	27	16	2	4	25	24	80,000	891,739	11.15	160,000	1,726,523	10.79
606 S	17	6	1	2	16	16	40,000	187,992	4.70	80,000	371,893	4.65
611 N	82	23	2	5	75	67	80,000	4,085,757	51.07	200,000	7,778,268	38.89
611 S	123	32	3	6	106	92	120,000	8,284,181	69.03	240,000	15,480,343	64.50
715 N	22	6	1	2	22	21	40,000	248,738	6.22	80,000	492,063	6.15
822 N	19	11	1	2	18	17	40,000	452,928	11.32	80,000	884,457	11.06
822 S	21	14	1	3	20	19	40,000	653,509	16.34	120,000	1,267,977	10.57
902 N	16	4	N/A[4]	1	16	16	N/A[4]	N/A[4]	N/A[4]	40,000	291,732	7.29
910 S	18	10	1	2	17	17	40,000	402,867	10.07	80,000	788,393	9.85
924 N	22	9	1	2	21	20	40,000	442,054	11.05	80,000	866,944	10.84
924 S	18	4	N/A[4]	1	17	17	N/A[4]	N/A[4]	N/A[4]	40,000	316,029	7.90
925 N	27	22	2	4	25	23	80,000	1,298,512	16.23	160,000	2,477,220	15.48

[1]Total expected crashes before any reduction in commercial entrances.
[2]Percentage reductions in commercial entrances.
[3]Expected crashes after reduction of commercial entrances.
[4]No reduction in commercial entrances.

Table 17. Urban Divided Highway Benefit/Cost Analysis for Closure of Commercial Entrances Assuming Interest Rate of 5%

Site ID	Expected Crash Counts[1]	No. of Existing Commercial Entrances	No. of Commercial Entrances Closed		Expected Crash Counts[3]		Benefit/Cost Analysis					
			10%[2]	20%	10%	20%	10%			20%		
							Cost	Benefit	B/C	Cost	Benefit	B/C
113 N	46	31	3	6	40	35	120,000	2,721,464	22.68	240,000	5,095,924	21.23
218 N	18	8	1	2	17	17	40,000	290,690	7.27	80,000	571,325	7.14
218 S	22	12	1	2	20	19	40,000	515,422	12.89	80,000	1,004,336	12.55
304 S	21	11	1	2	20	19	40,000	471,612	11.79	80,000	920,941	11.51
317 N	22	18	2	4	20	18	80,000	766,164	9.58	160,000	1,473,988	9.21
512 N	29	8	1	2	28	27	40,000	469,776	11.74	80,000	923,304	11.54
517 N	22	10	1	2	21	20	40,000	436,605	10.92	80,000	854,416	10.68
517 S	27	16	2	4	25	24	80,000	807,219	10.09	160,000	1,562,881	9.77
606 S	17	6	1	2	16	16	40,000	170,174	4.25	80,000	336,645	4.21
611 N	82	23	2	5	75	67	80,000	3,698,505	46.23	200,000	7,041,037	35.21
611 S	123	32	3	6	106	92	120,000	7,498,999	62.49	240,000	14,013,102	58.39
715 N	22	6	1	2	22	21	40,000	225,162	5.63	80,000	445,425	5.57
822 N	19	11	1	2	18	17	40,000	409,999	10.25	80,000	800,628	10.01
822 S	21	14	1	3	20	19	40,000	591,569	14.79	120,000	1,147,797	9.56
902 N	16	4	N/A[4]	1	16	16	N/A[4]	N/A[4]	N/A[4]	40,000	264,081	6.60
910 S	18	10	1	2	17	17	40,000	364,683	9.12	80,000	713,668	8.92
924 N	22	9	1	2	21	20	40,000	400,155	10.00	80,000	784,774	9.81
924 S	18	4	N/A[4]	1	17	17	N/A[4]	N/A[4]	N/A[4]	40,000	286,076	7.15
925 N	27	22	2	4	25	23	80,000	1,175,438	14.69	160,000	2,242,427	14.02

[1]Total expected crashes before any reduction in commercial entrances.
[2]Percentage reductions in commercial entrances.
[3]Expected crashes after reduction of commercial entrances.
[4]No reduction in commercial entrances.

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APPENDIX A: STUDY SITES

Table A-1. Selected Sites

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
101 N	11	1	R	Traversable	95	18	19
102 N	19	1	R	Divided	83	26	27
102 S	19	1	R	Divided	83	26	27
103 S	19	1	R	Divided	95	20	21
103 N	19	1	R	Divided	95	20	21
104 N	19	1	R	Divided	95	15	16
104 S	19	1	R	Divided	95	15	16
105 S	19	1	R	Divided	95	18	19
105 N	19	1	R	Divided	95	18	19
106 N	19	1	R	Divided	95	22	23
106 S	19	1	R	Divided	95	22	23
107 E	460	1	R	Divided	92	57	58
107 W	460	1	R	Divided	92	57	58
108 S	23	1	U	Divided	84	13	14
108 N	23	1	U	Divided	84	13	14
109 S	23	1	R	Divided	97	39	40
109 N	23	1	R	Divided	97	39	40
110 S	23	1	R	Divided	97	40	41
110 N	23	1	R	Divided	97	40	41
111 S	23	1	R	Divided	84	14	15
111 N	23	1	R	Divided	84	14	15
112 N	23	1	R	Divided	84	17	18
112 S	23	1	R	Divided	84	17	18
113 N	23	1	U	Divided	84	2	3
113 S	23	1	U	Divided	84	2	3
115 N	23	1	R	Divided	97	44	45
115 S	23	1	R	Divided	97	44	45
117 S	23	1	U	Undivided	84	3	4
117 N	23	1	U	Undivided	84	3	4
118 W	460	1	R	Divided	92	37	38
118 E	460	1	R	Divided	92	37	38
119 W	460	1	R	Divided	92	35	36
119 E	460	1	R	Divided	92	35	36
122 W	460	1	R	Divided	92	47	48
122 E	460	1	R	Divided	92	47	48
201 N	11	2	R	Undivided	77	100	101
201 S	11	2	R	Undivided	77	100	101
203 W	58	2	R	Divided	44	276	277
203 E	58	2	R	Divided	44	276	277
204 S	100	2	R	Divided	77	28	29
204 N	100	2	R	Divided	77	28	29
205 S	100	2	R	Divided	77	27	28
205 N	100	2	R	Divided	77	27	28
206 W	114	2	R	Traversable	77	0	1
206 E	114	2	R	Traversable	77	0	1
208 N	220	2	U	Divided	80	58	59
208 S	220	2	U	Divided	80	58	59
209 S	220	2	R	Divided	44	6	7
209 N	220	2	R	Divided	44	6	7
210 N	220	2	R	Divided	80	57	58
210 S	220	2	R	Divided	80	57	58

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
211 S	220	2	U	Divided	11	76	77
211 N	220	2	U	Divided	11	76	77
212 S	220	2	R	Divided	33	44	45
212 N	220	2	R	Divided	33	44	45
213 S	220	2	R	Divided	33	50	51
213 N	220	2	R	Divided	33	50	51
214 S	220	2	R	Traversable	33	49	50
214 N	220	2	R	Traversable	33	49	50
215 S	220	2	R	Divided	44	3	4
215 N	220	2	R	Divided	44	3	4
218 S	419	2	U	Divided	80	2	3
218 N	419	2	U	Divided	80	2	3
220 S	419	2	U	Divided	80	3	4
220 N	419	2	U	Divided	80	3	4
221 W	460	2	U	Divided	80	159	160
221 E	460	2	U	Divided	80	159	160
224 W	460	2	U	Divided	80	158	159
224 E	460	2	U	Divided	80	158	159
225 E	460	2	U	Divided	9	119	120
225 W	460	2	U	Divided	9	119	120
226 E	460	2	U	Divided	11	161	162
226 W	460	2	U	Divided	11	161	162
227 W	460	2	R	Divided	9	194	195
227 E	460	2	R	Divided	9	194	195
228 W	460	2	R	Divided	9	167	168
228 E	460	2	R	Divided	9	167	168
301 N	29	3	U	Divided	5	76	77
301 S	29	3	U	Divided	5	76	77
302 S	29	3	U	Traversable	5	78	79
302 N	29	3	U	Traversable	5	78	79
303 N	29	3	U	Traversable	5	77	78
303 S	29	3	U	Traversable	5	77	78
304 N	29	3	U	Divided	5	66	67
304 S	29	3	U	Divided	5	66	67
305 N	29	3	U	Traversable	5	79	80
305 S	29	3	U	Traversable	5	79	80
308 N	29	3	U	Divided	5	75	76
308 S	29	3	U	Divided	5	75	76
309 S	29	3	U	Divided	5	80	81
309 N	29	3	U	Divided	5	80	81
312 N	29	3	R	Divided	62	99	100
312 S	29	3	R	Divided	62	99	100
314 E	58	3	R	Divided	41	326	327
314 W	58	3	R	Divided	41	326	327
315 E	58	3	R	Divided	41	324	325
315 W	58	3	R	Divided	41	324	325
316 W	58	3	U	Divided	71	282	283
316 E	58	3	U	Divided	71	282	283
317 E	58	3	U	Divided	71	303	304
317 W	58	3	U	Divided	71	303	304
318 E	58	3	U	Divided	71	287	288
318 W	58	3	U	Divided	71	287	288
319 W	58	3	R	Divided	71	281	282
319 E	58	3	R	Divided	71	281	282
321 W	460	3	U	Divided	15	196	197

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
321 E	460	3	U	Divided	15	196	197
322 W	58	3	R	Divided	15	215	216
322 E	58	3	R	Divided	15	215	216
323 E	460	3	R	Divided	6	223	224
323 W	460	3	R	Divided	6	223	224
324 W	460	3	U	Divided	15	201	202
324 E	460	3	U	Divided	15	201	202
403 S	1	4	U	Undivided	20	83	84
403 N	1	4	U	Undivided	20	83	84
404 S	1	4	U	Undivided	20	76	77
404 N	1	4	U	Undivided	20	76	77
405 N	1	4	U	Divided	26	66	67
405 S	1	4	U	Divided	26	66	67
408 W	10	4	U	Undivided	20	14	15
408 E	10	4	U	Undivided	20	14	15
409 E	10	4	U	Divided	20	10	11
409 W	10	4	U	Divided	20	10	11
412 E	10	4	U	Divided	20	7	8
412 W	10	4	U	Divided	20	7	8
413 W	33	4	U	Divided	43	127	128
413 E	33	4	U	Divided	43	127	128
414 E	33	4	U	Undivided	43	5	6
414 W	33	4	U	Undivided	43	5	6
415 W	33	4	U	Undivided	43	6	7
415 E	33	4	U	Undivided	43	6	7
417 E	60	4	R	Divided	20	167	168
417 W	60	4	R	Divided	20	167	168
418 E	60	4	U	Undivided	20	177	178
418 W	60	4	U	Undivided	20	177	178
420 E	147	4	U	Divided	20	2	3
420 W	147	4	U	Divided	20	2	3
421 S	156	4	U	Divided	43	47	48
421 N	156	4	U	Divided	43	47	48
422 S	157	4	U	Divided	43	5	6
422 N	157	4	U	Divided	43	5	6
424 N	301	4	U	Divided	42	85	86
424 S	301	4	U	Divided	42	85	86
425 N	301	4	U	Divided	42	84	85
425 S	301	4	U	Divided	42	84	85
426 W	360	4	U	Divided	20	124	125
426 E	360	4	U	Divided	20	124	125
427 E	360	4	U	Divided	42	151	152
427 W	360	4	U	Divided	42	151	152
428 W	360	4	U	Divided	42	149	150
428 E	360	4	U	Divided	42	149	150
429 W	360	4	U	Divided	20	122	123
429 E	360	4	U	Divided	20	122	123
501 W	32/10	5	U	Traversable	61	90	91
501 E	32/10	5	U	Traversable	61	90	91
503 S	13	5	R	Divided	1	138	139
503 N	13	5	R	Divided	1	138	139
504 N	13	5	R	Divided	1	114	115
504 S	13	5	R	Divided	1	114	115
505 N	13	5	R	Divided	65	100	101
505 S	13	5	R	Divided	65	100	101

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
507 N	13	5	R	Divided	65	84	85
507 S	13	5	R	Divided	65	84	85
508 S	13	5	R	Divided	1	119	120
508 N	13	5	R	Divided	1	119	120
509 S	13	5	R	Divided	1	129	130
509 N	13	5	R	Divided	1	129	130
510 N	13	5	R	Divided	1	133	134
510 S	13	5	R	Divided	1	133	134
511 S	13	5	R	Traversable	1	123	124
511 N	13	5	R	Traversable	1	123	124
512 S	17	5	U	Divided	99	59	60
512 N	17	5	U	Divided	99	59	60
513 S	17	5	U	Divided	99	57	58
513 N	17	5	U	Divided	99	57	58
514 S	17 / 52	5	U	Divided	46	43	44
514 N	17 / 52	5	U	Divided	46	43	44
515 S	17	5	U	Divided	99	67	68
515 N	17	5	U	Divided	99	67	68
517 S	17	5	U	Divided	99	63	64
517 N	17	5	U	Divided	99	63	64
518 S	17 / 52	5	U	Divided	46	42	43
518 N	17 / 52	5	U	Divided	46	42	43
520 W	58	5	R	Divided	40	409	410
520 E	58	5	R	Divided	40	409	410
521 W	58	5	U	Divided	61	467	468
521 E	58	5	U	Divided	61	467	468
522 W	460/58	5	U	Divided	61	470	471
522 E	460/58	5	U	Divided	61	470	471
524 E	60	5	U	Traversable	99	238	239
524 W	60	5	U	Traversable	99	238	239
528 E	143	5	U	Traversable	47	32	33
528 W	143	5	U	Traversable	47	32	33
530 E	460/58	5	U	Divided	61	373	374
530 W	460/58	5	U	Divided	61	373	374
602 N	1	6	U	Undivided	89	148	149
602 S	1	6	U	Undivided	89	148	149
604 S	1	6	U	Undivided	88	139	140
604 N	1	6	U	Undivided	88	139	140
606 N	1	6	U	Divided	88	144	145
606 S	1	6	U	Divided	88	144	145
607 N	1	6	U	Undivided	89	161	162
607 S	1	6	U	Undivided	89	161	162
608 S	1	6	U	Undivided	89	163	164
608 N	1	6	U	Undivided	89	163	164
611 W	3	6	U	Divided	88	30	31
611 E	3	6	U	Divided	88	30	31
612 W	3	6	U	Divided	88	27	28
612 E	3	6	U	Divided	88	27	28
613 E	3	6	R	Divided	20	20	21
613 W	3	6	R	Divided	20	20	21
614 E	3	6	R	Divided	88	25	26
614 E	3	6	R	Divided	88	25	26
616 S	17	6	U	Divided	36	71	72
617 N	17	6	U	Divided	89	182	183
617 N	17	6	U	Divided	89	182	183

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
619 N	17	6	R	Divided	89	181	182
619 N	17	6	R	Divided	89	181	182
620 N	17	6	U	Divided	89	183	184
620 N	17	6	U	Divided	89	183	184
621 S	17	6	U	Divided	36	73	74
622 S	17	6	U	Divided	36	73	74
623 S	17	6	R	Divided	36	76	77
623 N	17	6	R	Divided	36	76	77
624 S	17	6	U	Divided	36	75	76
624 N	17	6	U	Divided	36	75	76
625 S	17	6	R	Divided	36	78	79
625 N	17	6	R	Divided	36	78	79
626 E	33	6	R	Divided	49	45	46
626 W	33	6	R	Divided	49	45	46
628 E	208	6	U	Divided	88	48	49
628 W	208	6	U	Divided	88	48	49
630 E	218	6	U	Divided	89	0	1
630 W	218	6	U	Divided	89	0	1
631 S	301	6	R	Divided	48	139	140
631 N	301	6	R	Divided	48	139	140
702 N	15	7	R	Divided	54	120	121
702 S	15	7	R	Divided	54	120	121
703 N	15	7	R	Divided	30	177	178
703 S	15	7	R	Divided	30	177	178
704 S	29	7	R	Divided	23	166	167
704 N	29	7	R	Divided	23	166	167
705 S	29	7	R	Divided	23	168	169
705 N	29	7	R	Divided	23	168	169
706 N	15	7	R	Divided	30	178	179
706 S	15	7	R	Divided	30	178	179
708 N	29	7	R	Divided	23	178	179
708 S	29	7	R	Divided	23	178	179
710 S	29	7	R	Divided	2	127	128
710 N	29	7	R	Divided	2	127	128
711 S	29	7	R	Divided	56	163	164
711 N	29	7	R	Divided	56	163	164
712 N	29	7	R	Divided	23	175	176
712 S	29	7	R	Divided	23	175	176
713 N	29	7	U	Divided	2	134	135
713 S	29	7	U	Divided	2	134	135
714 N	29	7	U	Divided	2	146	147
714 S	29	7	U	Divided	2	146	147
715 N	29	7	U	Divided	2	142	143
715 S	29	7	U	Divided	2	142	143
717 S	15	7	R	Divided	30	211	212
717 N	15	7	R	Divided	30	211	212
718 S	29	7	R	Divided	39	150	151
718 N	29	7	R	Divided	39	150	151
719 S	29	7	R	Divided	2	148	149
719 N	29	7	R	Divided	2	148	149
720 N	29	7	R	Divided	2	133	134
720 S	29	7	R	Divided	2	133	134
721 N	15	7	R	Divided	30	208	209
721 S	15	7	R	Divided	30	208	209
724 S	29	7	R	Divided	56	164	165

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
724 N	29	7	R	Divided	56	164	165
726 E	33	7	R	Divided	39	59	60
726 W	33	7	R	Divided	39	59	60
728 E	250	7	U	Divided	2	99	100
728 W	250	7	U	Divided	2	99	100
730 E	250	7	U	Traversable	2	98	99
730 W	250	7	U	Traversable	2	98	99
801 E	7	8	U	Divided	34	2	3
801 W	7	8	U	Divided	34	2	3
802 E	7	8	U	Divided	34	4	5
802 W	7	8	U	Divided	34	4	5
803 E	7	8	U	Divided	34	3	4
803 W	7	8	U	Divided	34	3	4
804 W	7	8	R	Divided	21	8	9
804 E	7	8	R	Divided	21	8	9
806 S	11	8	R	Divided	81	205	206
806 N	11	8	R	Divided	81	205	206
807 N	11	8	R	Divided	81	204	205
807 S	11	8	R	Divided	81	204	205
808 W	33	8	R	Divided	82	27	28
808 E	33	8	R	Divided	82	27	28
809 E	33	8	R	Divided	82	34	35
809 E	33	8	R	Divided	82	34	35
810 W	33	8	U	Divided	82	26	27
810 E	33	8	U	Divided	82	26	27
811 E	33	8	R	Divided	28	28	29
811 W	33	8	R	Divided	28	28	29
812 N	37	8	U	Divided	34	0	1
812 S	37	8	U	Divided	34	0	1
814 S	50	8	R	Divided	34	19	20
814 N	50	8	R	Divided	34	19	20
815 S	50	8	U	Traversable	34	18	19
815 N	50	8	U	Traversable	34	18	19
817 W	250	8	R	Divided	7	61	62
817 E	250	8	R	Divided	7	61	62
818 E	250	8	R	Traversable	7	60	61
818 W	250	8	R	Traversable	7	60	61
819 E	250	8	R	Divided	7	62	63
819 W	250	8	R	Divided	7	62	63
820 W	340	8	R	Traversable	7	8	9
820 E	340	8	R	Traversable	7	8	9
822 S	522	8	U	Divided	34	139	140
822 N	522	8	U	Divided	34	139	140
823 S	522	8	R	Divided	93	120	121
823 N	522	8	R	Divided	93	120	121
824 S	522	8	R	Divided	34	142	143
824 N	522	8	R	Divided	34	142	143
825 N	522	8	R	Divided	93	127	128
825 S	522	8	R	Divided	93	127	128
902 S	1	9	U	Divided	76	171	172
902 N	1	9	U	Divided	76	171	172
903 S	1	9	U	Undivided	29	185	186
903 N	1	9	U	Undivided	29	185	186
904 E	7	9	R	Divided	53	30	31
904 W	7	9	R	Divided	53	30	31

Site #	Route #	District	Rural/Urban	Median Type	County	Begin Milepost	End Milepost
101 S	11	1	R	Traversable	95	18	19
905 W	7	9	U	Traversable	29	66	67
905 E	7	9	U	Traversable	29	66	67
907 N	28	9	U	Traversable	76	25	26
907 S	28	9	U	Traversable	76	25	26
908 N	29	9	U	Divided	29	226	227
908 S	29	9	U	Divided	29	226	227
910 N	29	9	U	Divided	0	244	245
910 S	29	9	U	Divided	0	244	245
911 E	50	9	U	Divided	53	58	59
911 W	50	9	U	Divided	53	58	59
913 E	50	9	U	Divided	29	80	81
913 W	50	9	U	Divided	29	80	81
914 E	50	9	R	Divided	53	57	58
914 W	50	9	R	Divided	53	57	58
916 N	123	9	U	Divided	76	1	2
916 S	123	9	U	Divided	76	1	2
918 N	123	9	U	Divided	29	27	28
918 S	123	9	U	Divided	29	27	28
919 S	123	9	U	Divided	29	18	19
919 N	123	9	U	Divided	29	18	19
920 N	228	9	U	Divided	29	3	4
920 S	228	9	U	Divided	29	3	4
921 S	234	9	U	Divided	76	14	15
921 N	234	9	U	Divided	76	14	15
922 N	234	9	R	Divided	76	25	26
922 S	234	9	R	Divided	76	25	26
923 S	234	9	U	Divided	76	20	21
923 N	234	9	U	Divided	76	20	21
924 W	236	9	U	Divided	29	7	8
924 E	236	9	U	Divided	29	7	8
925 S	237	9	U	Divided	0	11	12
925 N	237	9	U	Divided	0	11	12
926 S	241	9	U	Undivided	29	0	1
926 N	241	9	U	Undivided	29	0	1
927 W	244	9	U	Divided	29	0	1
927 E	244	9	U	Divided	29	0	1
930 S	309	9	U	Undivided	29	0	1
930 N	309	9	U	Undivided	29	0	1

APPENDIX B: CRASH DOCUMENT VARIABLES

The following variables are recorded in the crash document database and were extracted for this project: Route Number, Node Number, Crash Date, Crash Hour, Lane Width, Shoulder Width, Weather, Surface Condition, Road Defects, Lighting, Collision Type, Major Factor, Severity, Persons Injured, Persons Killed, Number of Vehicles, Day of Week, Vehicle Type, Vehicle Maneuver, Driver Age, Driver Sex, and Driver Action. The following tables provide the various codes for each variable.

Table B-1. Weather

Code	Field
0	Not stated
1	Clear
2	Cloudy
3	Fog
4	Mist
5	Raining
6	Snowing
7	Sleeting
8	Smoke or dust
9	Other

Table B-2. Surface Condition

Code	Field
1	Dry
2	Wet
3	Snowy
4	Icy
5	Muddy
6	Oily
7	Other
8	Not stated

Table B-3. Road Defect

Code	Field
0	Not stated
1	No defects
2	Holes, ruts, or bumps
3	Soft or low shoulders
4	Under repair
5	Loose material
6	Restricted width
7	Slick pavement
8	Roadway obstructed
9	Other defects

Table B-4. Lighting

Code	Field
1	Dawn
2	Daylight
3	Dusk
4	Darkness (highway lighted)
5	Darkness (highway not lighted)
6	Not stated

Table B-5. Collision Type

Code	Field
1	Rear-end
2	Angle
3	Head-on
4	Sideswipe (same direction)
5	Sideswipe (opposite direction)
6	Fixed object in road
7	Train
8	Non-collision
9	Fixed object off road
10	Deer
11	Other animal
12	Pedestrian
13	Bicyclist
14	Motorcyclist
15	Backed into
16	Other
17	Not stated

Table B-6. Major Factor

Code	Field
0	Miscellaneous
1	Driver or pedestrian handicap
2	Driver under the influence
3	Driver speeding
4	Driver inattention or error
5	Vehicle defective
6	Weather or visibility conditions
7	Road defective
8	Road slick
9	Not stated

Table B-7. Severity

Code	Field
0	Fatal pedestrian
1	Fatal vehicular
2	Injury pedestrian
3	Injury vehicular
4	Property damage only
5	No injury but pedestrian

Table B-8. Day of Week

Code	Field
1	Monday
2	Tuesday
3	Wednesday
4	Thursday
5	Friday
6	Saturday
7	Sunday

Table B-9. Vehicle Type

Code	Field
0	Not stated
1	Passenger car
2	Passenger truck, pick-up, or jeep
3	Van
4	Straight truck, flatbed
5	Tractor-trailer
6	Tractor-double trailer
7	Motor home, RV
8	Oversized vehicle, road equipment
9	Bicycle
10	Moped
11	Motorcycle
12	Emergency vehicle
13	School bus
14	City or privately-owned bus
15	Commercial passenger bus
16	Other

Table B-10. Vehicle Maneuver

Code	Field
1	Going straight ahead
2	Making right turn
3	Making left turn
4	Making u-turn
5	Slowing or stopping
6	Starting in traffic lane
7	Starting from parked position
8	Stopped in traffic lane
9	Ran off road (right)
10	Ran off road (left)
11	Parked
12	Backing
13	Passing
14	Changing lanes
15	Other
16	Not stated

Table B-11. Driver Sex

Code	Field
1	Male
2	Female
3	Unknown

Table B-12. Driver Action

Code	Field
1	None
2	Exceeded speed limit
3	Exceeded safe speed but not speed limit
4	Overtaking on hill
5	Overtaking on curve
6	Overtaking at intersection
7	Improper passing of school bus
8	Cutting in
9	Other improper passing
10	Wrong side of road, not overtaking
11	Did not have right-of-way
12	Following too close
13	Fail to signal or improper signal
14	Improper turn – wide right turn
15	Improper turn – cut corner on left turn
16	Improper turn from wrong lane
17	Other improper turning
18	Improper backing
19	Improper start from parked position
20	Disregarded officer or watchman
21	Disregarded stop-go light
22	Disregarded stop or yield sign
23	Driver inattention
24	Fail to stop at through highway – no sign
25	Drive through safety zone
26	Fail to set out flares or flags
27	Fail to dim headlights
28	Driving without lights
29	Improper parking location
30	Avoiding pedestrian
31	Avoiding other vehicle
32	Avoiding animal
33	Crowded off roadway
34	Hit and run
35	Car ran away – no driver
36	Blinded by lights
37	Other violations
38	Avoiding object in roadway
39	Eluding police
40	Fail to maintain proper control
41	Improper passing
42	Improper or unsafe lane change
43	Over correction

APPENDIX C: FAULT TREE RESULTS

Table C-1. Fault Tree Results for Urban Divided Highways

Collision Types	Injury Crashes	Property Damage Crashes
Angle	**Crashes: 1487**	**Crashes: 2141**
	Signals/mi	1-Signals/mi
	3-5 Cross Routes/mi	3-5 Cross Routes/mi
	AADT: 9500-13000	AADT: 9500-13000
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45
	Driver Action: Did not have right of way	Driver Action: Did not have right of way
	3-5 Median Crossovers/mi	3-5 Median Crossovers/mi
	Commercial entrances/mi	Commercial entrances/mi
	4-6' Shoulder width	4-6' Shoulder width
Fixed Object	**Crashes: 463**	**Crashes: 598**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Cross Routes/mi	3-5 Cross routes/mi
	No Turn lanes	No Turn lanes
	4-6' Shoulder width	4-6' Shoulder width
	Night and Day Crashes	Night and Day Crashes
	AADT: 9500-13000	AADT: 9500-13000
	AADT: 9500-13000	Op Speed: 55-65
Rear End	**Crashes: 3515**	**Crashes: 5928**
	Signals/mi	Signals/mi
	3-5 Routes/mi	3-5 Routes/mi
	AADT: 9500-13000	AADT: 9500-13000
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45
	3-5 Median Crossovers/mi	3-5 Median Crossovers/mi
	Commercial entrances/mi	Commercial entrances/mi
	4-6' Shoulder width	4-6' Shoulder width
	Age 25 - 40	Age 25 - 40
	Vehicle Stopped in Traffic Lane	1-2 Signals/mi
	1-2 Signals/mi	
Sideswipe	**Crashes: 346**	**Crashes: 1367**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi	3-5 Routes/mi
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45
	3-5 Median Crossovers/mi	3-5 Median Crossovers/mi
	AADT: 9500-13000	AADT: 9500-13000
	4-6' Shoulder width	4-6' Shoulder width
	1-2 Signals/mi, commercial entrances/mi	1-2 Signals/mi
Other	**Crashes: 291**	**Crashes: 636**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi	3-5 Routes/mi
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45,55
	No Turn lanes	No Turn lanes
	4-6' Shoulder width	4-6' Shoulder width
	Night and Day Crashes	Night Crashes
		No Driveways
		AADT: 9500-13000; >13000
		Age: 25-40

Table C-2. Fault Tree Results for Rural Divided Highways

Collision Types	Injury Crashes	Property Damage Crashes
Angle	**Crashes: 1055**	**Crashes: 941**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 55-65; Speed Limit 55	Op Speed: 55-65; Speed Limit 55
	Driver Action: Did not have right of way	Driver Action: Did not have right of way
	3-5 Median Crossovers/mi, Ramps/mi	3-5 Median Crossovers/mi, Ramps/mi
	AADT: 9500-13000	AADT: 9500-13000
	4-6' Shoulder width	4-6' Shoulder width
	Truck: 5-10%	Truck: 5-10%
Fixed Object	**Crashes: 698**	**Crashes: 699**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 55-65; Speed Limit 55	Op Speed: 55-65; Speed Limit 55
	No of left turn lanes	No of Left Turn lanes, Curb and Gutter
	4-6' Shoulder width	4-6' Shoulder width
	Vehicle Maneuver: Ran off Road	Vehicle Maneuver: Ran off Road
	Age: <25	Age: <25
	Both Day and Night Crashes	Both Day and Night Crashes
Rear End	**Crashes: 1324**	**Crashes: 1843**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Truck: 5-10%, commercial entrances/mi	Truck: 5-10%, commercial entrances/mi
	Op Speed: 55-65; Speed Limit 55	Op Speed: 55-65; Speed Limit 55
	AADT: 9500-13000, No Left turn Lanes	AADT: 9500-13000, No Left Turn Lanes
	3-5 Median Crossovers/mi, Ramps/mi	3-5 Median Crossovers/mi, Ramps/mi
	4-6' Shoulder width	4-6' Shoulder width
Sideswipe	**Crashes: 317**	**Crashes: 802**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Truck: 5-10%	Truck: 5-10%, Curb and Gutter
	Op Speed: 55-65; Speed Limit 55	Op Speed: 55-65; Speed Limit 55
	AADT: 9500-13000	AADT: 9500-13000
	3-5 Median Crossovers/mi	3-5 Median Crossovers/mi
	4-6' Shoulder width	4-6' Shoulder width
Other	**Crashes: 343**	**Crashes: 743**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Truck: 5-10%	Truck: 5-10%
	Op Speed: 55-65; Speed Limit 55	Op Speed: 55-65; Speed Limit 55
	No Turn lanes	No Turn lanes
	4-7 Commercial Entrances/mi	4-7 Commercial Entrances/mi
	4-6' Shoulder width	4-6' Shoulder width
	Age: 25-40	Age: 25-40
	Night Crashes	Night Crashes

Table C-3. Fault Tree Results for Rural Undivided Highways

Collision Types	Injury Crashes	Property Damage Crashes
Angle	**Crashes: 676**	**Crashes: 880**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5; >5 Routes/mi; 1-2 Signals/mi
	Commercial Entrances/mi: >12	Commercial Entrances/mi: >12
	Op Speed: 40-50; Speed Limit 45	Op Speed: 40-50; 50-55; Speed Limit 45
	Driver Action: Did not have right of way	Driver Action: Did not have right of way
	Curb and Gutter	Curb and Gutter
	No Turn lanes; 4-6' Shoulder width	No Turn lanes; 4-6' Shoulder width
	AADT: 9500-13000	AADT: 9500-13000
	Vehicle Maneuver: Right, Left, and U-Turns	Vehicle Maneuver: Right, Left, and U-Turns
Fixed Object	**Crashes: 84**	**Crashes: 104**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Commercial Entrances/mi >12	Commercial Entrances/mi >12
	Curb and Gutter	Curb and Gutter
	No Turn lanes	No Turn lanes
	Speed Limit 45	Speed Limit 45
	Crashes Occur both day and night	Crashes Occur both day and night
	Age 25 -40	Age: 25-40
Rear End	**Crashes: 925**	**Crashes: 1351**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5; >5 Routes/mi; 1-2 Signals/mi
	Commercial Entrances/mi >12	Commercial Entrances/mi >12
	Op Speed: 40-50; Speed Limit 45	Op Speed: 40-50; 50-55; Speed Limit 45
	Curb and Gutter	Curb and Gutter
	No Turn lanes; 4-6' Shoulder width	No Turn lanes; 4-6' Shoulder width
	Vehicle Maneuver: Stopped in Traffic	Age: 25-40
	Age: 25-40, AADT: 9500-13000	AADT: 9500-13000
Sideswipe	**Crashes: 110**	**Crashes: 425**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5; >5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Commercial Entrances/mi: >12	Commercial Entrances/mi >12
	Op Speed: 40-50; Speed Limit 45	Op Speed: 40-50; Speed Limit 45
	Curb and Gutter	Curb and Gutter
	No Turn lanes; 4-6' shoulder width	No Turn lanes; 4-6' shoulder width
	Age: 25-40	Age: 25-40
Other	**Crashes: 117**	**Crashes: 110**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5; >5 Routes/mi; 1-2 Signals/mi	3-5; >5 Routes/mi; 1-2 Signals/mi
	Commercial Entrances/mi: >12	Commercial Entrances/mi: >12
	Op Speed: 40-50; Speed Limit 45	Op Speed: 40-50; Speed Limit 45
	Curb and Gutter	Curb and Gutter
	No Turn lanes; 4-6' Shoulder width	No Turn lanes; 4-6' Shoulder width
	Age: 41-55	Age: 25-40
		Crash occurs both day and night

Table C-4. Fault Tree Results for Urban Traversable Highways

Collision Types	Injury Crashes	Property Damage Crashes
Angle	**Crashes: 317**	**Crashes: 545**
	1-4 Advisory Signs/mi; 10-15% Trucks	3-5 Routes/mi; 1-2 Signals/mi
	3-5 Routes/mi, 1-2 Signals/mi	AADT: 5100-9500; 9500-13000
	AADT: 5100-9500; 9500-13000	Op Speed: 55-65; Speed Limit 45
	Op Speed: 55-65; Speed Limit 45	Driver Action: Did not have right of way
	Ramps/mi	No Turn lanes; Curb and Gutter, Ramps/mi
	No Turn lanes; Curb and Gutter	Commercial Entrances/mi: >12
	Commercial Entrances/mi: >12	10-15% trucks
Fixed Object	**Crashes: 0**	**Crashes: 48**
		3-5 Routes/mi; 1-2 Signals/mi
		AADT: 5100-9500; 9500-13000
		Op Speed: 55-65; Speed Limit 45
		No Turn lanes; Curb and Gutter
		Commercial Entrances/mi: >12
		1-4 Advisory Signs/mi; 10-15% Trucks
		Age: <25
		Vehicle Maneuver: Ran off Road
		Crashes occurred both day and night
Rear End	**Crashes: 569**	**Crashes: 1038**
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	AADT: 5100-9500; 9500-13000	AADT: 5100-9500; 9500-13000
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45
	No Turn lanes; Curb and Gutter	No Turn lanes; Curb and Gutter
	Commercial Entrances/mi: >12	Commercial Entrances/mi: >12
	1-4 Advisory Signs/mi; 10-15% Trucks	1-4 Advisory Signs/mi; 10-15% Trucks
	Age: 25-40	Age: 25-40
	Vehicle Maneuver: Stopped in Traffic	Driver Action: Following too close
Sideswipe	**Crashes: 63**	**Crashes: 193**
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	AADT: 5100-9500	Op Speed: 55-65; Speed Limit 45
	Op Speed: 50-55; 55-65; Speed Limit 45	No Turn lanes; Curb and Gutter
	No Turn lanes; Curb and Gutter	Commercial Entrances/mi: >12
	Commercial Entrances/mi: >12	1-4 Advisory Signs/mi
	1-4 Advisory Signs/mi	Age: 41-55, Truck Percentage
	Age: 41-55, Truck Percentage	Vehicle Maneuver: Changed Lanes
Other	**Crashes: 88**	**Crashes: 106**
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	AADT: 5100-9500	AADT: 5100-9500
	Op Speed: 55-65; Speed Limit 45	Op Speed: 55-65; Speed Limit 45
	No Turn lanes; Curb and Gutter	AADT: 5100-9500; 9500-13000
	Commercial Entrances/mi: >12	No Turn lanes; Curb and Gutter
	1-4 Advisory Signs/mi	Commercial Entrances/mi: >12
	Both day and night crashes	1-4 Advisory Signs/mi; 10-15% Trucks
		Both day and night crashes
		Age: 25-40

Table C-5. Fault Tree Results for Rural Traversable Highways

Collision Types	Injury Crashes	Property Damage Crashes
Angle	**Crashes: 125**	**Crashes: 198**
	1-4 Advisory Signs/mi	5-8 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 55-65; 40-49.9; Speed Limit 45	Driver Action: Did not have right of way
	Driver Action: Did not have right of way	No Turn lanes; Curb and Gutter
	No Turn lanes; Curb and Gutter	Speed Limit 45
	8-12 Driveways/mi	8-12 Driveways/mi; 8-12 Commercial Entrances/mi
	AADT: 5100-9500	AADT: 5100-9500
	Vehicle Maneuver: Right, Left, U-turns	Vehicle Maneuver: Right, Left, U-turns
Fixed Object	**Crashes: 40**	**Crashes: 47**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 40-49.9; Speed Limit 45	No Turn lanes; Curb and Gutter
	No Turn lanes; Curb and Gutter	Speed Limit 45
	AADT: 5100-9500	AADT: 5100-9500
	Vehicle Maneuver: Ran off Road	Vehicle Maneuver: Ran off Road
	Age: <25	Age: <25
	Night and Day Crashes	Night and Day Crashes
	Dry and Raining Crashes	Wet Conditions
Rear End	**Crashes: 173**	**Crashes: 253**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 40-49.9; 55-65; Speed Limit 45	No Turn lanes; Curb and Gutter
	No Turn lanes; Curb and Gutter	Speed Limit 45
	8-12 Driveways/mi	AADT: 5100-9500
	AADT: 5100-9500	Age: <25
	Age: <25; 25-40	Vehicle Maneuver: Stopped in Traffic lane
Sideswipe	**Crashes: 26**	**Crashes: 253**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 55-65; Speed Limit 55	No Turn lanes;4-6' Shoulder width
	No Turn lanes; 4-6' Shoulder width	Speed Limit 55
	AADT: 5100-9500	AADT: 5100-9500
	4-7 Driveways/mi	4-7 Driveways/mi
	Vehicle Maneuver: Passing Changing lanes	Vehicle Maneuver: Passing Changing lanes
		Age: 25-40
Other	**Crashes: 61**	**Crashes: 51**
	1-4 Advisory Signs/mi	1-4 Advisory Signs/mi
	3-5 Routes/mi; 1-2 Signals/mi	3-5 Routes/mi; 1-2 Signals/mi
	Op Speed: 55-65; 40-50; Speed Limit 45, 55	Op Speed: 55-65; Speed Limit 45, 55
	No Turn lanes; 4-6' Shoulder width	No Turn lanes; 4-6' Shoulder width
	4-7, 8-12 Driveways/mi	4-7, 8-12 Driveways; 8-12 Commercial Entrances/mi
	AADT: 5100-9500	AADT: 5100-9500
	Age: <25	Age: 41-55

APPENDIX D: GLM RESULTS

Rural Divided Injury

$$\text{Rear End Crashes} = \exp(-0.7627 + 0.00008 \times AADT + 0.1950 \times Signals - 0.1204 \times Left\,Turn\,Lanes)$$

Rural Divided PDO

$$\text{Rear End Crashes} = \exp(-1.0072 + 0.0001 \times AADT + 0.1173 \times Signals + 0.2133 \times Ramps)$$

$$\text{Total Crashes} = \exp(0.9156 + 0.00006 \times AADT + 0.0961 \times Signals + 0.1190 \times Ramps - 0.6033 \times Curb\,and\,Gutter)$$

Rural Divided Injury + PDO

$$\text{Rear End Crashes} = \exp(-0.2065 + 0.0001 \times AADT - 0.5329 \times Curb\,and\,Gutter + 0.2056 \times Signals - 0.1138 \times Left\,Turn\,Lanes + 0.2076 \times Ramps)$$

$$\text{Total Crashes} = \exp(1.5028 + 0.1585 \times Signals - 0.0596 \times Left\,Turn\,Lanes - 0.4899 \times Curb\,and\,Gutter + 0.00005 \times AADT)$$

Urban Divided Injury

$$\text{Rear End Crashes} = \exp(0.1799 + 0.0415 \times CommercialEntrances + 0.00006 \times AADT)$$

$$\text{Total Crashes} = \exp(1.2075 + 0.00003 \times AADT + 0.0396 \times Commercial\,Entrances)$$

Urban Divided PDO

$$\text{Rear End Crashes} = \exp(0.2765 + 0.1354 \times Signals + 0.0356 \times Commercial\,Entrances + 0.00006 \times AADT)$$

$$\text{Total Crashes} = \exp(1.0312 + 0.0843 \times Cross\,Routes + 0.0272 \times Commercial\,Entrances + 0.00006 \times AADT)$$

Urban Divided Injury + PDO

$$\text{Angle Crashes} = \exp(1.8164 + 0.000008 \times AADT - 0.1927 \times Shoulder\,Width + 0.0655 \times Median\,Crossovers)$$

$$\text{Rear End Crashes} = \exp(0.9460 + 0.00006 \times AADT + 0.0481 \times Commercial\,Entrances)$$

$$\text{Total Crashes} = \exp(1.9806 + 0.0440 \times Commercial\,Entrances + 0.00004 \times AADT)$$

Urban Undivided Injury + PDO

$$\text{Total Crashes} = \exp(2.1827 + 0.00005 \times AADT + 0.0980 * \text{Cross Routes})$$

Urban Traversable Injury

$$\text{Rear End Crashes} = \exp(0.4660 + 0.00007 \times AADT)$$

$$\text{Total Crashes} = \exp(1.1819 + 0.00006 \times AADT)$$

Urban Traversable PDO

$$\text{Rear End Crashes} = \exp(1.0241 + 0.00008 \times AADT)$$

$$\text{Total Crashes} = \exp(1.3083 + 0.00008 \times AADT + 0.0399 \times \mathit{Truck\ Percentage})$$

Urban Traversable Injury + PDO

$$\text{Angle Crashes} = \exp(1.1689 + 0.00005 \times AADT + 0.3047 \times \mathit{Ramps})$$

$$\text{Rear End Crashes} = \exp(1.4461 + 0.00008 \times AADT)$$

$$\text{Total Crashes} = \exp(2.2412 + 0.00007 \times AADT)$$

Table D-1. GLM Injury *P*-Value

Highway Type	Crash Type	Variables	*P*-Value
Urban Divided	Rear End	Commercial Entrances	0.0030
		AADT	<0.0001
	Total	AADT	0.0038
		Commercial Entrances	0.0004
Rural Divided	Rear End	AADT	<0.0001
		Signals	<0.0001
		Left Turn Lanes	0.0247
Urban Traversable	Rear End	AADT	0.0013
	Total	AADT	0.0057

Table D-2. GLM PDO *P*-Value

Highway Type	Crash Type	Variables	*P*-Value
Urban Divided	Rear End	Signals	0.0103
		Commercial Entrances	0.0092
		AADT	<0.0001
	Total	Cross Routes	0.0044
		Commercial Entrances	0.0063
		AADT	<0.0001
Rural Divided	Rear End	AADT	<0.0001
		Signals	0.0473
		Ramps	0.0077
	Total	AADT	<0.0001
		Signals	0.0019
		Ramps	0.0215
		Curb and Gutter	0.0010
Urban Traversable	Rear End	AADT	<0.0001
	Total	AADT	<0.0001
		Truck Percentage	0.0466

Table D-3. GLM Injury + PDO *P*-Value

Highway Type	Crash Type	Variables	*P*-Value
Urban Divided	Angle	AADT	0.5339
		Shoulder Width	<0.0001
		Median Crossovers	0.0832
	Rear End	AADT	<0.0001
		Commercial Entrances	0.0003
	Total	Commercial Entrances	<0.0001
		AADT	<0.0001
Rural Divided	Rear End	AADT	<0.0001
		Curb and Gutter	0.0301
		Signals	0.0002
		Left Turn Lane	0.0272
		Ramps	0.0029
	Total	Signals	<0.0001
		Left Turn Lane	0.0526
		Curb and Gutter	0.0012
		AADT	<0.0001
Urban Traversable	Angle	AADT	<0.0001
		Ramps	0.0040
	Rear End	AADT	<0.0001
	Total	AADT	<0.0001
Urban Undivided	Total	AADT	0.1413
		Cross Routes	0.1308