

ROADWAY MEDIAN TREATMENTS

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Phase 1 and Phase 2
MBTC DOT 2055 and MBTC DOT 2067
February 2010

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REPORT DOCUMENTATION PAGEForm Approved
OMB No. 074-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY <i>(leave blank)</i>		2. REPORT DATE Submitted to MBTC 2/1/2010	3. REPORT TYPE AND DATES COVERED Submitted to MBTC 2/1/2010	
4. TITLE AND SUBTITLE ROADWAY MEDIAN TREATMENTS – Phase 1 and Phase 2			5. FUNDING NUMBERS <i>(leave blank)</i>	
6. AUTHOR(S) J. L. Gattis, L. K. Duncan, M. S. Tooley, A. S. Brewer, M.Q. Le, and P. Muthu				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Mack-Blackwell Transportation Center 4190 Bell Engineering Center University of Arkansas Fayetteville, AR 72701			8. PERFORMING ORGANIZATION REPORT NUMBER MBTC DOT 2055	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Special Programs Administration 400 Seventh Street, SW Washington, DC 20590-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER <i>(office use - leave blank)</i>	
11. SUPPLEMENTARY NOTES Supported by a grant from the U.S. Department of Transportation University Transportation Centers program.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT <i>(to be completed by reporting agency - leave blank)</i>			12b. DISTRIBUTION CODE N/A	
13. ABSTRACT <i>(Maximum 200 Words)</i> This research project examined relationships among crash rates, cross section design elements, and other operational attributes of multilane urban and suburban roadways in Arkansas. Crash rates for four cross section categories (roadways with no median, roadways with occasional left-turn lanes, roadways with continuous two-way left turn-lanes, and roadways with raised or depressed medians) were compared. Freeways were not considered. Crash histories were examined for cross section types, speed limits, volumes, widths of through lanes, presence of curb or shoulder, outer shoulder widths, median widths, and the densities of various types of access. Some variables were correlated, and it was suspected that such correlations can skew crash prediction models. Generally, the raised or depressed median group had slightly lower crash rates. The findings can help planners and designers when selecting the median type and cross section design for multilane roadways in rural areas that face future urban development, and in urban areas.				
14. SUBJECT TERMS Access, Crash rate, Lane width, Median, Signal density, Speed, Volume			15. NUMBER OF PAGES 82	
			16. PRICE CODE N/A	
17. SECURITY CLASSIFICATION OF REPORT none	18. SECURITY CLASSIFICATION OF THIS PAGE none	19. SECURITY CLASSIFICATION OF ABSTRACT none	20. LIMITATION OF ABSTRACT N/A	

Technical Report Documentation Page

1. Report No. MBTC DOT 2055	2. Government Accession No. <i>(leave blank)</i>	3. Recipient's Catalog No. <i>(leave blank)</i>	
4. Title and Subtitle ROADWAY MEDIAN TREATMENTS – Phase 1 and Phase 2		5. Report Date Submitted to MBTC 2/1/2010	
		6. Performing Organization Code	
7. Author(s) J. L. Gattis, L. K. Duncan, M. S. Tooley, A. S. Brewer, M.Q. Le, and P. Muthu		8. Performing Organization Report No.	
9. Performing Organization Name and Address Mack-Blackwell Transportation Center 4190 Bell Engineering Center University of Arkansas Fayetteville, AR 72701		10. Work Unit No. (TRAIS) <i>(leave blank)</i>	
		11. Contract or Grant No. <i>(leave blank)</i>	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Special Programs Administration 400 Seventh Street, SW Washington, DC 20590-0001		13. Type of Report and Period Covered Final Report 7/1/2010-12/31/2004	
		14. Sponsoring Agency Code <i>(leave blank)</i>	
15. Supplementary Notes Supported by a grant from the U.S. Department of Transportation University Transportation Centers program.			
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17. Key Words Access, Crash rate, Lane width, Median, Signal density, Speed, Volume		18. Distribution Statement No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 82	22. Price N/A

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ACKNOWLEDGMENTS

The support of the Mack-Blackwell Transportation Center, and the Department of Transportation, University Transportation Centers Program made this research possible.

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arkansas State Highway and Transportation Department or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ROADWAY MEDIAN TREATMENTS

by

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CHAPTER 1 INTRODUCTION

Transportation agencies are faced with the question of how to develop rural multilane roadways before urban development expands and encroaches upon what had been a rural roadway environment. It is often easier to alter the median when the roadway environment is still rural, rather than to wait until urbanized development has occurred along the roadway.

The purpose of this research project was to examine relationships among crash rates, cross section design elements, and other operational attributes of multilane urban and suburban roadways in Arkansas. The findings can help planners and designers when selecting the median type and cross section design for multilane roadways in rural areas that face future urban development, and in urban areas.

BACKGROUND

The Green Book (*A Policy on Geometric Design of Highways and Streets*, 2004) by the American Association of State Highway and Transportation Officials (AASHTO) defines a median as “the portion of a highway separating opposing directions of the traveled way.” The functions performed by a median include the following.

- separate traffic traveling in opposing directions
- provide a recovery area for out-of-control vehicles
- provide a stopping area in case of emergencies
- allow space for speed changes and storage of left-turning and U-turning vehicles
- minimize headlight glare
- provide width for future lanes
- provide an open green space
- provide a refuge area for pedestrians crossing the street

The Green Book categorizes medians as depressed, raised, or flush with respect to the traveled way surface. Median width is defined as the cross-section dimension between the edges of the traveled way and includes inside shoulders, if any.

In order to identify and distinguish among the various types of medians, the following categories or types were defined for the study (see Exhibit 1-1).

- None: four or more through lanes with no median.
- None+LTL: four or more through lanes, no median, with one or more left turn lanes
- Narrow (Nar): four or more through lanes, flush center median not wide enough for a lane
- Wide: four or more through lanes, flush median with a width greater than or equal to eight feet (ft).
- TWLTL: four or more through lanes, flush median marked for TWLTL (two-way left-turn lane).
- Raised (Rais): four or more through lanes with raised, curbed median
- Depressed (Dep): four or more through lanes with depressed median.

Both the Raised and the Depressed medians can be categorized as “restrictive” medians, in that opportunities to turn left across or to cross over the median are more restricted than with other types. Due to sample size limitations, some types were eliminated or combined, and the following types were analyzed: None, None+LTL, TWLTL, and Raised+Depressed.

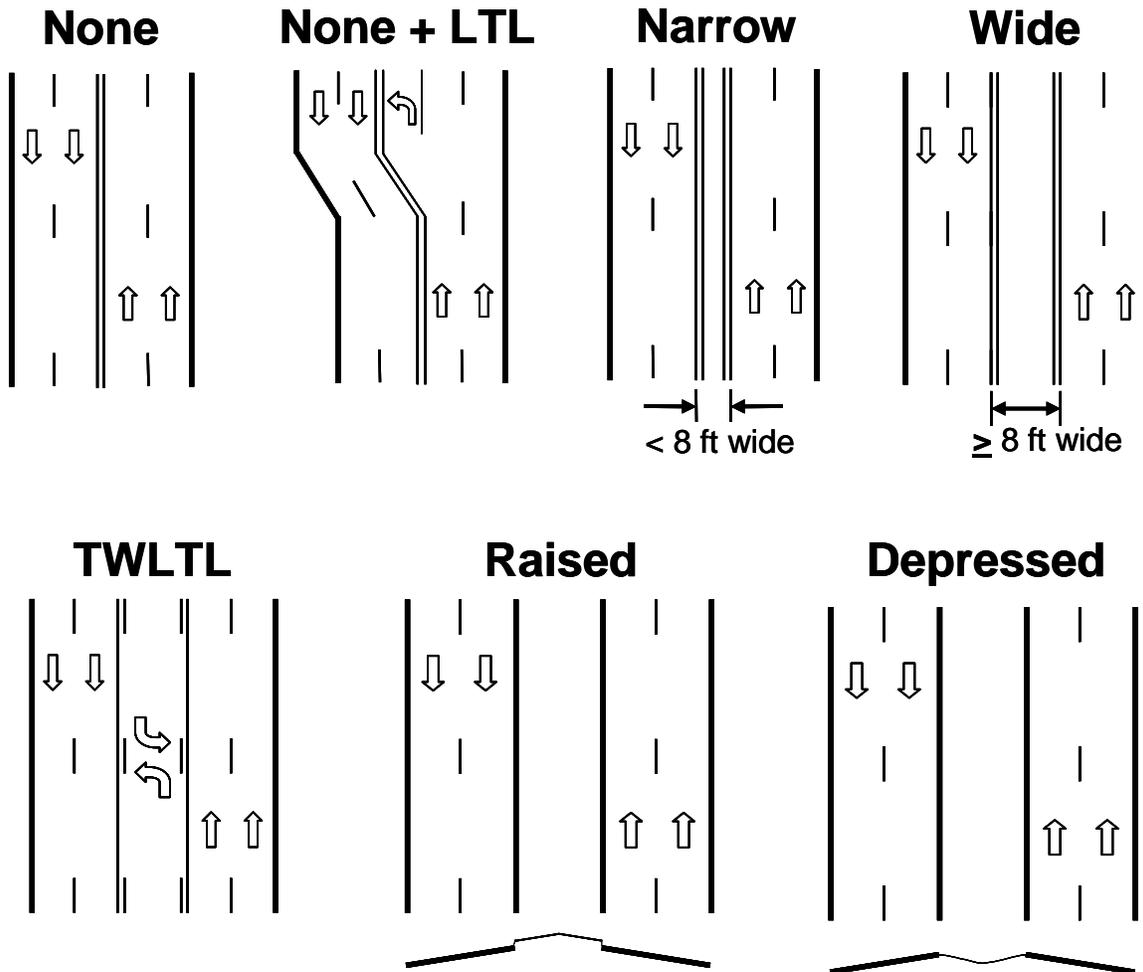


EXHIBIT 1-1 Median categories

CHAPTER 2

LITERATURE REVIEW

The findings from a number of studies that have examined relationships among various combinations of cross section elements, traffic characteristics, and safety are summarized in this chapter.

SAFETY EFFECTS OF MEDIANS TYPES AND WIDTHS

The research study findings presented in this section are confined to relationships between safety and median type or width.

Long Study

Long (1993) compared median treatments on Florida arterial crash rates. Four years of crash data, categorized as total crashes and mid-block crashes, were used. The median types included were undivided cross section, TWLTL, flush-paved, TWLTL plus flush-paved, flush-grass, raised, and raised plus flush-grass. Long found that for four-lane urban arterials, roadways with a median had the lowest crash rate, while roadways with an undivided cross section had the highest total crash rates and mid-block crash rates.

Bowman and Vecellio Study

Bowman and Vecellio (1994) determined the vehicle and pedestrian crash rates for 15 arterial roadways. The sites were in both central business districts (CBD) and in suburbs of Atlanta, Phoenix, Los Angeles, and Pasadena. They compared rates among roadways with raised-curb medians, TWLTL medians, and undivided cross sections.

Crashes were categorized as having occurred at mid-block or at signalized intersections, and also by crash type and severity. Segments were categorized as being in a CBD or suburb. Land use was categorized as residential, office, and business. They reported the following results.

- In CBD areas, undivided roadways had the highest vehicle crash rate, and TWLTL roadways had the lowest crash rate. The TWLTL crash rate was significantly lower than undivided, but no significant difference was found between the raised-curb median and TWLTL, or between the raised-curb median and the undivided cross section.
- In suburban areas, raised median had significantly lower vehicular accident rate than TWLTL and undivided median.
- In both CBD and suburban areas, the raised-curb median had lower vehicular crash rates with personal injuries than either TWLTL or undivided cross section. In suburban areas, the vehicular crash rate with personal injuries for raised-curb median sections was significantly lower than that for TWLTL sections. Undivided cross section roadways had lower vehicle crash rates than TWLTL median roadways in suburban areas.

Harwood et al. Study

Harwood et al. (1995) examined the operational and safety impacts of median widths on divided highways (i.e., depressed and raised median highways) at rural and suburban intersections. Forty selected

highways in ten states were observed; however, only California state highways were examined for a crash analysis (2,140 total intersections). It should be noted that the crash analysis actually included suburban and urban intersections, but, as the authors state, most divided highway intersections on state highways in California are suburban. Three years of crash data were used. A summary of the urban/suburban crash analysis is listed below.

- At urban/suburban, four-legged, unsignalized intersections, crash frequency increased as median width increased over the range of median widths (14 to 80 ft). This result was statistically significant.
- At urban/suburban, three-legged, unsignalized intersections, crash frequency increased as median width increased over the range of median widths (14 to 80 ft). This result was statistically significant.
- At urban/suburban, four-legged, signalized intersections, crash frequency increased as median width increased over the range of median widths (14 to 80 ft). This result was statistically significant.

Harwood et al. made the following recommendations about median widths based on safety considerations at suburban intersections.

- At suburban, unsignalized intersections, median widths should be as narrow as possible while providing sufficient space in the median for appropriate left-turn treatment (e.g., approximately 14 to 18 ft for raised medians). Median widths greater than 50 ft generally should be avoided.
- At suburban, signalized intersections, median widths should be as narrow as possible while providing sufficient space in the median for appropriate left-turn treatment.

Parsonson et al. Study

Parsonson et al. (2000) described a Georgia study comparing the safety effects of TWLTL and of divided, non-traversable medians (raised or depressed) on multilane highways. The study did not distinguish between urban and rural locations or between four-lane highways and six-lane highways. Three years of crashes were categorized as intersection related or mid-block related. Crashes were also categorized according to severity. Both total and mid-block crashes were lower for all levels of severity (including pedestrian fatalities) on roadways with divided, non-traversable medians than on roadways with a TWLTL.

Self Study

A study conducted by Self (2003) for the Charlotte Department of Transportation compared the crashes on median divided and five lane roadways (TWLTL) in Charlotte. Three and a half years of crash data in eleven major arterials were used in the study. Crashes at signalized intersection were excluded from the study. Self found out that median divided roadways were safer than five lane roadways.

SAFETY EFFECTS OF MEDIANS AND OTHER CHARACTERISTICS

This section reports outcomes from studies that examined combinations cross section and operational variables.

Hadi et al. Study

A study conducted by Hadi et al. (1995) estimated the effects of roadway design attributes on crashes for the Florida Department of Transportation. The divided roadway median categories were depressed, raised-curb, crossover resistance, and TWLTL. Roadway categories included:

1. four-lane, non-freeway urban divided roadways with an average annual daily traffic (AADT) between 10,000 and 50,000 vehicles per day (vpd); and
 2. four-lane, non-freeway urban undivided roadways with AADT between 5,000 and 40,000 vpd.
- The variables considered were posted speed limit, volume, median width and type, lane width, shoulder width, presence of curb, and number of intersections. Crashes over a four-year period were categorized by severity and as mid-block (non-intersection) or intersection related.

The study reported the following findings related to crashes on urban four-lane, non-freeway roadways.

- **Speed:** For undivided roadways, as the posted speed limit increased, the total and mid-block crash frequencies increased significantly. For divided roadways, as the posted speed limit increased, the crash frequencies also increased, but not significantly.
- **Volume:** For undivided and divided roadways, as AADT increased, both the total and mid-block crash frequency increased significantly. However, the authors' graph of mid-block crash rate (crash/MVkm) versus AADT (Hadi et al. did not graph crash rates) shows that the crash rate increased for divided roadways but decreased for undivided roadways. The authors offered no explanation for or discussion about this difference.
- **Median Type:** For divided roadways, there was a significant relationship between the mid-block crash frequencies and the depressed, raised, and crossover resistance median types. The depressed median had the lowest crash frequency, followed by raised median, crossover resistance, and TWLTL.
- **Median Width:** For divided roadways, as the square root of median width increased, the total and mid-block crash frequencies decreased significantly.
- **Lane Width:** For undivided roadways, as lane width increased, the crash frequency decreased significantly for both the total and mid-block crash analysis. They found no significant relationship for lane width on divided roadways.
- **Curb:** For four lane urban undivided roadways, the presence of curb was associated with lower crash frequency. However, the presence of curb was adverse in most other cases.
- **Shoulder Width:** For divided roadways, as the outer paved shoulder width increased, the crash frequency decreased significantly for both the total and mid-block crash analysis. The authors found no significant relationship for outer paved shoulder width on undivided roadways.
- **Intersection Frequency:** For both divided and undivided roadways, as the intersection frequency increased, the crash frequency increased significantly for both total and mid-block crashes.

Squires and Parsonson

Squires and Parsonson (1989) compared crash rates for raised medians and TWLTL medians on four and six-lane urban roadways in Georgia. Two to three years of crash data were categorized by severity and as mid-block or intersection related. Signal density and driveway density were also considered in the analysis.

Only signal density was found to be significant in the regression model. Squires and Parsonson found that in general on four-lane roadways, raised medians had a lower mid-block crash rate and lower crash rate than TWLTL medians. But, the difference between their rates decreases from 26% to 3% as the signal density increases from 1 to 4 per mile. However, at a smaller sample size, the TWLTL median was safer on six lane roadways only when (1) the driveway density was greater than 70 driveways per mile,

(2) the signal density was equal or less than two signals per mile, and (3) the non-signalized intersection density was less than 5 to 6 approaches per mile.

Bonneson and McCoy Study

Bonneson and McCoy (1997) examined crash frequencies on urban arterials for different median types over three years in Phoenix and Omaha. The median types studied were raised-curb median, TWLTL, and undivided cross section. Bonneson and McCoy also included undivided medians with on-street parallel parking in the analysis. Crashes which occurred at intersections, crashes which occurred on ice or snow-covered streets, and crashes which occurred when the driver was under the influence of drugs or alcohol were eliminated from analysis. Access densities according to type were considered in Bonneson and McCoy's analysis. The two access categories used were office/business and residential/industrial. A summary of Bonneson and McCoy's findings follows.

- As driveway density and unsignalized street approach density increased, crash frequency on segments with office or business land uses increased significantly. However, no significant relationship was found for segments with residential or industrial land uses.
- In general, crash frequencies were higher when the land use was office/business as opposed to residential/industrial.
- As the ADT increased, the crash frequency increased significantly.
- Overall, no significant differences in crash frequency were found between the undivided, TWLTL, and raised-curb medians. However, the undivided median with on-street parking had significantly higher crash frequency than the other three median types. For office/business land use areas, the difference between the undivided and TWLTL median treatments was negligible. For both office/business and for residential/industrial areas, the raised-curb median had a slightly lower crash frequency than the other two median types. The TWLTL median was associated with a higher crash frequency than the undivided median for volumes less than about 25,000 vpd in residential/industrial areas; the opposite was true for volumes greater than about 25,000 vpd.

Brown and Tarko Study

A study conducted by Brown and Tarko (1999) for the Indiana Department of Transportation examined the effects of urban arterial access densities on crash rates through the use of a negative binomial model. Other factors considered included presence of outside shoulder, proportion of access points which were signalized, and median type. The median categories were TWLTL, no median, and non-TWLTL median with no openings between signalized intersections. A summary of Brown and Tarko's findings is listed below (Brown and Tarko 1999).

- As access density increased, the crash frequency increased significantly.
- The presence of an outside shoulder was significantly related to a decrease in crash frequency, compared to no shoulder.
- The presence of signals was significantly related to an increase in crash rates, compared to no signals.
- Segments without medians appear to have no significant relationship with crash frequency. Brown and Tarko stated that this information was included in the model, but later make no mention nor presents the results of this variable in any way.

- The presence of a TWLTL was significantly related to crash frequency, as was non-TWLTL medians with no openings between signalized intersections. However, Brown and Tarko did not explicitly test for differences in crash frequencies between the median types.

Mouskos et al. Study

Mouskos et al. (1999) examined the effects of mid-block access points on crash rates for 200 sections taken from four arterials in New Jersey. A few of the sections had only two-lanes. Other factors, such as AADT time of day, shoulder treatment, presence of median, and speed limit were considered. Crashes were categorized by location (at a signalized intersection or not) and by severity. A summary of the authors' findings follows.

- On both two-lane and four-lane roadways, the crash rate decreased as the speed limit increased.
- For combined two-lane and four-lane roadways, Mouskos et al. reported that the crash rate increased from 25 mph to 35 mph, then decreased from 35 mph to 55 mph. Roadways with speed limits between 30 to 40 miles per hour had the highest crash rate.
- The crash rate increased with access density when access density was relatively low. However, when access density reaches 20 access points per mile, the increasing trend slows down. At the level of 40-50 access points per mile, the crash rate reaches its peak then declines significantly.
- Approximately 70 percent of all the crashes occurred at signalized intersections.
- Left turn and angle crashes were proportionally higher at signalized intersections than in between signalized intersections. However, single vehicle and rear-end crashes were proportionally higher in between signalized intersections than at signalized intersections.
- The evening peak hour between 4:00 PM and 5:00 PM exhibited the highest percentages of crashes.
- The crash rate was slightly higher on four-lane roadways with shoulders than those without.
- The mean crash rate, along with the variance, was moderately higher on four-lane roadways with a median (the author does not state the type or types of medians included in this study) than those without a median.

Papayannoulis et al. Study

A study conducted by Papayannoulis et al. (1999) investigated the effects of access spacing on crash rates on selected arterials from eight states. The characteristics considered included signalized and unsignalized access density, urban or rural designation, median type (undivided, TWLTL, and non-traversable median), land use, and ADT. The findings for urban plus suburban subset in this study are summarized below.

- In general, as access density increased, the crash rate increased.
- Comparing the three types, the non-traversable median had the lowest crash rate across all access densities, while the undivided cross section median treatment had the highest crash rate across all access densities. No statistical analysis was performed between the median types.
- The crash rate increased as the signalized access density increased.

Sawalha and Sayed Study

Sawalha and Sayed (2001) developed a model for evaluating safety of urban arterial roadways. A total of 392 segments from 58 arterials in the cities of Vancouver and Richmond (British Columbia,

Canada) were used for the study. Crashes that occurred at signalized intersection were excluded from the analysis. The generalized linear modeling approach was used to develop the model.

Sawalha and Sayed found out that traffic volume, length of section, unsignalized intersection density, driveway density, pedestrian cross over density, number of traffic lanes, types of medians, and nature of land use had a significant positive impact on accident rates. Converting an undivided arterial to a raised curb median would result in an average 10% accident reduction.

Strathman et al. Study

Strathman et al. (2001) developed a statistical relationship between roadway design attributes and crashes for the Oregon Department of Transportation. The two years of crash data for 11,635 segments did not include work zone or intersection-related crashes.

The study distinguished between freeway or non-freeway, and location urban or rural. It included a number of attributes such as roadway geometry, lane/shoulder widths, posted speed limits, median type (only depressed and raised-curb medians were considered), and ADT. A summary of the urban, non-freeway findings follows. It should be noted that Strathman et al. made no specific conclusions from the analysis, as the estimated parameters which were used in the statistical analysis “are not directly interpreExhibit”.

- Roadway curvature and gradient attributes were found to have little statistical relationship with crashes.
- As ADT increased, crash frequency increased significantly
- As the posted speed limit increased, crash frequency decreased significantly.
- As the number of lanes increased, crash frequency increased significantly
- As lane width increased, crash frequency increased. This relationship was not statistically significant.
- As outer shoulder width increased, crash frequency decreased. This relationship was not statistically significant.
- Crash frequency was decreased significantly with the presence of raised median.
- Raised-curb medians appeared to be associated with lower crash frequencies than vegetated medians. Although presence of either median type was inversely related to crash rate, raised-curb medians were statistically significant in the model while vegetated medians were not.

Access Management Manual

The 2003 *Access Management Manual* (CAM) related that crash rates increase with the square root of access density, up to about 40 access points per mile.

Gattis, Balakumar, and Duncan

This 2003 study examined the safety records of different rural and suburban highway cross-section alternatives in Arkansas. It attempted to assess the safety effects of various median types. From their findings, the following conclusions about selecting roadway design features for future construction, or reconstruction of existing roadways were offered.

- On the roadways with lower access density (< 20 access points per mile), roadways with depressed medians had the best safety record, followed by no median, then by narrow median. Sample size was not sufficient to study the roadways with barrier median, raised/curbed median, and TWLTL.
- On the roadways with medium access density (20 – 40 access points per mile), roadways with narrow medians had the better safety record, followed by TWLTLs. Roadways with no median had the worst safety record on medium access density roadways. Although depressed median roadways had the best safety record, the small sample size limited inferences from this dataset. There were no samples for the roadways with barrier medians and raised or curbed medians. Further investigation revealed that the comparison between roadways with Narrow medians and those with TWLTLs was somewhat skewed by the fact that the roadways with Narrow medians had lower volumes, wider average lane width, and lower access density. When the comparison between “Narrow” and TWLTL crash rates was confined to roadways with the same volume range, the TWLTL were safer, but the sample size was small.
- On roadways with high access density (> 40 access points per mile), the TWLTL had the best safety record, followed by roadways with no median. Sample size was not sufficient to compare roadways with depressed medians. There were no samples of roadways with barrier medians, raised or curbed medians, and narrow medians.
- For all the access density groups, the roadways with curbs immediately adjacent to the traveled lanes had a higher crash rate than the roadways with shoulder, irrespective of the median type.
- The negative binomial analysis indicated that the crash rates were significantly higher on the roadway segments with a curb compared to roadway segments with a shoulder. As the width of the median increased, the crash rate decreased significantly. As ADT increased, the crash rate also increased. The relationship between ADT and crash rate was not as strong as the relationship between the other two variables and the crash rate.

Saito et al. Study

Saito et al. (2004) compared crashes before and after the installation of raised medians on four arterials in Salt Lake County, Utah. They found the following.

- Crash rates for all four arterials increased after installation of a raised median.
- Mid-block and intersection crash rates increased on all four sites.
- Right angle crash rates decreased at mid-block and stayed the same or decreased at intersections.
- Rear end crash rates increased at mid-block and stayed the same or increased at intersections.
- Crash severities decreased at mid-block and at intersections.
- The comparison of raised medians with non-raised medians showed no definite trend.

Saito et al. offered the criteria listed in Exhibit 2-1 for evaluating the need for a raised median.

Phillips et al. Study

Phillips et al. (2005) analyzed three years of crash data from midblock segments and the adjacent signalized intersection for five lane, TWLTL and four-lane, divided median roadways in North Carolina. Geometric, volume, land use, collision data, segment length, and approach density were the variables used for building the model. The findings are summarized as follows.

- Traffic volume, predominant land use, segment length, and approach density were significantly related to accidents.

- For predominantly residential or industrial land uses, raised median is safer than the TWLTL.
- For predominantly office or office land uses with low to medium approach densities (0-25 approaches per mile), raised median is safer than the TWLTL.
- For predominantly business or office land uses with medium to high approach densities (25-90 approaches per mile), TWLTL is safer than the raised median.

EXHIBIT 2-1 Raised median evaluation criteria (Saito et al.2004)

Crashes	If there are a high number of crashes that could be prevented with a raised median on a 4 or 6 lane roadway, then installing a raised median should be considered.
Pedestrians	If there are a high number of mid-block or intersection pedestrian crossings a, raised median should be provided, particularly on arterials with four or more lanes.
Volume	If the daily volume exceeds 24,000 to 28,000 on a principal or minor arterial in urban areas, a raised median installation should be considered.
Delay	If there is excessive delay on an undivided roadway because of left turns, then install a TWLTL or a raised median. If a TWLTL does not accommodate all the left-turning vehicles and causes back-ups and delay, then install a raised median and route the traffic to an intersection where it can be better accommodated.
Driveways per mile	If there are more than 60 driveways per mile, consider a raised median.
Mid-block opening	Consider mid-block openings if distance constraints are met and the opening would reduce movements at nearby intersections when a large generator is present.
Number of lanes	A raised median should be given consideration when the number of through lanes is more than four.

CHAPTER 3

DATA COLLECTION AND REDUCTION

The objective of this study was to examine relationships among crash rates and other attributes for all urban or suburban multilane roadways that are a part of the Arkansas State Highway system, excluding freeways. This chapter explains the rather lengthy and involved data collection and reduction process that was employed to improve the quality of the resulting data.

DATA SOURCES

The study made use of many sources and types of data. These include data provided by the Arkansas State Highway & Transportation Department (AHTD), data collected in the field, crash data from Arkansas State Police (ASP), and internet maps and aerial photographs.

Both AHTD and ASP identify exact locations along a roadway by means of the highway route, section, and log mile (LM) numbers. AHTD uses this method to define the physical location of features such as bridge ends, and the beginning and ending of a roadway segment. ASP uses the system to designate the location of crashes.

Data from AHTD

AHTD provided the following data.

- lists of candidate roadway segments and segment inventory data
- video recording of roadways (shot with a straight ahead field of view)
- list of construction projects, showing type and beginning/ending dates
- lists of traffic signal installations
- daily traffic volumes, both on maps and in a database list

Data Collected or Verified in the Field

The purposes of field data collection were to verify information from others and to obtain accurate, up-to-date roadway characteristic, access, and land use data. Much information was obtained by video taping roadway segments as the research vehicle traveled through the segment, and by making measurements. Roadway characteristic data includes the following:

- Inventory or identification information, such as district, county, route, section, beginning and ending log miles
- Posted speed limits and location
- Volume data (average daily traffic, or ADT)
- Number of through lanes
- Roadway widths: through lane width, median width, outer shoulder width
- Presence of curb (or curb and gutter) or shoulder
- Presence and location of on-street parking or bicycle lanes
- Median type: None, None with occasional left turn lanes (None+LTL), flush median with a two-way left-turn lane (TWLTL), Raised (Rais), Depressed (Dep)

- Number, location, and type (i.e., with left-turn lane or without) of median openings in segments with Raised or Depressed medians
- Number and location of left-turn lanes in segments with None+LTL medians
- Number and location of traffic signals
- Number and location of railroad crossings
- Number, location, and type of access points

Dates of construction activity and traffic signal installation helped determine which months of crash data to exclude from the subsequent analyses.

Crash Data

ASP supplied crash data for the years 1998 through 2002. These files included the following crash severity and crash type information.

Crash severity categories

- category 1 = fatal (Fat)
- category 2 = significant injury (Sig)
- categories 3 and 4 = minor injury
- category 5 = property damage only (PDO)

Crash type categories

- single vehicle crashes
- head-on crashes
- rear-end crashes
- right-angle crashes
- sideswipe (same direction) crashes
- sideswipe (opposite direction) crashes
- backing crashes
- other/unknown crashes

Internet Maps and Aerial Photos

Throughout the project, street maps obtained from the AHTD website (www.ahtd.state.ar.us/maps.htm) were utilized. The researchers also used information from internet line and aerial maps.

INITIAL PROCEDURES

In order to direct the field data collection and the subsequent data analysis efforts, a number of guidelines and procedures had to be agreed upon.

Establish Rules to Limit the Scope

To exclude inappropriate roadway segments from the study, it was necessary to create a definition for urban, non-freeway, multilane state highways. To be considered for analysis, the candidate roadway segment had to satisfy the following conditions.

- Lanes: The segment must have four or more through lanes, with an equal number of through lanes in each direction (i.e., not three lanes in one direction and two in the other).
- Speed: The segment must have a posted speed limit of 45 mph or less. Segments with a posted speed limit of 50 mph were also included if they were bounded on the “outer” end (i.e., end away from the town center) by a traffic signal.
- Access Control: Fully-controlled access roadways (freeways) were excluded.

Define Usable Roadway Segments

After a preliminary list of candidate segments was created, the researchers began to identify what were termed “usable segments” for analysis. This was an ongoing process, affected by subsequent field data collection and analysis.

To be deemed usable, certain characteristics of the segment had to remain unchanged (or constant) for a length of at least 0.3 mi. This minimum length requirement was implemented based on previous studies and researchers’ concerns. Hadi et al. used a minimum length requirement of 0.05 mi; Knuiman et al. used 0.07 mi; Bowman and Vecellio, and Council and Stewart used 0.10 mi; and Squires and Parsonson, and Bonneson and McCoy used 0.75 mi. Segments in the study by Mouskos et al. had lengths ranging from 0.3 to 2.0 mi, but the authors made no mention of minimum length requirements. Strathman et al. (Strathman et al. 2001) expressed concern over the phenomenon of “censoring”, where very short segments may have no crashes over the analysis time period, thus falsely indicating a “safe” roadway segment. Kihlberg and Tharp (Kihlberg and Tharp 1968) found an “enormous” number of zero-crash segments which were 0.10 mi in length, and thus increased the minimum length requirement to 0.30 mi for analysis.

The following characteristics of a segment had to be constant in order for the segment to remain in the study.

- Same posted speed limit in both directions
At locations where the log mile of the posted speed limit change in one direction was slightly different from the other direction, one posted speed limit log mile was used or, if close enough, averaged (e.g., if the posted speed limit change in one direction was at LM 10.26, and in the other direction it was at LM 10.24, then the boundary between the two segments was set as LM 10.25). If the directional posted speed limits were too far apart (e.g., 0.20 miles), the length of roadway between the different speed limits would be eliminated.
- Constant median type
It should be noted that there is a subtle distinction between no median type (None) and no median type with left-turn lanes (None+LTL). If a segment had at least one left-turn lane, the segment median was recorded as “None+LTL.” If the segment had no left-turn lanes, then the segment median was recorded as “None.”
- Constant edge treatment
Either curb (curb and gutter) or shoulder treatment immediately adjacent to the outside through lane had to remain the same. For the few cases where the shoulder was not paved (i.e., grass), the width was entered as zero.

- **Constant cross-sectional width**
Constant, as defined for width, is somewhat more subjective than for other elements. For practical purposes in this study, as long as any given cross-sectional element did not vary to a noticeable degree (either by visible field observation or by measured road width), the segment was considered constant in this regard. For example, if an edge line of the outside travel lane varied noticeably (e.g., the through lanes varied by about one foot), but the total cross-section width was constant, the segment was considered constant and “average” widths were recorded. For curbed segments, the cross-section width that was considered usable by driver was recorded. In most cases, it was to the joint where the gutter pan met the traveled way, not the curb face. The exception to this was for segments which had asphalt overlay up to the curb face (with no joint), in which case the width was considered up to the curb face. The justification for this was that the usable outside through lane, from the perspective of the driver, would be to the curb face if there was no joint present. If the width of one cross-section element gradually changed from one width to another, a point of change was estimated.
- **Constant on-street parking on both sides of the roadway.**
Any time there was a change between allowing and prohibiting on-street parking -- either angle parking or parallel parking -- a new segment began. (Due to the small sample size, no segments with on-street parking were included in the analysis.)

Eliminate Periods of Construction

At the beginning of the study in 2003, it was decided to compute crash rates based on crash data from the most recent available three year period. If the time period is too short (i.e. less than 21 months), then the true picture of roadway safety may not be captured due to the randomness of crash occurrence. As the length of the time period increases, the chances of a chance that roadway and/or abutting property increase. Another decision was to exclude from consideration those time intervals during which significant construction activities were in progress.

Since it was likely that construction activities had taken place on some segments during that time, it was decided to request crash data for the most recent available five year period (1998 through 2002), then use the most recent 36 months during which no significant construction activities occurred. Exhibit 3-1 is a graphical depiction of this procedure.

Develop Initial List of Segments

To identify candidate urban multilane roadway segments for this study, AHTD furnished an initial list of roadway segments. The segments were marked on AHTD maps and sent to each of the ten AHTD districts for verification. The list was then modified based on responses from the districts.

For each roadway segment on the list, the research team members viewed VHS video tapes and Multi Media Highway Information System (MMHIS) videos of the segments. AHTD supplied these videos. During the viewing, team members recorded additional roadway characteristic, log mile location, and segment definition information onto a video log form. From this process came the list of segments for field inspection and data collection.

Objective was to use data from the latest 36 month period that was not disqualified due to construction or other factors.

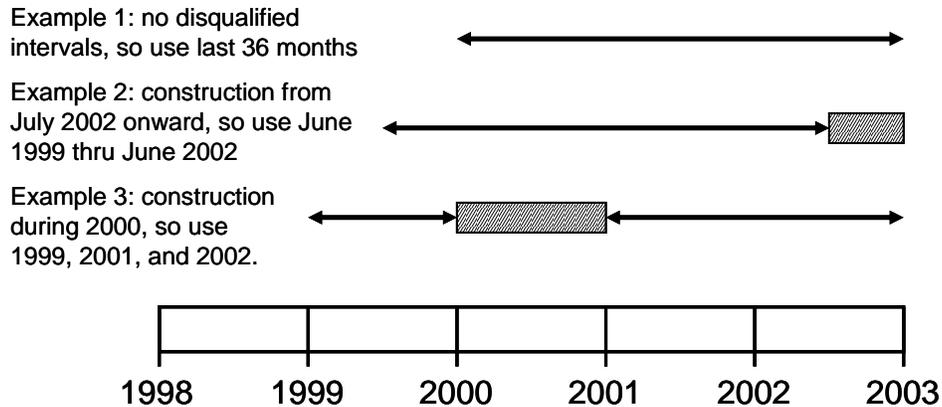


EXHIBIT 3-1 Identifying time window for crash data without construction activity

FIELD DATA COLLECTION

Field data were collected for urban and suburban multilane roads on the AHTD-numbered system. The research team used the AHTD log-mile system to define the location of features, such as the location of a speed limit sign or of a driveway.

Equipment Used

Field data were collected on all segments by two primary methods: video taping and cross-section roadway measurements. A minivan retrofitted with a yellow light bar and rear flashing lights was used for field data collection (Exhibit 3-2). The words “VEHICLE MAY SLOW OR STOP IN TRAFFIC” were displayed in large red letters on the rear hatch. These measures were taken to warn other drivers, especially those following the vehicle, of our presence.

An 8mm camcorder was set on a tripod in front of the front passenger seat. The camcorder was aimed out the front window slightly to the right. A laminated “cheat sheet” was placed on the dashboard to help the operator verbally record information into the camcorder (Exhibit 3-3).

To record accurate log miles for data collection, a distance measuring device (DMD) was installed and calibrated. The DMD display was placed on the inside of the windshield on the passenger side, so that the camcorder captured the displayed log mile in the field of view. The operator could start, stop, or reverse (i.e., count down) the mile count on the DMD at any time.

A measuring wheel was used to measure cross-sectional features. The researcher making roadway measurements always wore a reflective safety vest. Walkie-talkies were used to communicate between the measurer and the person recording the data in the minivan. Along with data recording sheets and pencils, maps and video log forms were taken into the field for reference.



EXHIBIT 3-2 Data collection vehicle



EXHIBIT 3-3 View from inside of the data collection vehicle

Field Data Collection Procedure

The field data collection process involved two people. When video taping, one person would drive while the passenger observed roadway characteristics and verbally recorded the information into the camcorder. The driver typically drove between 20 and 35 mph, depending on the driveway density. The driver also acted as a checker, reminding the recorder of anything he or she missed.

The log miles displayed on the DMD were obtained or, in rare instances, estimated from the AHTD published AADT Estimates book. Before recording, the researchers would identify a reference point in which to base the mileage on the DMD. Reference points often were bridges, intersections with state or other highways, or freeway interchanges.

When recording a segment, the recorder began by “calling out” the county, city, route, and section. The recorder would then call out the median type, curb/shoulder type, and number of lanes. After determining a known reference point, the recorder would push a button on the DMD to begin counting (either up or down). While moving, the following information was verbally recorded into the camcorder:

- Any roadway characteristic changes
This includes median change, curb/shoulder change or posted speed limit. Other information, such as an observed roadway width change or access characteristic change was recorded into the camcorder or written on the roadway measurement data form.
- All access point types, including driveways and street intersections
Driveways were generally categorized and therefore called out as commercial, industrial, residential, multi-family residential, school, church, park, or open area. Street intersections were called out along with their street names if possible, or with their highway designation if possible. If an intersection was signalized, it was called out as such.
- Other items
Examples include railroad crossings, bridge ends (along with the posted log mile if possible), overpasses, or interchanges were called out as well. This was primarily used as reference information.
- Median Openings
If the segment had a Raised or Depressed median with frequent median openings, the segment would be driven again with the camcorder pointed at the median to record the type and location of median openings.

These procedures would be repeated for both directions of travel.

Typically after the video taping was finished, the cross-section of the roadway was measured and recorded. The strategy often used was to measure homogeneous parts of the roadway once or more at the judgment of the field researcher. For some roadways, if the researcher was not as confident or had time available, more frequent measurements, usually at fixed intervals, were taken to confirm the width of homogeneous segments.

However, the goal of recording cross-sectional width and width changes was to obtain the most information as practically possible. Often, this was difficult to undertake, since the person doing the measuring could only do it during hours of off-peak traffic (weekends or mid-mornings) for safety reasons. Other factors, such as roadway curves in areas with fast-moving traffic or standing traffic near traffic signals, dictated where width measurements could be taken.

DATA REDUCTION

Once field data were collected, work began to reduce information recorded on the video tapes onto data forms (Exhibit 3-4). Each video would be viewed and transcribed to a data form which would include the log mile of each roadway feature change, reference point, driveway (along with driveway type), and street intersection (along with street name and/or designation). This was done for both direction of travel. Any extra information or notes which were spoken into the camcorder were also recorded on these forms. These video data forms were stapled with the roadway cross-sectional data sheet for each route and section.



EXHIBIT 3-4 Data reduction in progress

Data reduction procedures were developed in an attempt to garner data that were both more accurate and were presented in a way to facilitate subsequent analyses. These more detailed procedures were often done in response to a specific scenario on a specific route and section.

Segment-Related Procedures

Each roadway segment that was to be included in the analysis was defined by a beginning and an ending log mile, and had to have the previously-mentioned homogeneous attributes.

At some segments that began or ended at an intersection, what was (i.e., for the rest of the segment) the outside through lane became an outside turn lane at the intersection. At some of these intersections, there were also triangular traffic islands. Although technically these segments have fewer than four through lanes at the intersection, these segments were considered to extend up to the middle of the intersection (Exhibit 3-5).

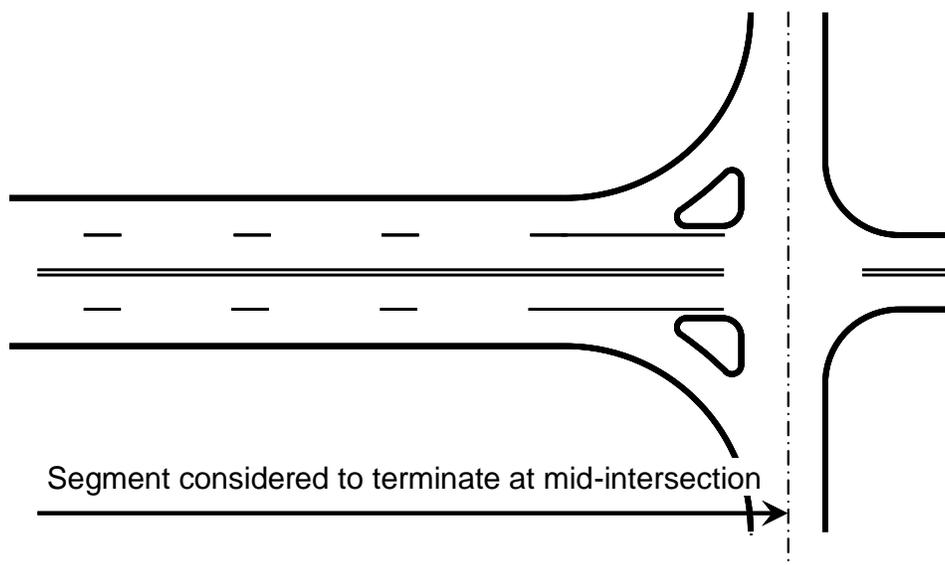


EXHIBIT 3-5 Procedure for defining segment-end at an intersection

A number of segments intersected freeway ramps or frontage roads which served the freeway ramps. In those cases, 0.10 miles was eliminated from either side of the interchange (i.e., 0.10 miles from the ramp or frontage road intersections). The primary reasons for this were: (1) the unusual characteristics of moving traffic in and around the freeway interchange; and (2) the extreme difficulty of locating crashes at interchanges, especially since most route/sections begin or end at the freeway interchange instead of continuing through it. More specifically, the records of crashes which occurred at freeway interchanges typically did not specify which freeway ramp in the “reference point” column (i.e., “I-540 ramp” is not helpful, but “I-540 NB ramp” is helpful). The only exception to this “0.10 mile from interchange rule” was if there were signalized intersections with frontage roads just “outside” the interchange (i.e., not connected to the freeway ramps), but within 0.10 miles of the ramp intersections. In these cases, the “0.05 mile” rule will be applied (i.e., the segment will begin or end 0.05 miles from the frontage road signalized intersection). In most cases, this would result in a total distance from the freeway interchange of close to 0.10 miles.

Construction-Related Segmenting Procedures

In a few instances, the mere occurrence of construction not only affected the dates used for analysis, but the segmentation process itself. Consider the following example. A two mile long segment had two verified construction jobs. Each was a different intersection improvement job, performed at different times (2000-2001, 2001-2002). Rather than excluding the years 2000 through 2002 (thus leaving only 1998-1999), one or both intersections could be “cut out” from the segment (thus creating two or more segments), which made a longer time period eligible for analysis. If this were the case, 0.05 miles from either side of the intersection was excluded from consideration.

Access-Related Procedures

Both driveways and street intersections are access points. Access points were counted separately on both sides of the street. For example, the number of access points at a four-legged intersection would be two, and at a T-intersection would be one. Access points at a five-point intersection were counted as one on one side and two on the other (three total).

There were some segments which may have met other criteria for inclusion, but were eliminated from analysis because of access issues. Namely, those segments for which access points were difficult to characterize were eliminated. This problem was compounded for access points (mostly retail-commercial buildings) where parking, even at right angle to the roadway, is so close to the through lanes that it is effectively similar to on-street parking (i.e., vehicles must either back into the parking space from the roadway or back out of the parking space onto the roadway). If a segment has only a few or less ill-defined access points with no effective on-street parking, then it was not eliminated from analysis. However, if there was some effective or true on-street parking with ill-defined access points, then the segment was eliminated from analysis.

Volume-Related Procedures

Two sources were used to determine ADT volumes: the AHTD database and the annual AHTD published AADT Estimates booklet. The database was used as the primary source. If either (1) the AADT was missing in the AHTD database, or (2) the AADT differed greatly from nearby volumes, then the AADT booklet source was used. In the latter case, almost all seemingly erroneous database volumes had a different, more “realistic” volume in the published booklet, in which case it was used instead.

Daily volume of a segment volume was computed as the weighted average over the time period. In addition, if there was more than one volume counting site within a given segment, those volume readings were averaged and sometimes weighted if warranted by the relative position of the counting site with respect to the overall length of the segment.

Consider the following example. Because of eight months of construction in 2001, the latest usable 36 months from the period 1998 through 2002 for a segment extended over 1999 (last 8 months), 2000 (12 months), 2001 (4 months), and 2002 (12 months). There were two traffic-counting sites within the segment, referred to as “count 1” and “count 2”. The following equation would have been used to calculate the segment volume.

$$\text{Volume} = \left\{ \begin{aligned} &8 \times [(1999 \text{ count}_1 + 1999 \text{ count}_2) / 2] + \\ &12 \times [(2000 \text{ count}_1 + 2000 \text{ count}_2) / 2] + \\ &4 \times [(2001 \text{ count}_1 + 2001 \text{ count}_2) / 2] + \\ &12 \times [(2002 \text{ count}_1 + 2002 \text{ count}_2) / 2] \end{aligned} \right\} / 36$$

Miscellaneous Procedures

Intersections at which the through roadway segment was stop controlled were removed from analysis (i.e., 0.05 miles from either end of the intersection was removed from analysis). Only four stop controlled intersections were found in the entire set of data (route 49/section 10B in Helena; route 100/section 1 in North Little Rock; route 112/section 0 in Fayetteville; and route 376/section 1 in Camden).

If there was more than one railroad track crossing the roadway, but only one pair of traffic control devices (one for each direction of traffic), then it was still considered as only one railroad crossing.

Median openings in Raised and Depressed median segments were defined as “with LTL” or “without LTL”. Median openings were counted as one half a median opening for each direction of travel. A median opening at the end of a divided median segment (and thus the end of the segment) at an intersection was counted as one half of an opening.

Summary of Segmentation Process

In addition to the preliminary guidelines as described in the beginning of the chapter to determine roadway segments for analysis, the following factors were also considered.

- Access type and/or density

If access point type or density or both change (either abruptly or slowly) within a segment, it was “cut” at the estimated point of change if it was practical and logical. For example, on route 10/section 8 in Little Rock (Cantrell Road), the segment from log miles 10.82 to 13.13 met the preliminary guidelines. However, it was cut at log mile 12.40 because of a major change in access density (10.82 to 12.40 had an access density of 80.4; 12.40 to 13.13 had an access density of 15.8) where the roadway began to make a hilly descent.

- City street

If a route/section followed part of two intersecting city streets, and therefore the route intersected itself, then the intersection would be the dividing point between segments. In almost all cases, the roadway characteristics were obviously different between the two streets and would have been divided regardless.

- Construction

In some cases, it was considered advantageous to cut-out a piece of segment due to construction if it meant keeping a longer time period for analysis (up to 36 months) of the rest of the segment.

- Signal density

If the signal density changed dramatically (i.e., if there were any “clusters” of signals) within segments with more than three signals and greater than or equal to one mile in length, then the segment would be divided. However, after a preliminary analysis of the segments, no further segmentation was done according to this criterion.

- Volume

If the volume was abruptly different between one piece of the segment and another, then the segment was cut at the point of difference. For example, on route 70/section 9 in Hot Springs (E. Grand Avenue), the segment from 0.00 to 1.55 has a noticeable difference between volume counts west of the intersection with Malvern Avenue (route 270/section 6B) at log mile 0.48 and east of the intersection (0.00 to 0.48 had an average volume of 22,463; 0.48 to 1.55 had an average volume of 16,893).

Crash Data Reduction

Due to concerns based on the researchers’ prior experience with crash data errors in previous studies, an involved screening process was followed, to identify and correct apparent errors in the crash data files. These steps helped improve the accuracy of the crash data.

Preliminary

Beginning with the crashes listed for an entire County, the following checks were performed to determine which crashes occurred within the segment limits and not within the verified construction months.

1. Removed all construction zone related crashes. However, they were first checked against construction dates to verify construction. In some cases, these crashes (along with the date of occurrence) were used to confirm the construction dates given by AHTD. Sometimes the crashes which occurred during construction did not match the dates given by AHTD, if at all. Either way, the presence of construction zone related crashes was sometimes used in the data verification process.
2. Removed all crashes in those roadway sections which would be very difficult to accidentally miscode or otherwise confuse with segments of interest. Roadway sections that did not intersect the route/section under question were also excluded. Note that some crashes were incorrectly coded under the wrong section number (Rte 64, section 4). Therefore, a cursory examination of all adjacent sections (e.g. Rte 64, sections 3 & 5) was also performed.
3. Verified that crash occurred on a roadway segment with four or more lanes (unless if it was referencing the intersecting side street), within an urban area type, within the city, and that the distance and direction from the given reference point (if provided) was within limits of the test segment.
4. Searched for crashes coded with alternate names of the test segment. Some roadways have multiple names, and as a result crashes on a given segment may be coded in different ways. For instance, a crash which occurred on route 71/section 16B, could have been coded as either route 71/section 16, US 71, Hwy 71, College Avenue, or N. College Avenue. Crashes recorded by a local street name or some slightly different route or section number were also searched for (e.g., with or without “B” in the previous example). This was done by either scrolling through the list and observing the location names, or, if there were many city crashes, by searching for key words (e.g., for route 71/section 16B, key words may include “71”, “College”, “School”, or “Archibald”). Crashes entered into the database by a street name instead of route number were quite common; some street names were misspelled.
5. Searched for crashes listed under the name of the intersecting roadway. If a roadway intersected the route/section under question, then entries for individual crashes were checked to see if the crash occurred at the intersection with the route/section under question. For example, most intersection crashes which were recorded as having occurred on SH 180/Sixth Street at the junction with 71/16B were included in the 71/16B crash database. Those which were determined to have not occurred at the intersection were eliminated.

Final

Once the preliminary set of potentially correct crashes was compiled, the data listed for each crash was checked to determine whether the crash should be included or excluded from the final data set. was reviewed for correctness based on various information recorded with each crash. If there was enough

justifiable reason to include or exclude a particular crash, it was done. Consequently, the following rules were also applied:

- Crashes which were recorded as having occurred on roadways which intersected the route/section under question were of interest. For example, most intersection crashes which were recorded as having occurred on SH 180/Sixth Street at the junction with 71/16B were included in the 71/16B crash database. Excluded from this were crashes recorded as rear-end or backing collisions. In these cases, it was reasoned that the crash occurred on the minor street and therefore had less of a relation to the roadway characteristics of the route/section under question. It was not uncommon for any given route and section of highway to be composed of more than one street. For example, route 70/section 12 in Pulaski County includes University Avenue, Asher Avenue, Roosevelt Road, and Broadway, all separate and identifiable streets. However, this situation can be problematic at the intersections of the streets, since rear-end and backing crashes were not counted on the minor street approach. Consider the following scenario shown in Exhibit 3-6.

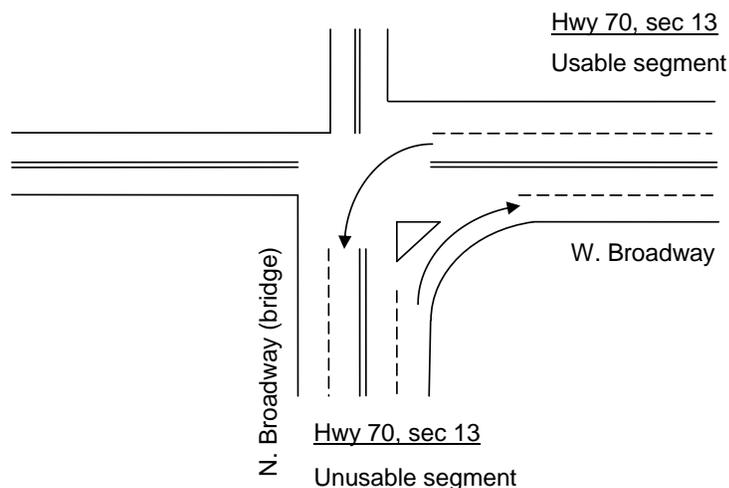


EXHIBIT 3-6 Schematic of N. Broadway and W. Broadway intersection in N. Little Rock

In this schematic diagram, route 70/section 13 approaches this intersection from the south and from the east. However, rear-end crashes, in addition to all other types of crashes (no backing crashes were found), at this intersection had not been recorded in a way that provided any identifiable “clues” to help determine on which approach they occurred. The rear-end crashes located at this intersection could have occurred at the two other approaches which are not part of the route and section. Therefore, the risk of inappropriately including (or excluding) rear-end crashes at this intersection increases dramatically. To eliminate this type of problem, 0.05 miles from either side of the intersection would be eliminated from analysis. The exception to this would be for intersections which were found to have few to no rear-end or backing crashes. In some cases, it may have been advantageous to keep the 0.05 miles on either side of the intersection, even with the slight

increase in risk of including non-applicable rear-end or backing crashes. For this particular example, 0.05 miles on each side of the junction were eliminated since over 75 percent of the crashes at this intersection had been recorded as rear-end.

- When a segment began or ended at an intersection, one half of each intersection crash was counted as having occurred within the limits of that segment. If two segments connected end-to-end at an intersection, one-half of each intersection crash was allocated to one segment and one-half to the other (Exhibit 3-7). The exception to this was a rear-end or backing crash which occurred on the side street (i.e. minor leg) of the intersection. For example, the rear-end/backing crashes on either the north or south approach the intersection in this drawing were not counted.

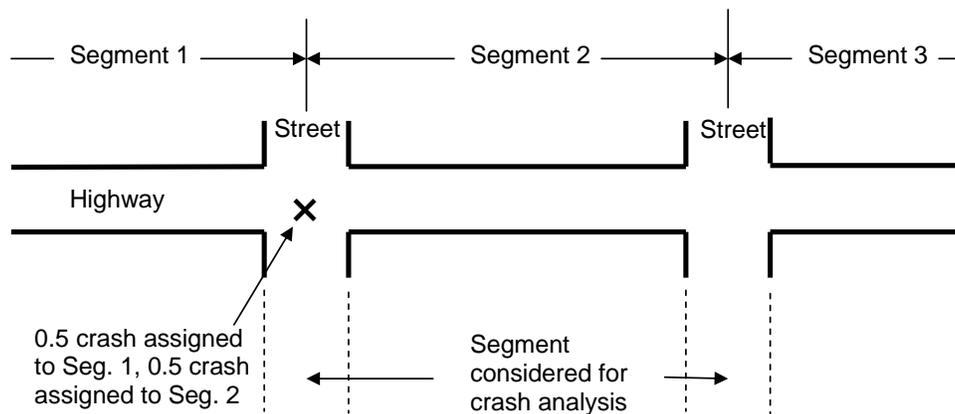


EXHIBIT 3-7 Illustration of the procedure for counting intersection crashes at segment end-points

- If a crash did not have a determinable reference point recorded, then the crash was given a corrected log mile. The log mile in the original crash database location was adjusted as needed to agree with the log mile found during field data collection. In other words, if the crash had “unknown” or was missing a reference point then its log mile was “corrected” using the field measured log mile of an adjacent referenced intersection. The difference between the original log mile and the field measured log mile was then applied (added/subtracted) to the original log mile. However, in a few route/sections, there were too many crashes recorded without a reference point (e.g., “unknown” or blank). For a long route/section with several segments, this could increase the risk of incorrectly locating crashes, especially if segments were similar in most respects (e.g. had the same number of lanes or median type). It was therefore decided that for any given year, if more than ten percent of the crashes could not be located, then the entire year for that route/section would be eliminated from analysis.

Examples of Problem-Crash Data Reduction

Although these general rules were used for all test segments, many times, due to particularities with the area, more difficult decisions were made based on the judgment of the researcher. This could be best explained by examples.

Example 1: SH 88 (Higdon Ferry Road) intersects route 7/section 9 in Hot Springs in two separate locations. Only one of those intersections was in a usable segment (LM 8.84, across from Oaklawn Racetrack). However, all of the crashes which reference SH88/Higdon Ferry Road did not give additional information such as “north” or “south”. Route 7/section 9 at both intersections has four lanes with a TWLTL and is in an urban area. Both intersections are three-legged. The only definite information to distinguish crashes between the two locations is the type of intersection: the intersection in the usable segment is signalized, while the other intersection is not. This information was used to determine if crashes originally located at the unusable intersection were most likely mis-recorded, and therefore located at the useable intersection. Thus, crashes at the unusable intersection which had “traffic signal” recorded in the “type of traffic control” column were relocated at the useable intersection. It should be important to note, however, that the reverse logic was not used to exclude crashes at the usable intersection (which was signalized) which did not have “traffic signal” recorded in the “type of traffic control” column. The reason for this was that it was not uncommon to find crashes at a known signalized intersection to have “lane markings”, “other”, “unknown”, or “no controls present” recorded in the “type of traffic control” column.

Example 2: Route 18/section 7 in Blytheville had a segment removed from analysis due to unusual geometric characteristics (two sharp horizontal curves). West of the curve segment, N. Hollywood Street intersects route 18/section 7; in the curve segment, E. Hollywood Avenue intersects route 18/section 7. Unfortunately, many crashes in the database only had “Hollywood” listed as the reference point. Therefore, to reduce the chance of incorrectly locating a crash, crashes which referenced “Hollywood” were closely examined. Both intersections and the road characteristics (e.g., T-intersection, five lanes, non-signalized) were identical with the exception of their geometry. The usable segment (to the west) was straight and flat, while the curve segment had a distinct horizontal curve where E. Hollywood Avenue intersects. Crashes which were referenced as occurring at “Hollywood” were checked by their “roadway alignment” and “roadway profile” column entries. If the “roadway alignment” entry was “curve” or the “roadway profile” was “grade”, then the crash was determined to have occurred at E. Hollywood Avenue in the curve segment.

Investigation and Verification Process

During the data reduction process, information and data sources were examined to re-check assumptions that had been made about each segment. The researcher consulted MMHIS videos, crash data files, AADT booklets, field data, internet maps (such as street maps and topographic maps), and digital USGS aerial photographs taken from the internet.

The items which required the most time and energy to verify were construction activities (both the location and dates of construction). It was important to accurately determine the location, dates, and scope of any construction project because it could effect the assumptions of constant roadway characteristics (e.g., a signal being installed or a roadway with no median being re-stripped for a TWLTL after overlay), the length and location of segments, and the time period to include in the analysis.

Other items which were investigated did not require as much time and energy. For example, to verify the extreme difference in ADT on route 65/section 14B in Pine Bluff in the years 1998 and 1999 compared to the years 2000 through 2002, the researcher assumed that this was not an error but due to the

construction of the new I-530 bypass. The construction of the bypass was confirmed through the AADT booklets, crash data files, and even an AHTD press release (April 1999). Therefore, it was decided that the analysis of route 65/section 14B should not include 1998 and 1999, since the volume had changed dramatically.

Another example of an investigation and verification process occurred at the intersection with 24th Street (LM 1.52) on route 62/section 2 (Hudson Road) in Rogers. According to the AHTD signal database, the signal at the intersection with 24th Street had been in place since 1987. However, all crashes which occurred at the intersection before 2002 indicated that the intersection was unsignalized (based on the column "type of traffic control"). Also, data collected from the field showed that the intersection was four-legged. An aerial photograph dated February 2001 clearly showed, however, the intersection with only three legs (i.e., the north leg was missing). No mention of the construction of this fourth-leg was found in the AHTD construction database. There were also apartment complexes near where the fourth leg should be, about 0.1 miles north of US 62 (Lost Springs and Turtle Creek Apartment Developments). Therefore, it was concluded that the fourth leg of the intersection with 24th Street was constructed, along with the signal installation, around late 2001 or early 2002. As stated in Appendix B, it was finally assumed that this intersection construction and signal installation occurred on January 1, 2002. In other words, for the time period used prior to this date, it was assumed that this intersection was three-legged and unsignalized.

Another example of an investigation and verification process occurred at the location of an access point on route 412/section 2 in Springdale. This is the access point (LM 8.21) to the Ozark Outlet Mall, just west of the I-540 interchange. Two crashes which occurred in this route/section in 2001 were referenced to "Outlet Mall Exit" and "Ozark Centerpoint". Four crashes in 2000 scattered through the route/section referred to "Centerpoint". All these crashes had been recorded as "intersection" or "intersection related". After a thorough investigation which also included internet searches for possible names of the Ozark Outlet Mall, it was determined that all six of these crashes occurred at the mall driveway (there were no other street names or shopping areas found which were named "Centerpoint"). During the field data collection, the access point had been called a driveway. Therefore, crashes at this access point were recorded as driveway related, not intersection related.

CHAPTER 4

DATA ANALYSIS AND RESULTS

The research team members used a variety of techniques to analyze the data and examine relationships between crash rates and a number of independent variables.

They performed initial analyses to determine the range of values within the data set. They identified sparsely-populated data categories that possibly would be considered for removal from the analysis, due to inadequate sample size. They also noted any outlier data points, to examine further and determine if these values were from segments with extreme combinations of negative attributes.

The researchers examined the distribution of the values of the independent variables across the four major median type categories (None, None+LTL, TWLTL, and Rais+Dep). They checked for uneven distribution of the values among the median types, to flag analyses whose outcomes could be distorted by the uneven distribution.

The team conducted statistical tests and constructed negative binomial regression models to predict crash rates on Arkansas' multilane state highways as a function of cross section and traffic attributes.

ANALYZING THE DATA

The initial dataset contained 349 usable segments. As the data were analyzed, it was observed that there were only 13 segments with an inside shoulder, seven segments with either on-street parking or bike lanes, two segments with a Narrow median, and one segment with a posted speed limit of 25 mph. The categories into which these 23 segments fell were removed from the analysis because of small sample size, leaving 326 segments. The relatively few segments with either Raised or Depressed medians were grouped together, creating a larger sample to improve the strength of the subsequent analyses.

Exhibit 4-1 presents the ranges of some of the continuous variables, grouped by median type. For many of the features, the values were not evenly distributed across the four median types. This eventually led to the creation of "constrained" data sets, subsets taken from a limited range of the overall data. This was done to have subsets of data that with attributes more evenly distributed among each median type, so that the subsequent analyses would be less likely to be unknowingly distorted. However, sometimes the need to maintain adequate sample sizes had to be considered when determining the limits of a constrained data set.

Statistical Tests

The statistical software package SAS[®] was used to conduct statistical tests. The significance level (i.e., alpha value or α) used was 0.10. Except where otherwise stated, the p-values presented here were taken from SAS type 3 analysis tables.

If certain independent variables are correlated, mathematical relationships and models that incorporate combinations of correlated variables may be distorted. Statistical tests were conducted to determine whether certain variables were correlated with each other.

All of the regression models were derived from a negative binomial analysis. This assumes that the dependent variable (i.e., crash rate) has a negative binomial distribution instead of a normal distribution or Poisson distribution. This assumption is consistent with a previous study conducted by Hadi et al. (1995).

Each model was also tested for goodness of fit, and all met the goodness of fit criteria for the negative binomial distribution.

During the initial data analysis, a test was performed to determine if crash rates were affected by segment length (i.e., determine if segment length biased the data). With a p-value of 0.5022, it was concluded that crash rates were not affected by the length of a study segment. A similar test with number of crashes as the dependent variable, segment length as the independent variable, and offset variables of $\ln(\text{number of years})$ and $\ln(\text{segment length})$ found that segment length was not significant ($p=0.83$); the relationship between segment length and number of crashes is linear.

EXHIBIT 4-1 Range of continuous variables by median type

	Median type				
	N =	None	None+LTL	TWLTL	Rais+Dep
	68	43	184	31	326
Volume (vehicles per day)					
maximum	21333	29167	36000	35111	36000
average	10049	14587	17031	16213	15174
minimum	2333	2633	4500	5000	2333
Through-lane width (average per lane, in ft)					
maximum	12.6	12.8	13.0	12.5	13.0
average	11.3	11.7	10.8	11.9	11.1
minimum	8.5	9.2	9.3	11.5	8.5
Access density (per mile, both sides)					
maximum	118.64	98.61	137.70	126.67	137.70
average	60.19	58.68	64.80	24.29	59.18
minimum	0.00	8.51	9.46	0.00	0.00
Com.+Ind. acc. density (per mile, both sides)					
maximum	87.64	81.82	101.69	97.78	101.69
average	29.22	28.00	40.64	12.84	33.95
minimum	0.00	0.00	0.00	0.00	0.00
Signal density (per mile)					
maximum	7.95	9.46	13.49	4.76	13.49
average	0.88	1.43	1.43	1.33	1.31
minimum	0.00	0.00	0.00	0.00	0.00

Data Presentation Explained

The methods used to describe the findings include scatter plots, box-and-whisker plots, tables, regression plots, and equations. Exhibit 4-2 explains the conventions employed in a box and whisker plot.

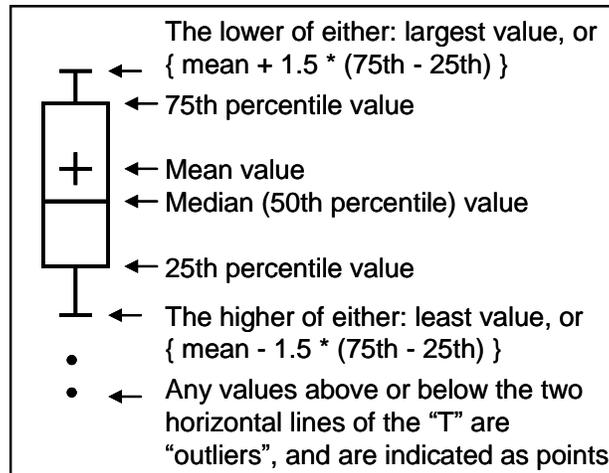


EXHIBIT 4-2 Box and whisker plot conventions

For the regression plots that show only one category or type of data, the following graphical conventions were adopted.

- In the scatter plots, dots represent observed data values
- The solid line represents the fitted model regression line
- The dashed lines represent the upper and lower 90% confidence limits

RESULTS FOR MEDIAN TYPE

Exhibit 4-3 lists mean crash rates for each of the four median categories. Exhibit 4-4 shows box-and-whisker plots for crash rate and fatal+significant crash rate by each median type for all 326 segments.

The None+LTL median type had the highest mean crash rate, followed by TWLTL median, None median, and Rais+Dep median. For fatal+significant crashes, the None median type had the highest mean fatal+significant crash rate, followed by None+LTL median, TWLTL median, and Rais+Dep median.

EXHIBIT 4-3 Sample sizes and mean crash rates by median type

Median Type	Sample Size (N)	Mean crash rate	Mean Fat+Sig rate
None	68	5.39	0.28
None+LTL	43	6.25	0.25
TWLTL	184	5.81	0.19
Rais+Dep	31	3.61	0.17

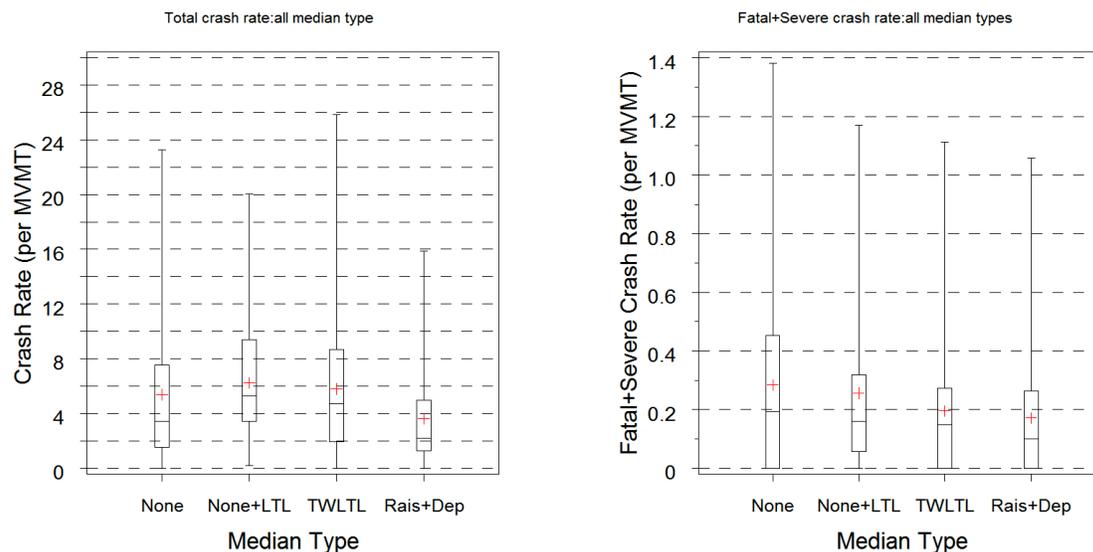


EXHIBIT 4-4 Box plots of crash rates by median type

The “Differences in Least Squares Means” analysis was conducted in the negative binomial model to determine if there were any statistically significant differences between any of the median types, either by crash rate or by fatal+significant crash rate. Exhibit 4-5 shows the p-values, which were taken from the differences of least square means SAS table, for each of the six pairs of median types for overall and for fatal+significant crash rate. With the alpha value (α) of 0.10 used to test for the significance of each p-value in the exhibit, it was concluded that None vs. Rais+Dep, None+LTL vs. Rais+Dep, and TWLTL vs. Rais+Dep had significantly different crash rates. No significant differences were found among the pairs of fatal+significant crash rates.

EXHIBIT 4-5 Significant differences between crash rates for pairs of median types

Median Type Pair	Crash Rate p-value	Fat+Sig Crash Rate p-value
None and None+LTL	0.385	0.596
None and TWLTL	0.549	0.165
None and Rais+Dep	0.042	0.367
None+LTL and TWLTL	0.620	0.610
None+LTL and Rais+Dep	0.010	0.685
TWLTL and Rais+Dep	0.008	0.951

In instances such as this, a Bonferroni correction could be used to prevent inflating the overall alpha (α) level. The Bonferroni correction is alpha divided by the number of pairwise tests being performed on the variable. Using the Bonferroni correction with these data, each pairwise comparison of median types would be tested against a p-value of 0.016 instead of 0.10. Applying the Bonferroni correction, then None+LTL vs. Rais+Dep, and TWLTL vs. Rais+Dep pairs would be considered significantly different. With the Bonferroni correction, no fatal+significant crash rate pairs were considered significantly different.

RESULTS FOR SPEED LIMIT

Exhibit 4-6 shows the distribution of speed limits across the four median types. The most common posted speed was 40 mph. The None and None+LTL types were more concentrated in lower speed environments, the TWLTL at 40 mph. The Raised or Depressed medians tended to be found on higher speed roadways.

EXHIBIT 4-6 Distribution of speed limits by median type

Posted speed limit (mph)	Median type				
	None	None+LTL	TWLTL	Rais+Dep	All
30	7	0	2	0	9
35	23	16	36	5	80
40	20	16	79	4	119
45	17	11	58	15	101
50	1	0	9	7	17
Total	68	43	184	31	326

An analysis was performed on all 326 segments to determine if any statistically significant relationships exist between crash rate and posted speed limit. Plots of the individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate are shown in Exhibit 4-7. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 5.5561 - 0.0970 \times \text{posted speed limit} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 5.5936 - 0.0628 \times \text{posted speed limit} \quad p = 0.001 \quad \text{significant}$$

The speed limit had a statistically significant inverse relationship with crash rate. As the posted speed limit increased, the crash rate decreased significantly. The posted speed limit also had a statistically significant inverse relationship with the fatal+significant crash rate. As the speed limit increased, the fatal+significant crash rate decreased significantly.

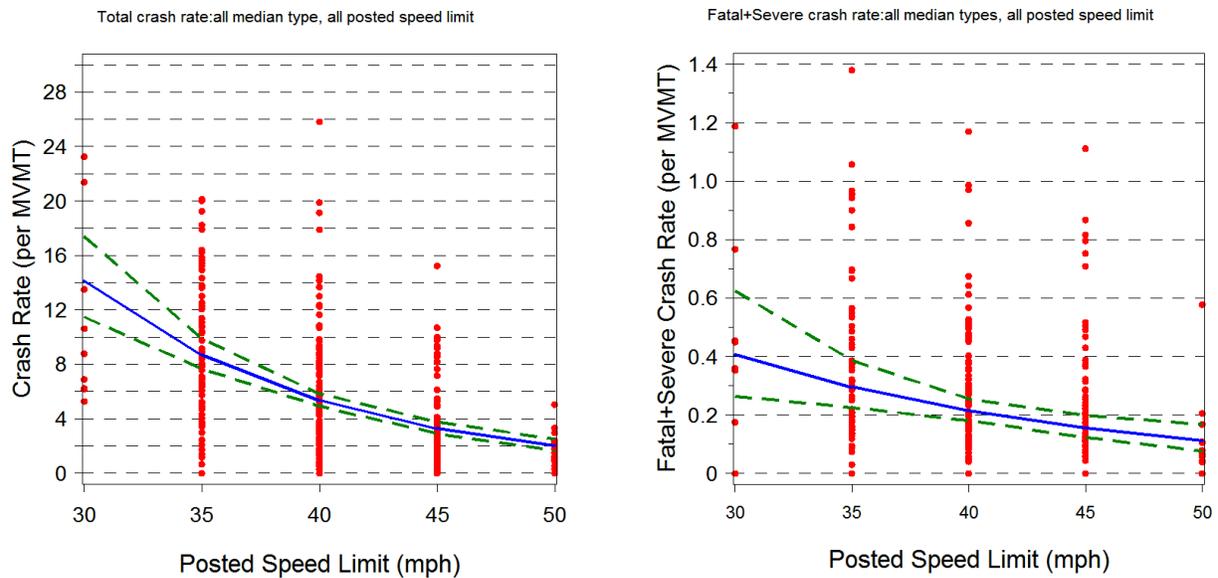


EXHIBIT 4-7 Regression of crash rates and speed limits

Crash Rates for Speed Limit by Median Type

A negative binomial regression analysis was performed separately on each of the four median types to examine relationships between crash rate and speed limit. Exhibit 4-8 shows the negative binomial regression graphs for crash rate and for fatal+significant crash rate for the four median types. In order from lowest to highest crash rate, the order of the median types was None (lowest), Rais+Dep, None+LTL, and TWLTL (highest).

None (N=68)

US 79, section 3 (California Avenue, LM from 20.66 to 21.07) in Camden was the only segment with a posted speed limit of 50 mph, so it was excluded from the analysis. The negative binomial regression equations for the remaining 67 segments follow.

$\ln(\text{crash rate})$	$= 6.1578 - 0.1200 \times \text{speed limit}$	$p < 0.001$	significant
$\ln(\text{Fat+Sig} \times 100)$	$= 5.8315 - 0.0654 \times \text{speed limit}$	$p = 0.176$	not significant

In general, as the speed limit on four-lane undivided roadways increased, both the crash rate and the fatal+significant crash rate decreased.

None+LTL (N = 43)

$\ln(\text{crash rate})$	$= 5.9728 - 0.1073 \times \text{speed limit}$	$p < 0.001$	significant
$\ln(\text{Fat+Sig} \times 100)$	$= 6.8725 - 0.0935 \times \text{speed limit}$	$p = 0.095$	significant

In general, as the posted speed limit increased, both the crash rate and the fatal+significant crash rate decreased significantly.

TWLTL (N=184)

Two segments with a posted speed limit of 30 mph, SH 18, section 7 (E. Main Street, LM from 1.21 to 2.02) in Blytheville and SH 365, section 14 (Dollarway Road, LM from 19.84 to 20.23) in Pine Bluff were removed from the analysis. The negative binomial regression equations for the remaining 182 segments follow.

$\ln(\text{crash rate})$	$= 5.5372 - 0.0935 \times \text{speed limit}$	$p < 0.001$	significant
$\ln(\text{Fat+Sig} \times 100)$	$= 4.5458 - 0.0386 \times \text{speed limit}$	$p = 0.172$	not significant

As the posted speed limit increased, the crash rate and the fatal+significant crash rate decreased.

Rais+Dep (N = 31)

$\ln(\text{crash rate})$	$= 6.7200 - 0.1289 \times \text{speed limit}$	$p < 0.001$	significant
$\ln(\text{Fat+Sig} \times 100)$	$= 5.6885 - 0.0665 \times \text{speed limit}$	$p = 0.217$	not significant

In general, as the speed limit increased, the crash rate and the fatal+significant crash rate decreased.

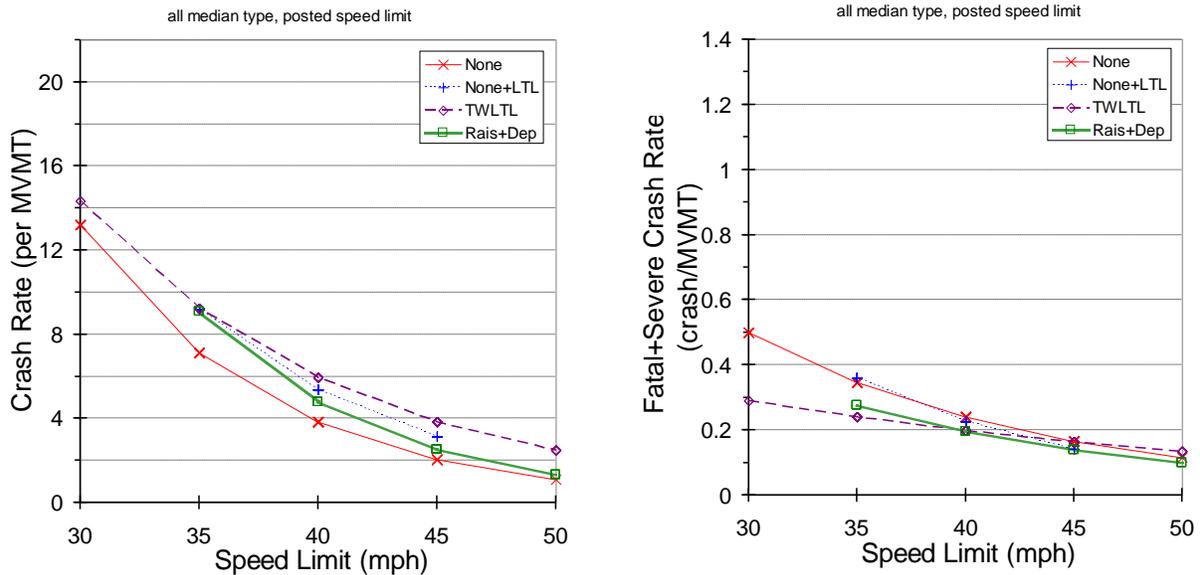


EXHIBIT 4-8 Regression of crash rates and speed limit by median type

Comparison for Speed Group Well-Represented in All Median Types

It was noted that the four median types were not well distributed across the different speeds limits. The speed limit that was best populated by all four median types was the 45 mph speed category, and even then, the sample sizes for three of the four median types were less than 20. Exhibit 4-9 compares the average crash rate and average fatal+significant crash rate for each of the four median types.

For a posted speed limit of 45 mph, the None+LTL median had the highest mean crash rate, followed by TWLTL median, Rais+Dep median, and None median. For fatal+significant crash rate, the TWLTL median had the highest fatal+significant crash rate, followed by None median, Rais+Dep median, and None+LTL median.

EXHIBIT 4-9 Comparing crash rates for segments with 45 mph speed limit by median type

Median Type	Sample Size	Mean crash rate	Mean Fat+Sig crash rate
None	17	2.1084	0.1670
None+LTL	11	3.6229	0.1257
TWLTL	58	3.4944	0.1931
Rais+Dep	15	2.8592	0.1520

RESULTS FOR VOLUME

An analysis was performed to determine if volume, in vehicles per day (vpd), had a statistically significant relationship with the crash rate. Plots of the 326 individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate performed on the full data set are shown in Exhibit 4-10. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 1.249394 + 0.000030 \times \text{volume} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 3.095146 - 0.000000 \times \text{volume} \quad p = 0.978 \quad \text{not significant}$$

The crash rate had a statistically significant relationship with volume, but the fatal+significant crash rate did not. As the volume increased, the crash rate increased significantly.

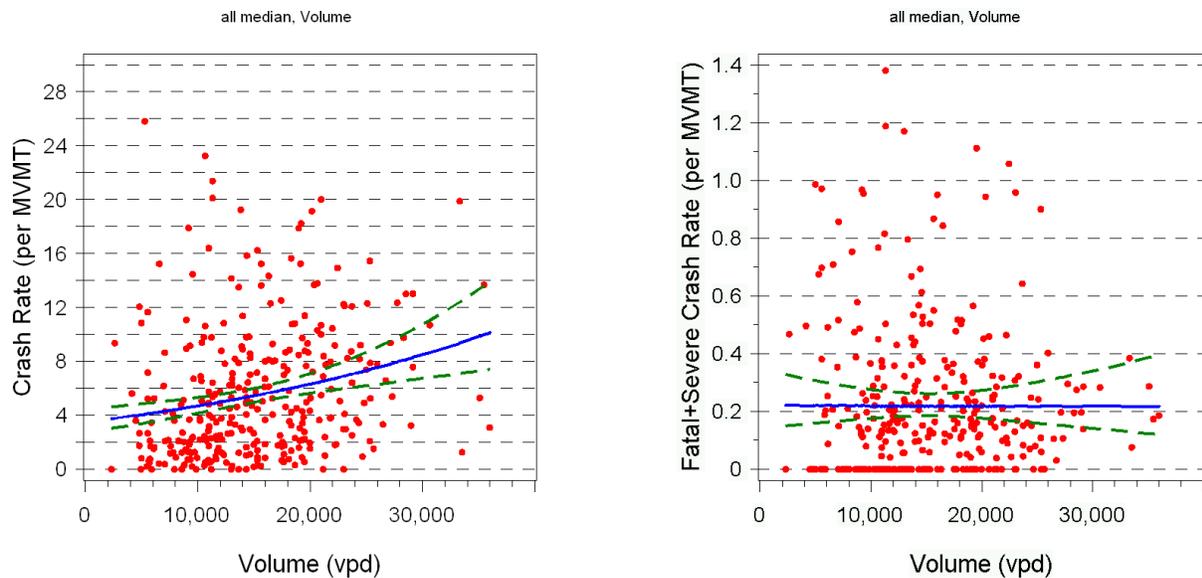


EXHIBIT 4-10 Regression of crash rates and volume

For all median types, the mean volume was 15,174 vpd, with 2,333 vpd and 36,000 vpd as the minimum and maximum, respectively. Among median types, the TWLTL and the Raised+Depressed had higher volumes than the None and the None+LTL. In fact, the None and the None+LTL had similar

ranges and mean volumes of 10,049 vpd and 14,587 vpd, respectively. Likewise, TWLTL and the Raised+Depressed median types had similar ranges and mean volumes of 17,031 vpd and 16,213 vpd, respectively. Therefore, in this set of data, the TWLTL and the Rasi+Dep roadways tended to have higher volumes than did the roadways with None or None+LTL treatments.

Wanting to create a few volume-based groups into which all of the segments could be assigned, the researchers examined the distribution of the volume data. This process was iterative, and was influenced by where the “naturally-occurring” breakpoints for each median type occurred.

Crash Rates for Volume by Median Type (6,000-26,000)

In order to improve the strength of comparisons made among the median types, it was desirable to identify a volume range that was well-populated by all four median types. The data distributions were inspected further, and it was found that no one range of any great extent was well-populated by all four. A range of 6,000 vpd – 26,000 vpd was selected, since for three of the four median types, this range was better-populated with data. There were 287 segments in this range, and the relationship between crash rate and volume again was found to be significant.

Plots of the individual data points (6,000 vpd – 26,000 vpd) and the negative binomial regression curves for crash rate and for fatal+significant crash rate are shown in Exhibit 4-11. The negative binomial regression equations follow.

$\ln(\text{crash rate})$	$= 1.143098 + 0.000036 \times \text{volume}$	$p < 0.001$	significant
$\ln(\text{Fat+Sig} \times 100)$	$= 3.070040 - 0.000002 \times \text{volume}$	$p = 0.933$	not significant

The crash rate had a statistically significant positive relationship with daily volume. That is, as the volume increased, the crash rate increased significantly.

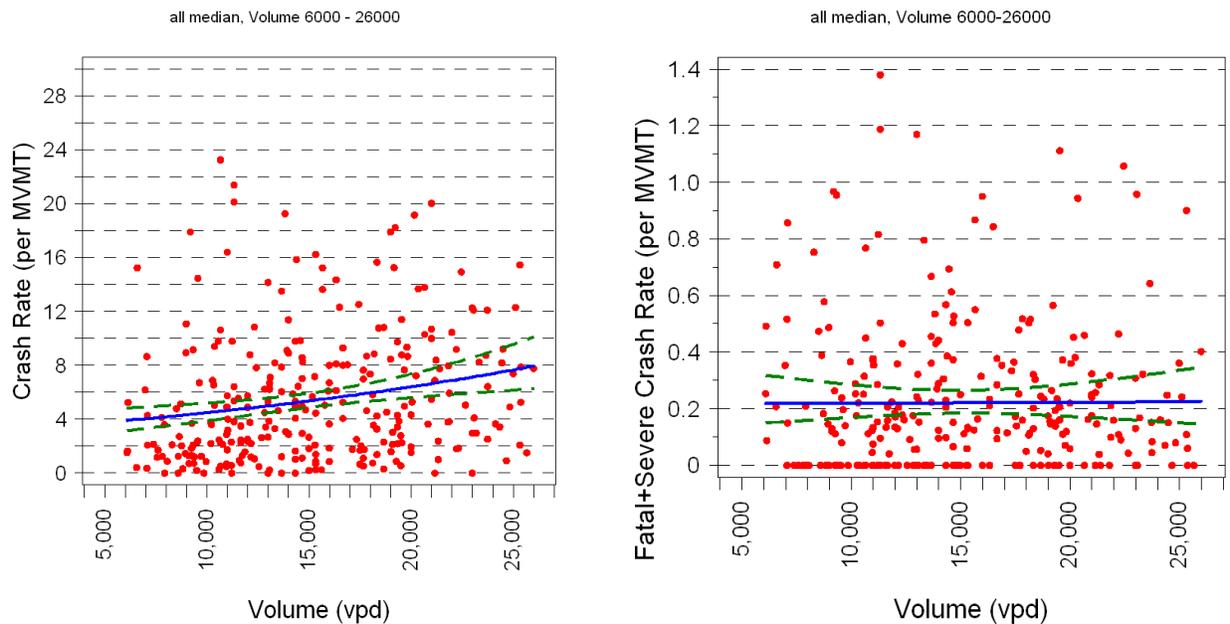


EXHIBIT 4-11 Regression of crash rates and volume 6,000-26,000

After determining that within the 6,000-26,000 range, a significant relationship existed between crash rate and volume for all median types, the relationships between crash rate and volume for each of the four median types were examined. These equations show a statistically significant relationship between crash rate and volume for the None+LTL, TWLTL, and Raised+Depressed groups. However, the relationship between the crash rate and the None median type was not significant.

An examination revealed that for the None median type, volume between 6000 and 26,000, there was only one data point greater than 17,000 and two points greater than 16,000. This could have contributed to the relationship not being significant. Another regression was performed on a better populated range of 4,000 to 18,000 vpd, but again the relationship was not significant. The negative binomial regression equations for these analyses follow.

None (N = 53, volume 6,000 to 26,000)

$$\ln(\text{crash rate}) = 1.692315 + 0.000004 \times \text{volume} \quad p = 0.9280 \quad \text{not significant}$$

None (N = 66, volume 4,000 to 18,000)

$$\ln(\text{crash rate}) = 1.42540 + 0.000028 \times \text{volume} \quad p = 0.4362 \quad \text{not significant}$$

None+LTL (N = 38)

$$\ln(\text{crash rate}) = 1.042366 + 0.000051 \times \text{volume} \quad p = 0.0091 \quad \text{significant}$$

TWLTL (N = 169)

$$\ln(\text{crash rate}) = 0.938976 + 0.000045 \times \text{volume} \quad p = 0.0013 \quad \text{significant}$$

Rais+Dep (N = 27)

$$\ln(\text{crash rate}) = 0.267177 + 0.000065 \times \text{volume} \quad p = 0.0586 \quad \text{significant}$$

Exhibit 4-12 shows a comparison among all median types, within the ranges of 4,000-18,000 vpd for the None, and 6,000-26,000 vpd for the other three. Again, not only does the Raised+Depressed median type have the lowest predicted crash rate, but it is approximately 40 percent lower than the TWLTL at the lower volume range and 20 percent lower than the TWLTL at the higher volume range.

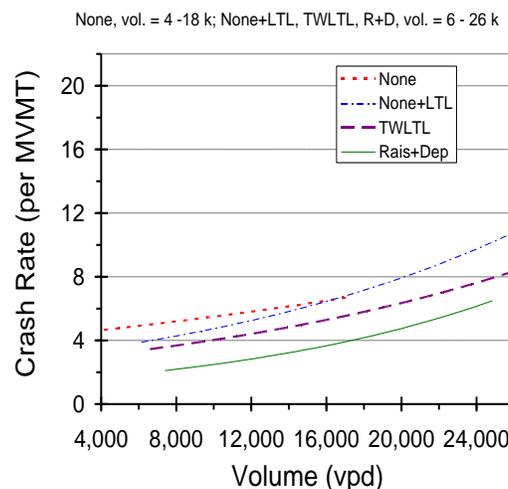


EXHIBIT 4-12 Regression of crash rate and volume 6,000-26,000 (None 4,000-18,000) by median type

RESULTS FOR LANE WIDTH

The roadway segments had average lane widths ranging from less than 9 ft up to 13 ft. The largest group was the 11 to 12 foot wide category. A higher proportion of TWLTL segments had relatively narrow lanes than did other median types. Exhibit 4-13 shows the distribution of lane widths across the median types.

EXHIBIT 4-13 Distribution of lane widths by median type

	Lane Width (ft)						Total	Average	Range
	8-9	9-10	10-11	11-12	12-13	13-14			
None	1	4	22	17	24	0	68	11.28	8.48-12.60
None+LTL	0	3	5	15	20	0	43	11.68	9.20-12.75
TWLTL	0	34	45	88	11	6	184	10.82	9.25-13.00
Rais+Dep	0	0	0	12	19	0	31	11.94	11.50-12.50
All	1	41	72	132	74	6	326	11.14	8.48-13.00

An analysis was performed on all 326 segments to determine if any statistically significant relationships exist between crash rate and through lane width. Plots of the individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate are shown in Exhibit 4-14. The negative binomial regression equations follow.

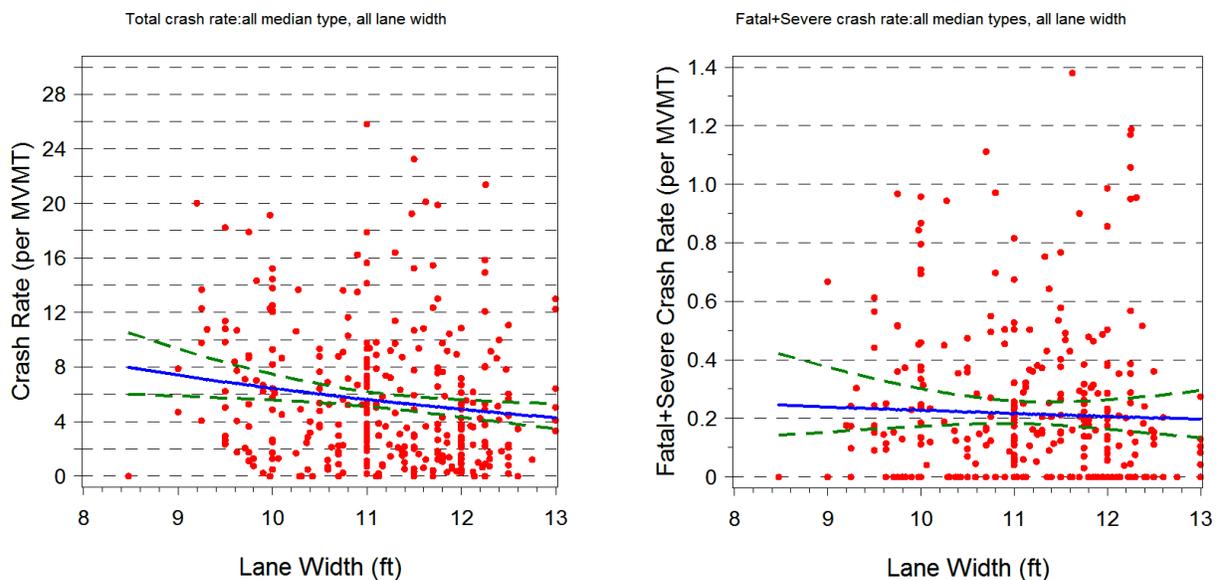


EXHIBIT 4-14 Regression of crash rates and lane width

ln (crash rate)	= 3.2302 - 0.1365 x lane width	p = 0.008	significant
ln (Fat+Sig x 100)	= 3.6177 - 0.0475 x lane width	p = 0.628	not significant

From this analysis, it was concluded that lane width had a statistically significant inverse relationship with crash rate. As the lane width increased, the crash rate decreased significantly. In general, as the lane width increased, the fatal+significant crash rate also decreased, but this relationship was not statistically significant.

Crash Rates for Lane Width by Median Type

The negative binomial regression analysis was performed separately on each of the four median types for crash rate and lane width. The negative binomial regression equations follow.

None (N = 68)

ln (crash rate)	= 2.9160 - 0.1095 LW	p = 0.421	not significant
ln (Fat+Sig x 100)	= 2.8225 + 0.0463 LW	p = 0.863	not significant

In general, as the lane width increased, the crash rate decreased. In general, as the lane width increased, the fatal+significant crash rate increased. Neither relationship was statistically significant.

None+LTL (N = 43)

ln (crash rate)	= 5.5974 - 0.3259 LW	p = 0.002	significant
ln (Fat+Sig x 100)	= 4.3829 - 0.0978 LW	p = 0.709	not significant

As the lane width increased, the crash rate decreased significantly. As the lane width increased, the fatal+significant crash rate also decreased, but this relationship was not statistically significant.

TWLTL (N = 184)

ln (crash rate)	= 2.7639 - 0.0931 LW	p = 0.185	not significant
ln (Fat+Sig x 100)	= 5.1413 - 0.2015 LW	p = 0.137	not significant

As the lane width increased, the crash rate and the fatal+significant crash rate decreased. Neither relationship was statistically significant.

Rais+Dep (N = 31)

The initial output showed crash rate increasing as lane width increased, which was contrary to the patterns exhibited by other median types where crash rate decreased as lane width increased. This precipitated a detailed examination of the Rais+Dep median data. The scatter plot and residual plot for all 31 segments are shown in Exhibit 4-15 and Exhibit 4-16.

It was found from the residual plot that three segments had a Pearson residual of more than 2. (Generally, a datum having a residual of more than two is considered to be a potential outlier.) The following three segments had an undue influence over the model.

1. US 70 section 8 (W. Grand Avenue, LM from 18.83 to 19.24) in Hot Springs
2. US 70 section 9 (E. Grand Avenue, LM from 0.00 to 0.48) in Hot Springs
3. SH 100 section 1 (Riverfront Drive, LM from 0.05 to 0.95) in North Little Rock

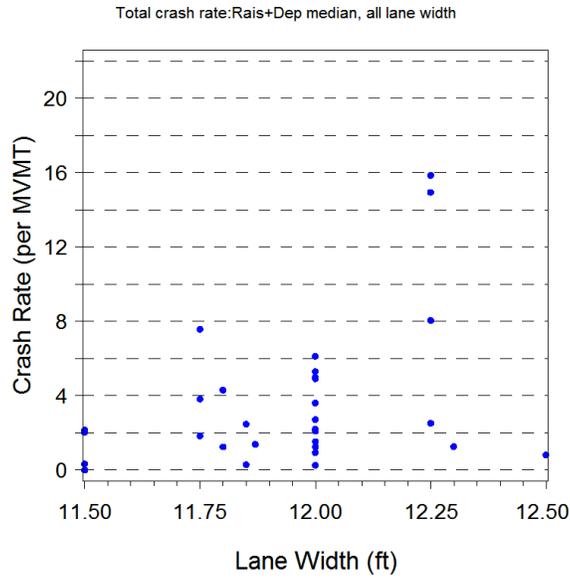


EXHIBIT 4-15 Plot of crash rate and lane width data for Rais+Dep median

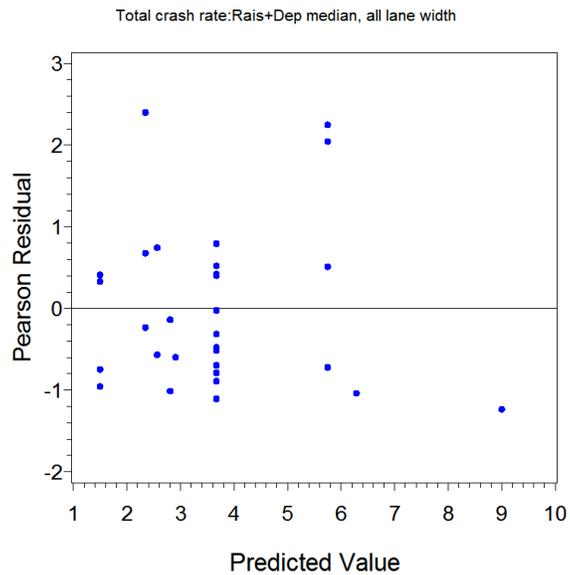


EXHIBIT 4-16 Pearson residual plot for crash rate and lane width for Rais+Dep median

Further investigation into these three segments showed that compared to other 28 segments, they had high signal density, high Commercial+Industrial access density, high overall access density, and high volume. Each of these factors alone was associated with increasing crash rates, and the combination of the factors in a single segment creates an unusual situation.

The three segments were excluded from the analysis. The negative binomial regression equations were rerun, with the following results.

$$\ln(\text{crash rate}) = -12.3545 + 1.1243 \text{ LW} \quad p = 0.102 \quad \text{not significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 1.6323 - 0.0832 \text{ LW} \quad p = 0.951 \quad \text{not significant}$$

In general, as the lane width increased, the crash rate increased, while the fatal+significant crash rate decreased. The relationship with the overall crash rate was marginally significant, while the fatal+significant relationship was not statistically significant.

Exhibit 4-17 displays the regression lines by lane width for the four median types. As lane width increased, crash rate decreased for the None, None+LTL, and TWLTL median types. As lane width increased, crash rate increased for Rais+Dep median. As lane width increased, fatal+significant crash rate decreased for the None+LTL, TWLTL and Rais+Dep median types. For the None median, fatal+significant crash rate increased as lane width increased.

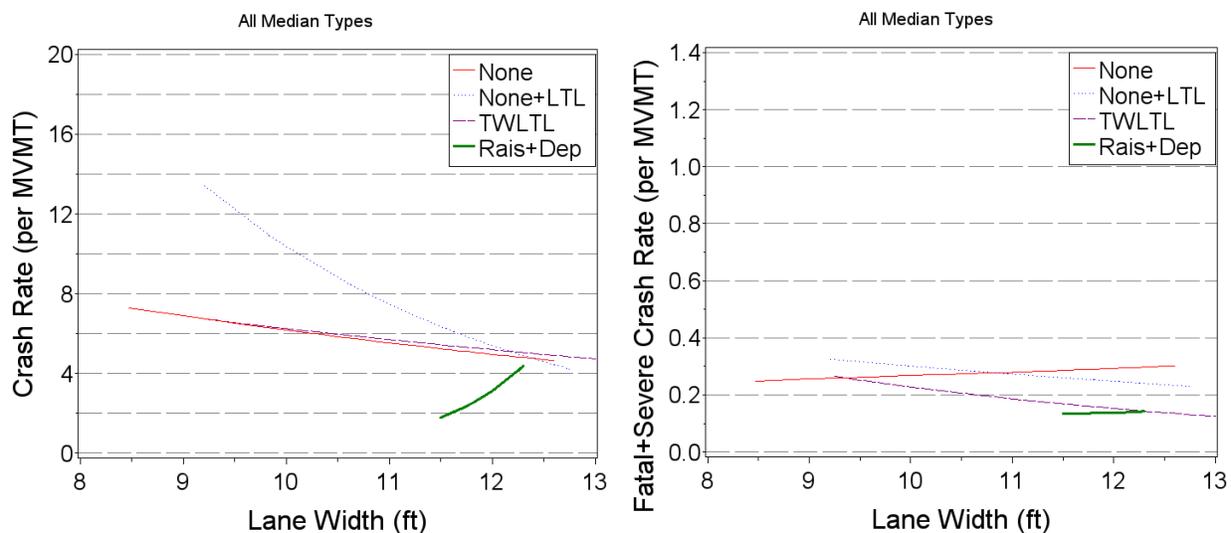


EXHIBIT 4-17. Regression of crash rates and lane width by median type

RESULTS FOR CURB OR SHOULDER

Exhibit 4-18 contains crash rate and fatal+significant crash rate box-and-whisker plots for all 326 segments, grouped according to having either curb or shoulder. The “likelihood ratio statistics” analysis was conducted in the negative binomial model to determine if either the crash rates or the fatal+significant crash rates of the curb and shoulder sections were statistically significantly different.

The mean crash rate for curb was 6.3003 crashes per MVMT, while the mean crash rate for shoulder was 2.806 crashes per MVMT. The negative binomial analysis for testing for differences of the two means resulted in a p-value less than 0.0001. Therefore, it was concluded that the crash rate for segments with curb was significantly higher than the crash rate for segments with shoulder.

The mean fatal+significant crash rate for curb was 0.2366 crashes per MVMT, while the mean fatal+significant crash rate for shoulder was 0.1385 crashes per MVMT. The p-value for the negative binomial analysis for fatal+significant crash rates between curb and shoulder was 0.0205. Therefore, it

was concluded that the fatal+significant crash rate for segments with curb was significantly higher than the fatal+significant crash rate for segments with shoulder.

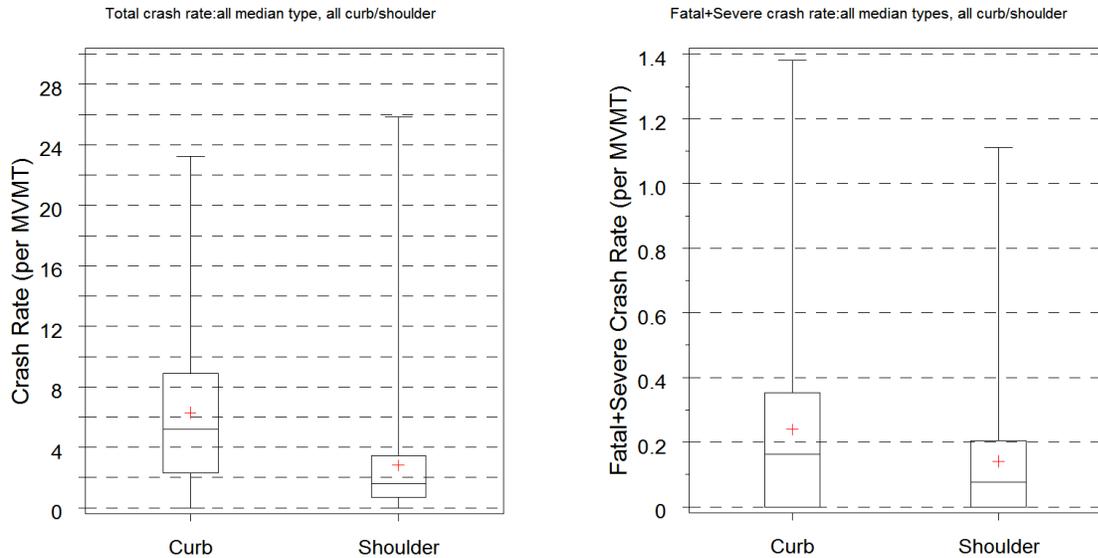


EXHIBIT 4-18 Box plots for curb or shoulder crash rates

Crash Rates for Curb or Shoulder by Median Type

The negative binomial analysis for testing for differences of means for curb and shoulder was performed on None and TWLTL median. This analysis was not performed on None+LTL (N = 43) and Rais+Dep (N = 31) median because of the smaller sample sizes.

None (N = 68)

The mean crash rate for segments with curb was significantly higher than the mean crash rate for segments with shoulder. The difference between the two mean fatal+significant crash rates was not statistically significant. Exhibit 4-19 lists the mean rates and p-values for None median.

EXHIBIT 4-19 Crash rates for curb and shoulder segments

Median type	Rate	Curb	Shoulder	p-value
None	Mean crash rate	6.2065	1.9520	0.0009
	Mean Fat+Sig crash rate	0.3100	0.1561	0.2875
TWLTL	Mean crash rate	6.3712	3.4232	0.0003
	Mean Fat+Sig crash rate	0.2012	0.1542	0.3616

TWLTL (N=184)

Exhibit 4-19 shows the mean crash rates and p-value for *TWLTL* median. The mean crash rate for segments with curb was significantly higher than the mean crash rate for segments with shoulder. The difference between the two mean fatal+significant crash rates was not statistically significant.

RESULTS FOR OUTER SHOULDER WIDTH

An analysis was performed on 68 segments with an outer shoulder to determine if any statistically significant relationships exist between crash rate and outer shoulder width. Exhibit 4-20 presents scatter plots of the individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate.

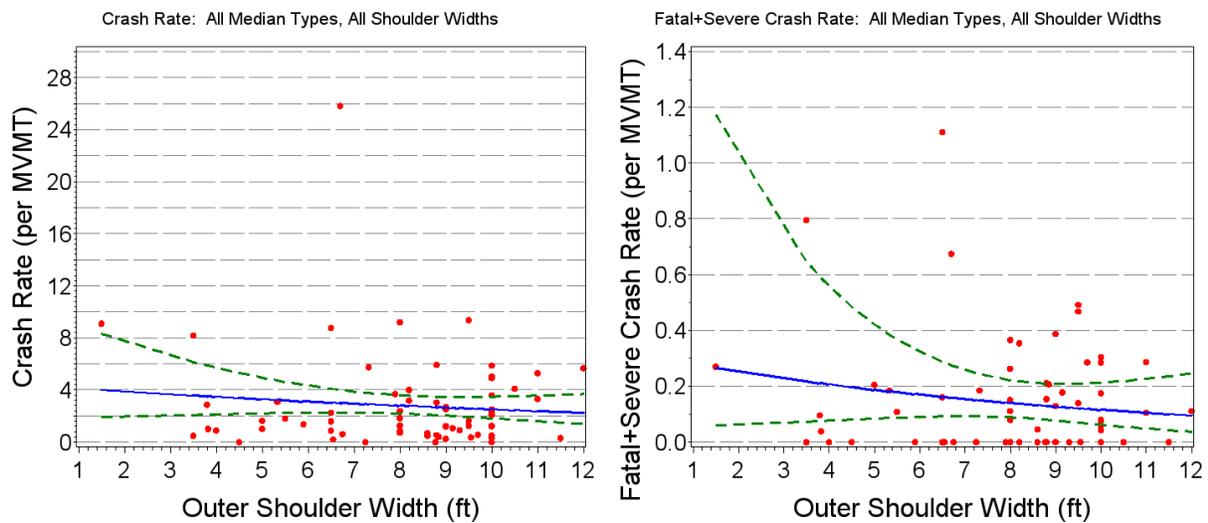


EXHIBIT 4-20 Regression of crash rate and outer shoulder width

The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 1.4625 - 0.0544 \times \text{outer shoulder width} \quad p = 0.320 \quad \text{not significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 3.4218 - 0.0978 \times \text{outer shoulder width} \quad p = 0.372 \quad \text{not significant}$$

In general, as the outer shoulder width increased, the crash rate and the fatal+significant crash rate decreased, but these relationships were not statistically significant.

RESULTS FOR MEDIAN WIDTH

An analysis was performed on the 215 segments with *TWLTL* or *Rais+Dep* median to determine if median width had a statistically significant relationship with crash rate. Exhibit 4-21 shows the distribution of median widths for roadways with *TWLTL* or *Rais+Dep* treatments.

EXHIBIT 4-21 Median width distribution for different median types

	Median Width (ft)							Total	Avg	Range
	0-10	10-20	20-30	30-40	40-50	50-60	80-90			
TWLTL	14	169	1	0	0	0	0	184	11.39	8.00-20.50
Rais+Dep	1	10	6	3	6	4	1	31	30.82	4.50-84.00
All	15	179	7	3	6	4	1	215	14.19	4.50-84.00

All but one segment had a median width 50 ft or less. The segment with the extremely wide median (84 ft) was State Highway 140 (West Keiser Avenue) in Osceola. Even though the regression line passes closely through this segment and the confidence limits are not spread out, the analysis was performed without the segment to see if it had undue influence on the model. However, the model without the outlying segment was almost identical to the model with the segment. Therefore, it was decided that this segment would be retained.

This analysis was affected by the relative sizes of the two groups. The size of the TWLTL (N=184) group overwhelms the effect of the smaller Rais+Dep median (N=31) group. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 1.9129 - 0.0154 \times \text{median width} \quad p = 0.026 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 3.0302 - 0.0054 \times \text{median width} \quad p = 0.604 \quad \text{not significant}$$

Exhibit 4-22 shows individual data points and the negative binomial regression curves.

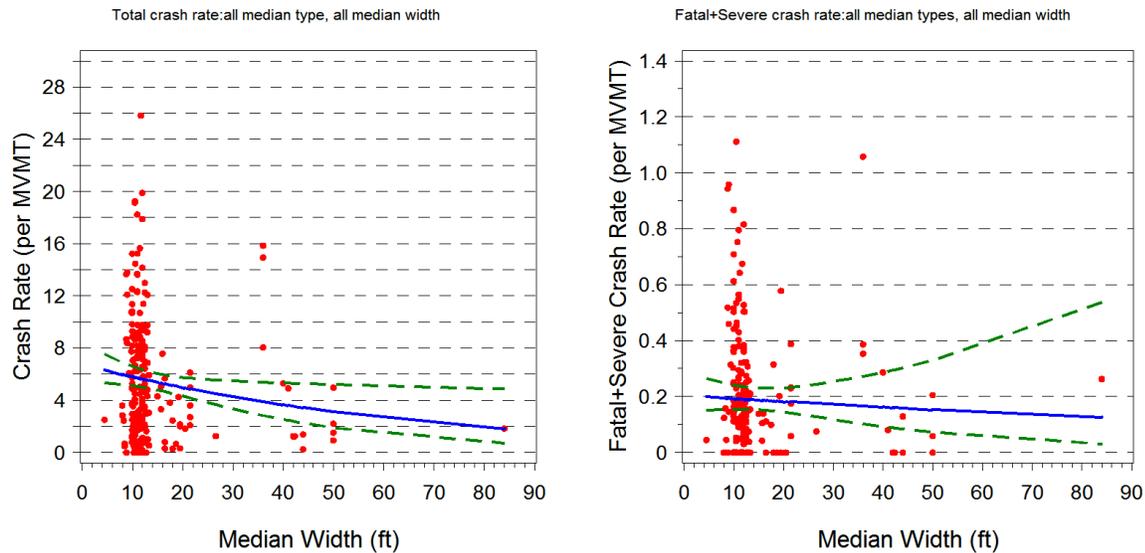


EXHIBIT 4-22 Regression of crash rates and median width

Median width had a inverse relationship with both crash rate and fatal+significant crash rate. As the median width increased, both crash rates decreased. Only the relationship for crash rate was statistically significant.

Crash Rates for Median Width by Median Type

The negative binomial regression analysis was performed on TWLTL and Rais+Dep median separately for crash rate and median width.

Typical TWLTL widths for new construction are often around 11 to 12 ft. A greater range of widths can be found on roads which have been retrofitted with TWLTLs. The average widths of two-way left-turn lanes measured in this study ranged from 8.00 ft to 20.50 ft.

Two separate analyses were conducted: one for the full range, and another for a range of 9.5 to 13.5 ft, which encompasses and extends 1.5 ft below and above the typical 11 to 12 ft range. The negative binomial regression equations follow.

TWLTL 8.0 ft to 20.5 ft (N = 184)

$\ln(\text{crash rate})$	$= 2.4694 - 0.0627 \times \text{MW}$	$p = 0.128$	not significant
$\ln(\text{Fat+Sig} \times 100)$	$= 4.7791 - 0.1613 \times \text{MW}$	$p = 0.014$	significant

As TWLTL widths increased within the range of 8.0 ft to 20.5 ft, the crash rate and the fatal+significant crash rate decreased. The relationship for all crashes was marginally not significant, while the relationship for fatal+significant crashes was statistically significant.

TWLTL 9.0 ft to 13.5 ft (N = 165)

$\ln(\text{crash rate})$	$= 2.1167 - 0.0300 \times \text{MW}$	$p = 0.664$	not significant
$\ln(\text{Fat+Sig} \times 100)$	$= 4.7901 - 0.1626 \times \text{MW}$	$p = 0.171$	not significant

For this range of widths (9.0 ft to 13.5 ft), as the TWLTL width increased, the crash rate decreased and the fatal+significant crash rate decreased. Neither relationship was statistically significant.

Rais+Dep (N = 30)

The segment with the extremely wide median 84 ft was removed from the analysis, as it was the only segment with median width more than 50 ft. The negative binomial regression equations follow.

$\ln(\text{crash rate})$	$= 1.0244 + 0.0092 \times \text{MW}$	$p = 0.514$	not significant
$\ln(\text{Fat+Sig} \times 100)$	$= 2.7833 + 0.0013 \times \text{MW}$	$p = 0.966$	not significant

For this median type, as the median width increased, the crash rate increased and the fatal+significant crash rate increased, but neither relationship was statistically significant.

RESULTS FOR LEFT-TURN LANE DENSITY

The negative binomial regression analysis was performed on the 43 None+LTL segments. The negative binomial regression equation for None+LTL medians follow.

$\ln(\text{crash rate})$	$= 1.8692 - 0.0156 \times \text{LTL density}$	$p = 0.842$	not significant
$\ln(\text{Fat+Sig} \times 100)$	$= 3.8410 - 0.2714 \times \text{LTL density}$	$p = 0.117$	not significant

No statistically significant relationships were found between crash rates and the left-turn lane densities on segments with the None+LTL treatment.

RESULTS FOR MEDIAN OPENING DENSITY

This test was performed on Rais+Dep median segments. All but four segments had a median opening density less than seven median openings per mile. The four segments with extremely high median opening density were Raised median segments in a densely developed commercial area. Three of the segments were located on US 70 (Grand Avenue) in Hot Springs, while the other segment was located on SH 107 (J.F.K. Boulevard) in North Little Rock. However, because the negative binomial model fit the four high-density segments very well, it was decided to include them in the analysis.

An analysis was performed on the 31 segments with a Raised or Depressed median to determine if median opening density had a statistically significant relationship with crash rate. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 0.5964 + 0.1028 \times \text{median opening density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = -2.2585 + 0.0931 \times \text{median opening density} \quad p = 0.112 \quad \text{not significant}$$

This indicated that for Raised and Depressed median segments, median opening density had a statistically significant positive relationship with crash rate; that is, as the median opening density increased, the crash rate increased significantly. The relationship between median opening density and fatal+significant crash rate was not statistically significant.

RESULTS FOR TRAFFIC SIGNAL DENSITY

Signal densities in the data ranged from 0.0 to 13.49, with an average of 1.31. Of the 326 segments, 121 had no signals. The mean crash rate for the 121 segments without signals was 2.59 crashes per MVMT. The mean crash rate for the 205 segments with one or more traffic signals was 7.33 crashes per MVMT.

Plots of the 326 individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate performed on the full data set are shown in Exhibit 4-23. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 1.2121 + 0.3027 \times \text{signal density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 2.7966 + 0.1902 \times \text{signal density} \quad p = 0.002 \quad \text{significant}$$

As the signal density increased, the overall and the fatal+significant crash rates increased significantly. The graphs show a marked increase in the crash rate as the signal density increases.

Based on an examination of the distribution of the data, the segments were grouped into the following ranges: less than 0.35, 0.35 to 2.24, 2.25 through 5.0, and greater than 5.0 signals per mile. Note that the less than 0.35 range only included segments without signals (signal density of 0.0). Much of the data fell into the 0.35-2.24 range. The 2.25-5.0 range had somewhat less data, with much of it concentrated in the lower half of the range. The 0.35 - 2.24 and the 2.25 - 5.0 groups were combined in to one group representing segments with a signal, but excluding segments with no signals or unusually high signal densities.

Exhibit 4-24 presents the regression lines for each median type. Each regression for crash rate was statistically significant, but the fatal+severe regression was not. As the number of signals per mile increased, crash rates increased. The negative binomial regression equations for crash rate by median type within the range of 0.35 to 5.0 signals per mile follow.

None	$\ln(\text{crash rate}) = 1.7478 + 0.1794 \times \text{signal density}$	(N = 22)	p = 0.069	significant
None+LTL	$\ln(\text{crash rate}) = 1.3357 + 0.3367 \times \text{signal density}$	(N = 35)	p = 0.012	significant
TWLTL	$\ln(\text{crash rate}) = 1.4224 + 0.2717 \times \text{signal density}$	(N = 121)	p < 0.001	significant
Rais+Dep	$\ln(\text{crash rate}) = 0.6757 + 0.4010 \times \text{signal density}$	(N = 20)	p = 0.001	significant
All	$\ln(\text{crash rate}) = 1.4164 + 0.2648 \times \text{signal density}$		p < 0.001	significant
All	$\ln(\text{Fat+Sig} \times 100) = 3.0278 + 0.1149 \times \text{signal density}$		p = 0.168	not significant

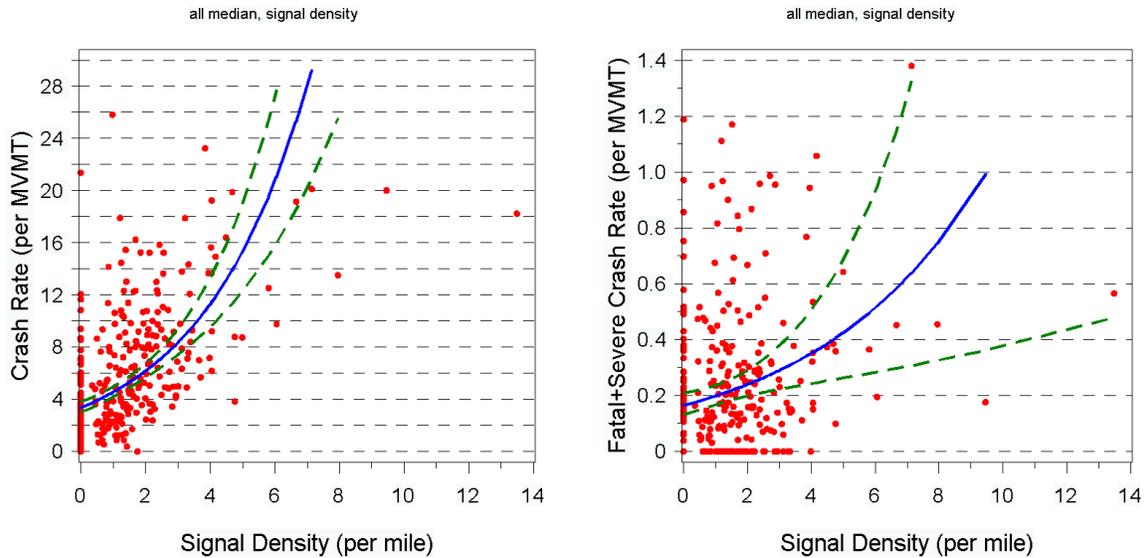


EXHIBIT 4-23 Regression of crash rate and signal density

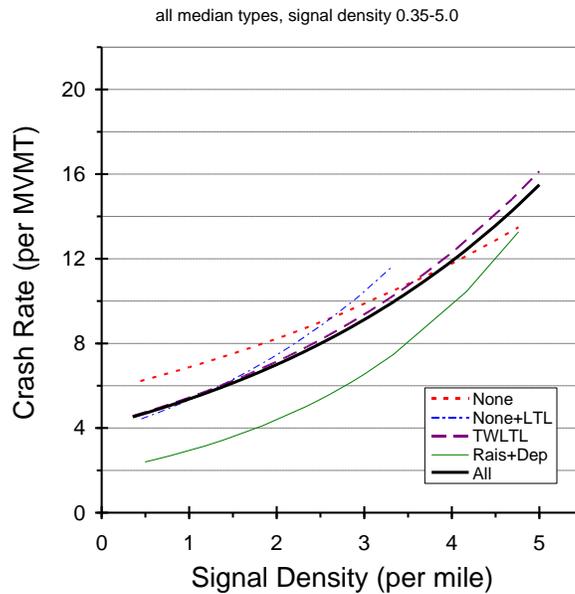


EXHIBIT 4-24 Regression of crash rate and signal density 0.35-5.0

RESULTS FOR ACCESS DENSITY

Access density is computed by counting the number of access points or connections (i.e. both streets and driveways) that intersect on either side of the subject roadway, then dividing by the length of the roadway. Access density is expressed as the number of access points (on both sides) per mile. Among the 326 segments, the access density ranged from 0.0 to 137.70 access points per mile, with an average of 59.18.

Crash Rates Considering All Access Density Data

Plots of the 326 individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate performed on the full data set are shown in Exhibit 4-25. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 0.8756 + 0.0131 \times \text{access density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 2.4567 + 0.0100 \times \text{access density} \quad p = 0.001 \quad \text{significant}$$

As the access density increased, both the overall and the fatal+significant crash rates increased. Both relationships were statistically significantly.

Among median types, the TWLTL had the highest average access density at 64.80 with the Raised+Depressed having the lowest density at 24.29 (62.5% lower). In between were the None and None+LTL median types at 60.19 and 58.68, respectively. Because of the significant spread between the data among the different median types, it was difficult to find an access density range that would have an adequate number of samples from all four median types.

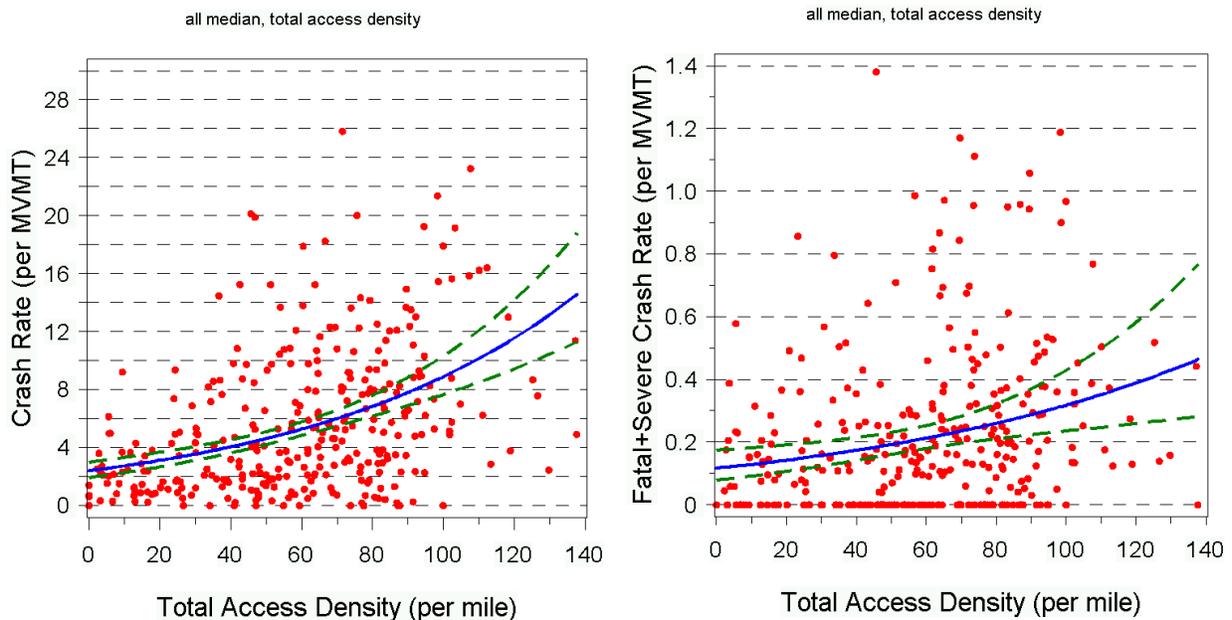


EXHIBIT 4-25 Regression of crash rate and access density

Crash Rates Considering a Subset of Access Density Data

After examining the distribution of the data, the segments were divided into preliminary groups. The relationships between crash rate and access density for the 8.5 through 27.99 and for the 28.0 through 53.99 ranges were found to be not significant, whereas the relationship for the 54.0 through 104.99 range was significant. However, the relationship for the range from 8.5 through 53.99 was significant. This finding prompted further tests, to gain more insight into the strength of the relationship between crash rate and access density within this range. It was found that the 8.5 through 31.99 range relationship was not significant and 32.0 through 104.99 range relationship was significant. The segments were grouped into the following ranges: less than 8.5, 8.5 through 27.99, 28.0 through 53.99, 54.0 through 104.99, and greater than or equal to 105.0 access points per mile. The less-than-8.5 range and the greater-than-or-equal-to-105.0 range were not analyzed, due to the small number of data in these ranges.

Exhibit 4-26 presents plots of the individual data points within the 32.0 to 104.99 range, and the negative binomial regression curves for crash rate and for fatal+significant crash rate. The negative binomial regression equations for crash rate for the 32-104.9 range follow.

$$\ln(\text{crash rate}) = 1.1425 + 0.0097 \times \text{access density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 2.4532 + 0.0103 \times \text{access density} \quad p = 0.056 \quad \text{significant}$$

From these analyses, it was concluded that both the overall and the fatal+significant crash rates had a statistically significant positive relationship with access density. That is, as the access density increased, the overall and the fatal+significant crash rates increased significantly.

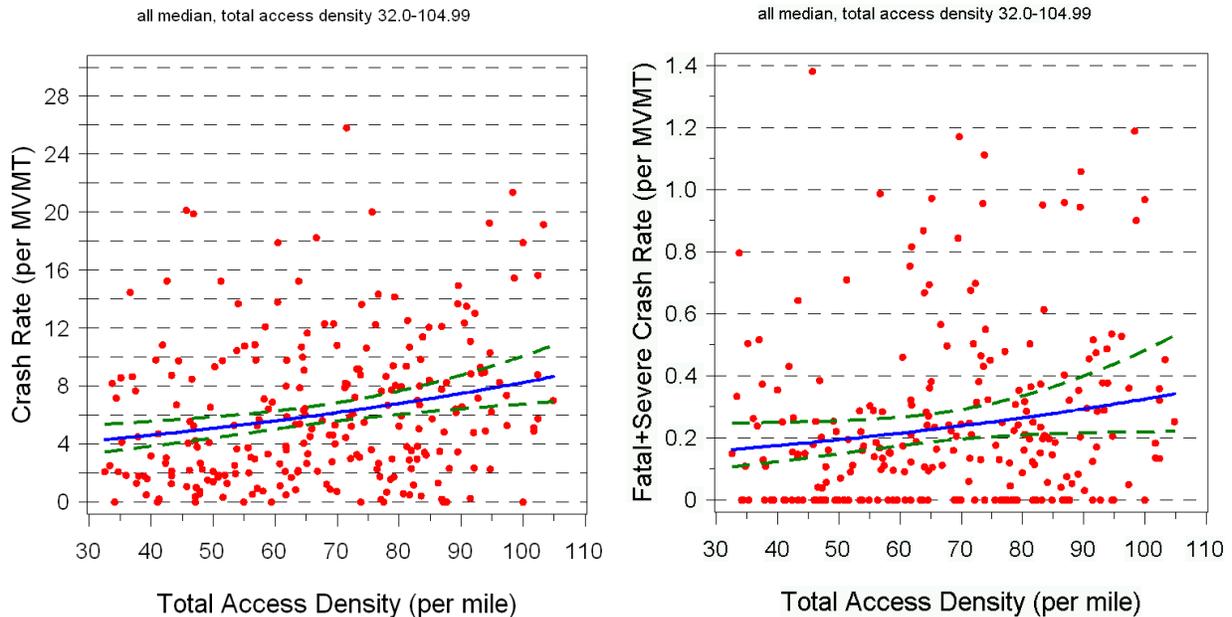


EXHIBIT 4-26 Regression of crash rate and access density 32.0-104.99

Crash Rates for Access Density by Median Type (32.0-104.9)

The relationship between crash rate and access density for each of the four median types was also performed for the access density range of 32.0-104.9. The resulting negative binomial regression equations follow.

None (N = 52)

$$\ln(\text{crash rate}) = 1.1157 + 0.0087 \times \text{access density} \quad p = 0.130 \quad \text{not significant}$$

None+LTL (N = 33)

$$\ln(\text{crash rate}) = 1.0385 + 0.0128 \times \text{access density} \quad p = 0.042 \quad \text{significant}$$

TWLTL (N = 157)

$$\ln(\text{crash rate}) = 1.2498 + 0.0081 \times \text{access density} \quad p = 0.028 \quad \text{significant}$$

Rais+Dep (N = 5)

$$\ln(\text{crash rate}) = -0.9130 + 0.0396 \times \text{access density} \quad p < 0.001 \quad \text{significant}$$

Note that the Raised+Depressed sample size is very small, so one cannot draw conclusions about that type with any degree of confidence.

Crash Rates for Access Density by Median Type (5.0-59.9)

Since there were few Raised+Depressed segments in the 32 to 105 density range, the data were reexamined to find another range with better Rais+Dep representation. A range from 5.0 up to 60.0 was identified. Although this range was not as well populated by the None and the None+LTL types as was the previous range, at least the 5 to 60 range did not exclude most of one of the four median types.

Plots of the individual data points (5.0-59.9) and the negative binomial regression curves for crash rate and for fatal+significant crash rate are shown in Exhibit 4-27. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 0.7866 + 0.0162 \times \text{access density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 2.7056 + 0.0014 \times \text{access density} \quad p = 0.884 \quad \text{not significant}$$

From these analyses, it was concluded that in the range of 5 to 60 access points per mile, only the crash rate had a statistically significant positive relationship with access density. That is, as the access density increased, the crash rate increased significantly.

Considering crash rates by median type produced the following negative binomial regression equations.

None (N = 26)

$$\ln(\text{crash rate}) = 0.4623 + 0.0251 \times \text{access density} \quad p = 0.072 \quad \text{significant}$$

None+LTL (N = 19)

$$\ln(\text{crash rate}) = 0.9231 + 0.0140 \times \text{access density} \quad p = 0.182 \quad \text{not significant}$$

TWLTL (N = 78)

$$\ln(\text{crash rate}) = 0.8553 + 0.0146 \times \text{access density} \quad p = 0.081 \quad \text{significant}$$

Rais+Dep (N = 20)

$$\ln(\text{crash rate}) = 0.8852 + 0.0040 \times \text{access density} \quad p = 0.710 \quad \text{not significant}$$

Exhibit 4-28 shows the predicted crash rates for each median type over an access density range of 5.0-59.9. Note that only the TWLTL had a robust sample size.

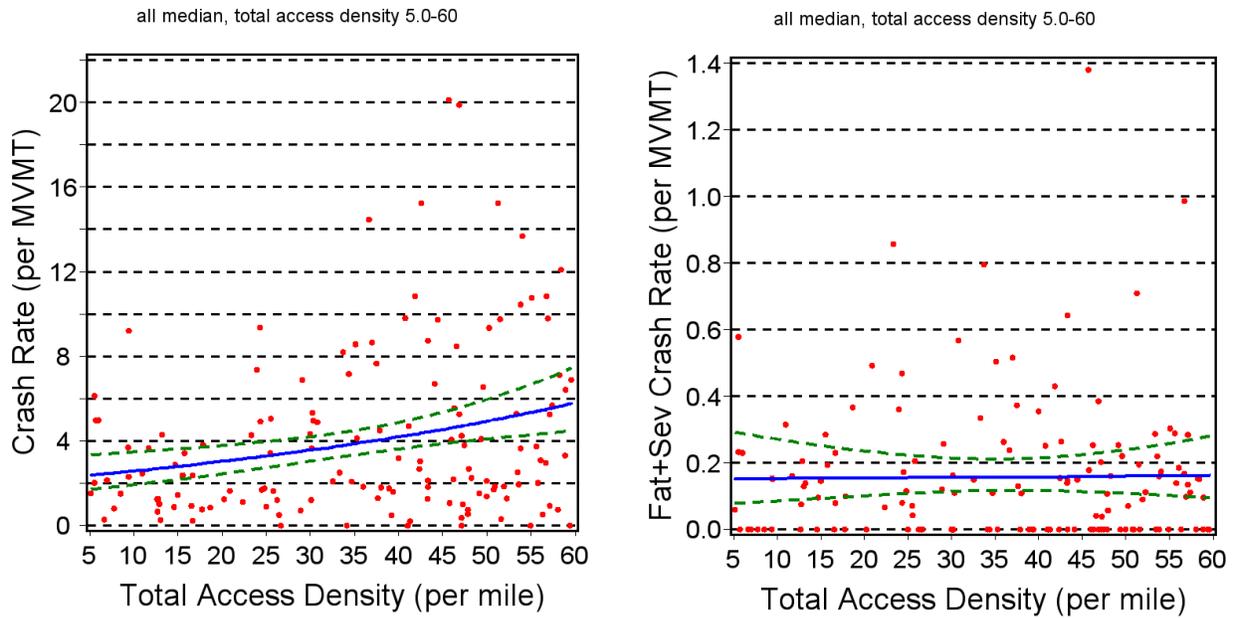


EXHIBIT 4-27 Regression of crash rates and access density 5.0-59.9

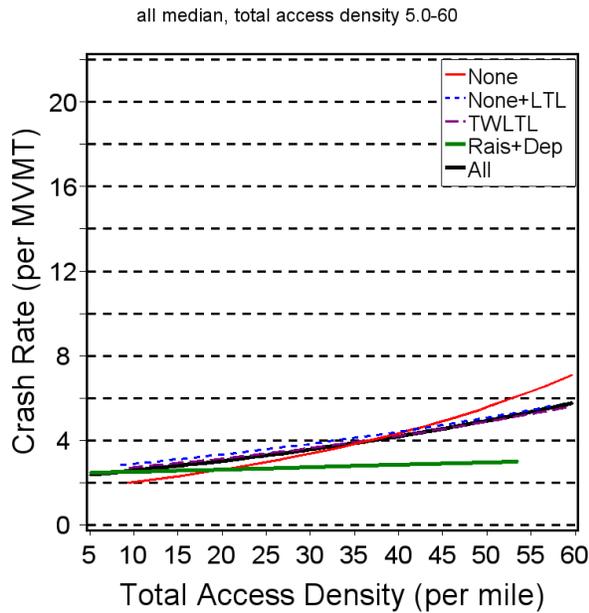


EXHIBIT 4-28 Regression of crash rate and access density 5.0-59.9 by median type

RESULTS FOR COMMERCIAL-PLUS-INDUSTRIAL ACCESS DENSITY

Commercial-plus-Industrial (C+I) access density is a subset of the overall access density. It is the number of commercial and industrial driveway per mile on both sides of the roadway. Among the 326 segments, the densities ranged from 0.0 to 101.7, and the average density was 34.0 C+I access points per

mile. As with the total access density, the TWLTL had the highest average C+I density at 40.6, with the Raised+Depressed having the lowest density at 12.8 (68% lower). In between were the None and None+LTL median types at 29.2 and 28.0, respectively.

Crash Rates Considering All C+I Access Density Data

Plots of the 326 individual data points and the negative binomial regression curves for crash rate and for fatal+significant crash rate performed on the full data set are shown in Exhibit 4-29. The negative binomial regression equations follow.

$$\ln(\text{crash rate}) = 1.0706 + 0.0168 \times \text{C+I density} \quad p < 0.001 \quad \text{significant}$$

$$\ln(\text{Fat+Sig} \times 100) = 2.7048 + 0.0105 \times \text{C+I density} \quad p = 0.007 \quad \text{significant}$$

From these analyses, it was concluded that both the overall and the fatal+significant crash rates had a statistically significant positive relationship with C+I access density. That is, as the C+I access density increased, the increases in the overall and the fatal+significant crash rates were statistically significantly.

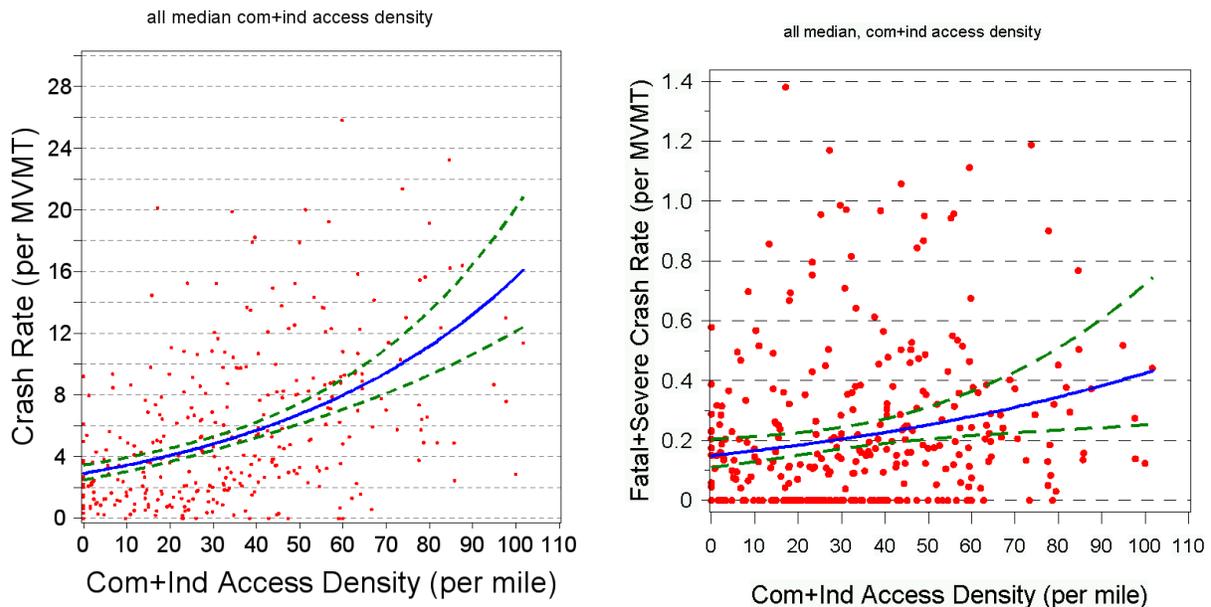


EXHIBIT 4-29 Regression of crash rates and C+I density

Crash Rates Considering a Subset of C+I Access Density Data

After examining the distribution of the data, the segments were initially grouped into the following ranges: less than 10.5, 10.5 through 20.9, 21.0 through 53.9, and greater than or equal to 54.0. The relationship between crash rate and density was not significant for 10.5-20.9, but was significant for 21-53.9.

There was a suspicion that for the 21-53.9 range, the data in the upper end of the range were in effect “pulling up” the data in the lower end, and therefore giving an overall finding of significance when in fact the data in the lower end had a poorer relationship. This concern was supported by a test of the 21

to 35 range, which resulted in a p-value of 0.14, which was close to significant. In other words, this seemed to be a range in which the relationship was changing from not significant (at the lower end) to significant (at the upper end).

After additional tests, it was concluded that the following grouping better reflected the change from non-significant to significant: less than 10.5, 10.5 through 27.9, 28.0 through 53.9, and greater than or equal to 54.0. Exhibit 4-30 shows that there is a definite increase in the crash rate as the C+I density increases.

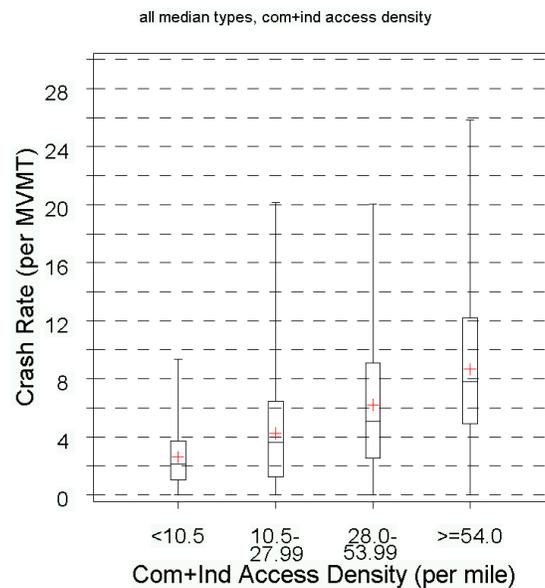


EXHIBIT 4-30. Box and whisker plot of C+I density ranges

Even though the principle of a factor or variable (such as access density) having an effect on crash rates when that factor reaches a certain level may be valid, determining the point at which that factor becomes significant can be somewhat arbitrary. It is always possible that if the sample size had been larger, the 21 to 35 C+I access density range would have a significant relationship with crash rate. While the choice of the 28 to 54 range is conservative, it may be that a range which includes lower densities may be just as valid.

Crash Rates for C+I Access Density (28.0-53.9)

The negative binomial regression equation for crash rate for the 110 segments in the 28.0 to 53.9 C+I access density range follows (see Exhibit 4-31).

$\ln(\text{crash rate}) = 0.9637 + 0.0216 \times \text{C+I density}$ $p = 0.039$ significant

From this analysis, it was concluded that C+I access density within this range had a statistically significant positive relationship with crash rate. As the C+I access density increased, the crash rate increased significantly.

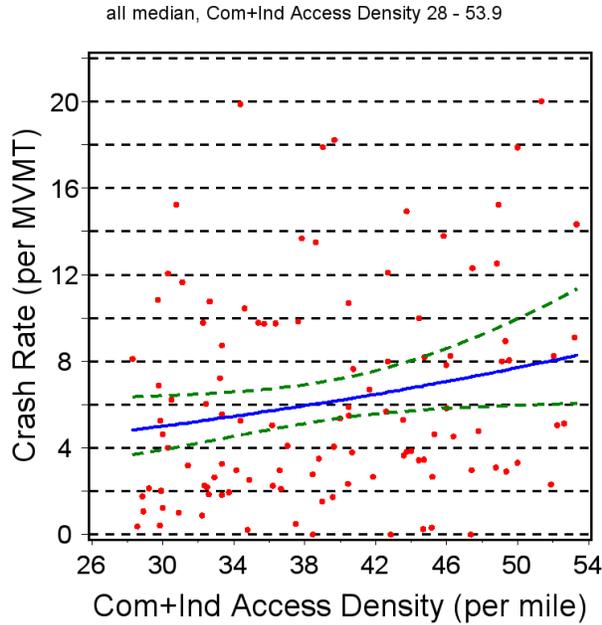


EXHIBIT 4-31 Regression for crash rate and C+I density 28.0-53.9

The relationship between crash rate and C+I access density for each of the four median types was also performed for the range of 28.0-53.9. The resulting negative binomial regression equations follow.

None (N = 26)

$$\ln(\text{crash rate}) = 1.9579 - 0.0068 \times \text{C+I density} \quad p = 0.786 \quad \text{not significant}$$

None+LTL (N = 15)

$$\ln(\text{crash rate}) = -0.1661 + 0.0513 \times \text{C+I density} \quad p = 0.004 \quad \text{significant}$$

TWLTL (N = 66)

$$\ln(\text{crash rate}) = 1.0861 + 0.0181 \times \text{C+I density} \quad p = 0.199 \quad \text{not significant}$$

Rais+Dep (N = 3)

$$\ln(\text{crash rate}) = 3.8135 - 0.0345 \times \text{C+I density} \quad p = 0.700 \quad \text{not significant}$$

Note that the Raised+Depressed sample size is very small, so one cannot draw conclusions for that type with any degree of confidence. Exhibit 4-32 displays the negative binomial regression curves for crash rates for a C+I access density range from 28 up to 54.

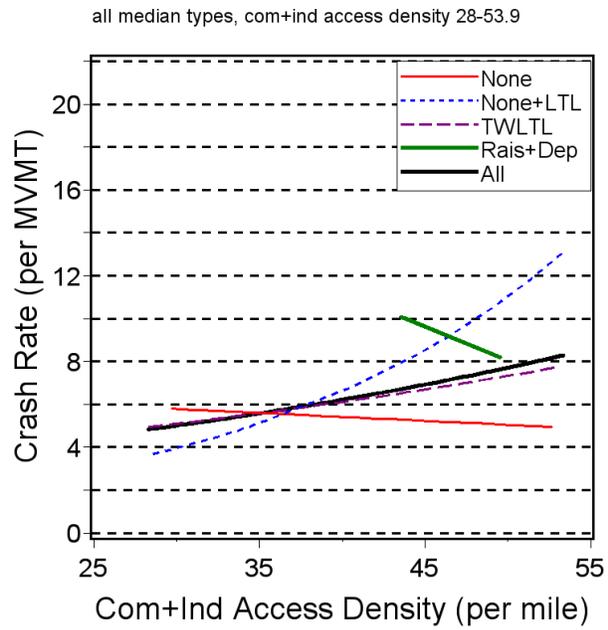


EXHIBIT 4-32 Regression for crash rate and C+I density 28.0-53.9 by median type

CORRELATIONS AND UNEVEN DISTRIBUTION OF THE VARIABLES

During preliminary data analyses, a number of instances of uneven distribution of data were noted. Exhibit 4-33 presents one such example, that of the distribution of signal density data (note that a number of 0.0 values are superimposed on each other). While the overall range extends from 0 to near 14 per mile, there were few data points above 5, and the bulk of the data plotted below 2.5. To address this, the researchers made adjustments, such as concentrating an analysis on a constrained data range (or subset) that was better-populated with data from all four of the median types.

Closely related to this is the problem of correlation, the case when one independent variable is related to another independent variable. For instance, was one median type more common where speeds were low, while another median type was found mainly on higher-speed roadways? Interrelationships between median types and speeds, or other interrelationships in which the four median types are not equally common in each category being tested, may affect the reliability of crash prediction models.

Chi square tests were conducted on the set of the 326 segments to determine if speed limit, lane width, or the presence of curb or shoulder was correlated with the median type. In other words, are they unevenly distributed across the four median types. As the following discussions show, each of these variables were found to be unevenly distributed across the four median types. Previous sections mentioned other correlations; for instance, Raised and Depressed medians were seldom found in the upper half of the range of access densities.

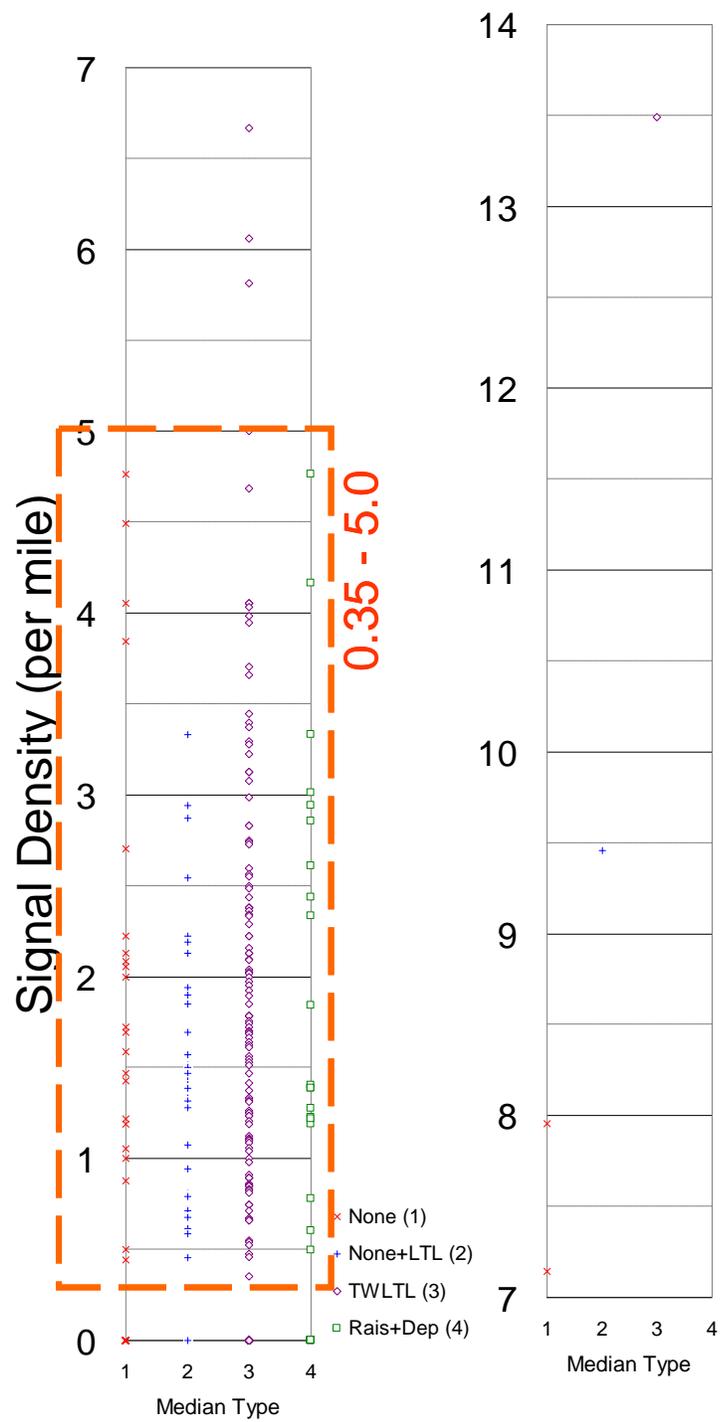


EXHIBIT 4-33 Illustration of the issue of the distribution of the data

Median Type with Speed Limit

Due to the low number of segments having a 30 mph speed limit, this category was removed before performing the Chi square test. Exhibit 4-34 shows the output. The test showed a correlation between median type and speed limit ($p < 0.0001$). For the 35 mph speed category, the None and None+LTL types had more segments than expected. The Rais+Dep type had fewer segments than expected in the 40 mph category, and more than expected in the 45 and 50 mph categories.

EXHIBIT 4-34 Chi square analysis of speed limit by median type

Median Type		Speed Limit (mph)				Total
		35	40	45	50	
None	Frequency	23	20	17	1	61
	Expected cell	15.394	22.899	19.435	3.271	
	Chi-Square	3.757	0.367	0.305	1.577	
	Cell Percent	7.260	6.310	5.360	0.320	19.24
	Row pct	37.700	32.790	27.870	1.640	
	Column pct	28.750	16.810	16.830	5.880	
None+LTL	Frequency	16	16	11	0	43
	Expected cell	10.852	16.142	13.700	2.306	
	Chi-Square	2.442	0.001	0.532	2.306	
	Cell Percent	5.050	5.050	3.470	0	13.56
	Row pct	37.210	37.210	25.580	0	
	Column pct	20.000	13.450	10.890	0	
TWLTL	Frequency	36	79	58	9	182
	Expected cell	45.931	68.322	57.987	9.760	
	Chi-Square	2.147	1.668	0.000	0.059	
	Cell Percent	11.360	24.920	18.300	2.840	57.41
	Row pct	19.780	43.410	31.870	4.950	
	Column pct	45.000	66.390	57.430	52.940	
Rais+Dep	Frequency	5	4	15	7	31
	Expected cell	7.823	11.637	9.877	1.662	
	Chi-Square	1.018	5.012	2.657	17.137	
	Cell Percent	1.580	1.260	4.730	2.210	9.78
	Row pct	16.130	12.900	48.390	22.580	
	Column pct	6.250	3.360	14.850	41.180	
Total number		80	119	101	17	317
Total column percent		25.24	37.54	31.86	5.36	100.00

Median Types with Lane Width

Exhibit 4-35 shows Chi square values for median types by width of the through lanes. Widths of less than 9 ft or greater than 13 ft were excluded. The Chi square test performed on median type and lane width also indicated a correlation ($p < 0.0001$). In the 12-13 ft width category, TWLTL segments occurred only about $\frac{1}{4}$ as often as expected, while the other three categories had more of these segments than expected. In the 9-10 ft category, TWLTL segments occurred more often than expected.

EXHIBIT 4-35 Chi square analysis of lane width by median type

Median Type		Lane Width (ft)				Total
		09-10	10-11	11-12	12-13	
None	Frequency	4	22	17	24	67
	Expected cell	8.61	15.12	27.72	15.54	
	Chi-Square	2.46	3.12	4.14	4.60	
	Cell Percent	1.25	6.90	5.33	7.52	21.00%
	% of row	5.97	32.84	25.37	35.82	
	% of column	9.76	30.56	12.88	32.43	
None+LTL	Frequency	3	5	15	20	43
	Expected cell	5.52	9.70	17.79	9.97	
	Chi-Square	1.15	2.28	0.43	10.07	
	Cell Percent	0.94	1.57	4.70	6.27	13.48%
	% of row	6.98	11.63	34.88	46.51	
	% of column	7.32	6.94	11.36	27.03	
TWLTL	Frequency	34	45	88	11	178
	Expected cell	22.87	40.17	73.65	41.29	
	Chi-Square	5.40	0.57	2.79	22.22	
	Cell Percent	10.66	14.11	27.59	3.45	55.80%
	% of row	19.10	25.28	49.44	6.18	
	% of column	82.93	62.50	66.67	14.86	
Rais+Dep	Frequency	0	0	12	19	31
	Expected cell	3.98	6.99	12.82	7.19	
	Chi-Square	3.98	6.99	0.05	19.39	
	Cell Percent	0.00	0.00	3.76	5.96	9.72%
	% of row	0.00	0.00	38.71	61.29	
	% of column	0.00	0.00	9.09	25.68	
Total number		41	72	132	74	319
Total column percent		12.850	22.57	41.38	23.20	100.00%

Median Types with Curb or Shoulder

About 4/5 of the segments had curbs, while only 1/5 had shoulders adjacent to the traveled lanes. The Chi square test output, shown in Exhibit 4-36, indicated a correlation between median type and the presence of either curb or shoulder ($p < 0.0001$). The primary imbalance was in the Rais+Dep type, which had fewer segments with curbs and more segments with shoulders than expected.

EXHIBIT 4-36 Chi square analysis of curb or shoulder by median type

Median Type		Curb	Shoulder	Total
None	Frequency	55	13	68
	Expected	53.8	14.2	
	Chi-Square	0.02	0.09	
	Cell Percent	16.87	3.99	20.86
	% of row	80.88	19.12	
	% of column	21.32	19.12	
None+LTL	Frequency	39	4	43
	Expected	34.0	9.0	
	Chi-Square	0.72	2.75	
	Cell Percent	11.96	1.23	13.19
	% of row	90.70	9.30	
	% of column	15.12	5.88	
TWLTL	Frequency	149	35	184
	Expected	145.6	38.4	
	Chi-Square	0.07	0.29	
	Cell Percent	45.71	10.74	56.44
	% of row	80.98	19.02	
	% of column	57.75	51.47	
Rais+Dep	Frequency	15	16	31
	Expected	24.5	6.5	
	Chi-Square	3.70	14.05	
	Cell Percent	4.60	4.91	9.51
	% of row	48.39	51.61	
	% of column	5.81	23.53	
Total number		258	68	326
Total column percent		79.14	20.86	100.00

RESULTS FOR FULL NEGATIVE BINOMIAL MODEL

To address the effects of the combinations of factors that are present in a roadway environment, multiple-factor models were pursued. The models were developed with the “backward elimination” method. This method begins by considering all variables in the model, then removing variables and/or interaction terms one at a time (starting with the largest non significant interaction terms first) until all variables and/or interaction terms remained statistically significant. Because a main objective was to evaluate the relative safety of the median types, this variable was included in the final model regardless of its p-value. Also, main effects (variables) were retained if it were a significant interaction term, regardless of its p-value.

Developing the Negative Binomial Model

The initial model was developed with the following variables: median type, posted speed limit, curb or shoulder, through lane width, median width, signal density, access density, volume, and all two-way interactions. Speed limit was evaluated as categorical rather than continuous. The output showed the following seven variables to be significant: median type, posted speed limit (30-50 mph), curb or shoulder, median width, signal density, access density, and volume. The model also included the seven following significant interactions:

- median type and speed limit,
- median type and median width,
- median type and access density,
- speed limit and curb or shoulder,
- speed limit and median width,
- speed limit and signal density, and
- speed limit and access density.

While reviewing the estimates and standard errors from the SAS output, it was found that the None median and its interaction with posted speed limit were different than other values (e.g., the standard error for the None median was 811.0580, while the standard errors for all other terms were less than 1.67). It was discovered that one segment (route 79/section 3 in Camden) was causing this aberration. This was the only None segment with a 50 mph speed limit. This segment had low traffic volume (5900 vpd) and no crashes reported over the three years evaluated. Therefore, this segment was removed from the full model.

The final model (see Exhibit 4-37) included the following five variables: median type, posted speed limit (30-50 mph), curb or shoulder, signal density, and access density. It also included three interactions: posted speed limit and curb or shoulder, posted speed limit and signal density, and posted speed limit and access density. The p-values for each term in the final access density model (N = 325 segments) follow.

median type	0.5468
speed limit	0.6546
curb or shoulder	0.0062
access density	0.1788
signal density	<0.0001
interaction of speed limit and curb or shoulder	0.0149
interaction of speed limit and access density	0.0288
interaction of speed limit and signal density	<0.0001

The interactions between median type and each of the variables were also tested separately, and no significance was found. Because the median type was not included in any interaction term, the predicted crash rate would be in the same order (from lowest to highest) relative to median type regardless of the environment tested with the equation. In other words, under a given set of conditions, the Rais+Dep would have the lowest predicted crash rate, and the None+LTL would have the highest.

$$\text{Ln (crash rate) (crash/MVMT)} = 3.8341 + 0.9843 \times \text{Signal density (per mi.)} + \text{If Curb, then } 1.2586; \text{ Shoulder}=0 + 0.0064 \times \text{Access Density (per mi)}$$

- equation continues below -

For columns below, select value from the row below corresponding to the speed in the far right column					
Median Type - + select value below	Speed Limit (mph)-select value below	Multiply these 3 values			posted mph
		Curb If present, choose value below	x Signal Density (per mi)	x Access density (per mi)	
+ _____	+ _____	(_____ x _____ x _____)			
If None, then 0.2416	0.5199	0.0000	-0.9731	0.0059	30
If None+LTL, then 0.3044	0.7630	-0.2797	-0.8095	0.0002	35
If TWLTL, then 0.1781	1.3327	-1.4375	-0.6858	0.0047	40
If Rais+Dep, then 0.0000	0.9823	-0.6999	-0.3430	-0.0118	45
	0.0000	0.0000	0.0000	0.0000	50

EXHIBIT 4-37 Equation for predicted crash rate

Negative Binomial Model Evaluation

After the models were constructed, combinations of factors were input and the resulting predicted crash rates were examined. Since presence of a curb or shoulder, signal density, and total access density all had significant interactions with the posted speed limit, a sensitivity analysis was done to see what effects of different combinations of these variables would have on the predicted crash rates. These

scenarios (see Exhibit 4-38) focused on conditions typically found in transition areas of urban or suburban environments.

The predicted crash rates for some combinations of factors occasionally seemed suspect. For instance, two calculations where all inputs except one were identical (e.g. one was for curb and the other for shoulder) sometimes yielded predicted crash rates for the shoulder section that were greater than that for the curb section, whereas a separate analysis had found that segments with shoulders had the lower crash rates. It was suspected that the complexity of the model actually detracted from its strength. In particular, at the “edges” of the range of independent variable values, certain combinations of input values may be prone to yield spurious crash rate predictions.

EXHIBIT 4-38 Sensitivity analysis of crash rate prediction equation

Scenario Number	Speed Limit	Median Type	Curb or Shoulder	Signal Density	Access Density	Crash Rate
1	40	None	c	2.0	40	5.2891
2	40	None	c	4.0	60	11.9992
3	40	None	s	2.0	40	6.3255
4	40	None	s	4.0	60	14.3504
5	40	None+LTL	c	2.0	40	5.6321
6	40	None+LTL	c	4.0	60	12.7772
7	40	None+LTL	s	2.0	40	6.7357
8	40	None+LTL	s	4.0	60	15.2809
9	40	TWLTL	c	2.0	40	4.9639
10	40	TWLTL	c	4.0	60	11.2614
11	40	TWLTL	s	2.0	40	5.9366
12	40	TWLTL	s	4.0	60	13.4681
13	40	Rais+Dep	c	2.0	40	4.1531
14	40	Rais+Dep	c	4.0	60	9.4243
15	40	Rais+Dep	s	2.0	40	4.9681
16	40	Rais+Dep	s	4.0	60	11.2709
17	45	None	c	1.0	20	4.6893
18	45	None	c	2.0	40	7.9970
19	45	None	s	1.0	20	2.6823
20	45	None	s	2.0	40	4.5742
21	45	None+LTL	c	1.0	20	4.9933
22	45	None+LTL	c	2.0	40	8.5155
23	45	None+LTL	s	1.0	20	2.8562
24	45	None+LTL	s	2.0	40	4.8708
25	45	TWLTL	c	1.0	20	4.4010
26	45	TWLTL	c	2.0	40	7.5053
27	45	TWLTL	s	1.0	20	2.5173
28	45	TWLTL	s	2.0	40	4.2930
29	45	Rais+Dep	c	1.0	20	3.6830
30	45	Rais+Dep	c	2.0	40	6.2809
31	45	Rais+Dep	s	1.0	20	2.1067
32	45	Rais+Dep	s	2.0	40	3.5927
33	50	TWLTL	c	0.5	8	3.3503
34	50	TWLTL	c	1.0	16	5.7687
35	50	TWLTL	s	0.5	8	0.9517
36	50	TWLTL	s	1.0	16	1.6387
37	50	Rais+Dep	c	0.5	8	2.8037
38	50	Rais+Dep	c	1.0	16	4.8276
39	50	Rais+Dep	s	0.5	8	0.7964
40	50	Rais+Dep	s	1.0	16	1.3713

SIMPLE MULTI-FACTOR CRASH NUMBER MODEL

After the examination of the multiple-factor binomial regression model showed that questionable crash rates were sometimes output, the nature of the variables was contemplated. It was hypothesized that while speed was well correlated ($p < 0.001$) with crash rate, speed was also somewhat of a dependent variable, in that the speed on any roadway reflects the drivers' response to a combination of many variables associated with that roadway. To some degree signal density also is a response to and therefore reflects other traffic attributes in that section of road. As was previously mentioned, the presence of either curb or shoulder was correlated with other factors. Commercial+Industrial access density is a subset of "overall" access density, and it was found that no one C+I range was well-populated with all four median types.

Crash models can predict crash rates or the number of crashes. When analyzing different scenarios with a wide range of volumes, models that predict crash rates can produce results that are more straightforward and easier to use than models that predict the number of crashes. However, some have raised objections to models that predict crash rates when one of the independent variables is volume, since the output (i.e., the dependent variable) is also volume-based.

The preceding considerations led to the decision to fit a simpler negative binomial model to crash frequency, using a subset of the data to better reflect all four median types within the range. To establish the lower limit of volumes to be included in the model, a compromise between the previous lower ranges of 4000 and 6000 led to selecting 5000 vehicles per day. The ranges were constrained as follows.

Access density: 5 to 60 access points per mile

Lane width: all

Signal density ≤ 5 signals per mile

Speed limit: 35, 40, 45 mph

Volume: 5,000 to 26,000 vehicles per day

As a check, the Chi square test was performed to evaluate correlations among the pairs of these five independent variables within the above ranges. Signal density was marginally correlated to speed limit ($p = 0.117$) and correlated to volume ($p < 0.01$). Lane width was correlated with access density ($p < 0.01$). None of the other pairs were significantly correlated.

The model inputs were access density, volume, through lane width, median type, and two-way interactions between the four independent variables. The significant variables in the resulting model were volume ($p < 0.01$) and access density ($p = 0.071$). Median type, while not significant, was retained in the model to permit comparisons among the four types. The other variables and two-way interactions were not significant, and therefore were not included in the model. The predictive equation follows.

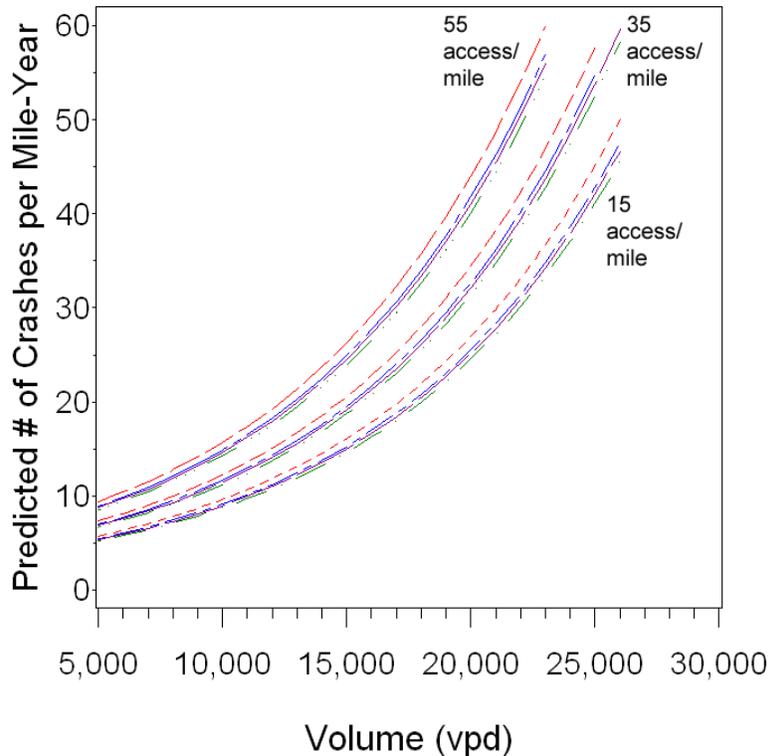
$$\ln(\text{number of crashes}) = e^{[0.9545484 + F + 0.0001031 (\text{Volume}) + 0.012272 (\text{Access Density})]}$$

where F varies by median type as follows:

$$\text{None} = 0.092939 \quad \text{None+LTL} = 0.041100 \quad \text{TWLTL} = 0.023569 \quad \text{Rais+Dep} = 0$$

Exhibit 4-39 presents plots of the crash frequency versus the volume for access densities of 15, 35, and 55 per mile. For a given volume, the median type with the least number of predicted crashes per mile-year was the Rais+Dep. The TWLTL had the next lowest, and was followed by the None+LTL. The differences between the any pair of these were slight but consistent. The None category had the greatest

number of predicted crashes, and the differences between the None and the other three median types were more pronounced.



- None, 15 -- None, 35 -- None, 55
- None+LTL, 15 -·- None+LTL, 35 -·- None+LTL, 55
- TWLTL, 15 — TWLTL, 35 — TWLTL, 55
- Rais+Dep, 15 ··· Rais+Dep, 35 ··· Rais+Dep, 55

EXHIBIT 4-39 Crash frequency for volume and access density by 4 median types

Since there were few None types with a volume over 16,000 vpd, the model was essentially extrapolating to make predictions within the 16,000 to 26,000 range. The following two models were formulated to address this. The first model in the lower volume range excludes the Raised+Depressed type, and the second model excludes the None type.

- for the None, None+LTL, and TWLTL within a range of 5,000 through 16,000 vpd

$$\ln(\text{number of crashes}) = e^{[0.6229678 + F + 0.0001233 (\text{Volume}) + 0.017696 (\text{Access Density})]}$$

where F varies by median type as follows:

$$\text{None} = 0.087264 \quad \text{None+LTL} = 0 \quad \text{TWLTL} = -0.068989$$

- for the None+LTL, TWLTL, and Rais+Dep within a range of 5,000 through 26,000 vpd

$$\ln(\text{number of crashes}) = e^{[0.90847 + F + 0.0001062 (\text{Volume}) + 0.012206 (\text{Access Density})]}$$

where F varies by median type as follows:

$$\text{None+LTL} = 0.04521 \quad \text{TWLTL} = 0.02233 \quad \text{Rais+Dep} = 0$$

The model created after excluding the None type was similar to the previous model that included all four median types.

Comparing the model based on all four median types with this one (see Exhibit 4-40), the predicted numbers of crashes are similar below 10,000 vpd. Above 10,000 vpd, this constrained-below 16,000 vpd model predicts somewhat higher numbers of crashes, and considerably higher numbers for a higher access density.

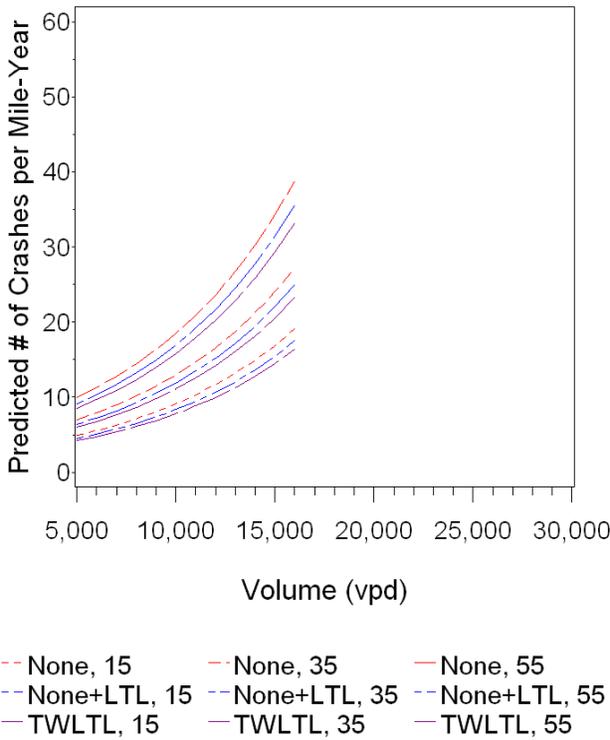


EXHIBIT 4-40 Predicted crash frequency for constrained ranges of volume and access density by 3 median types

CHAPTER 5

SUMMARY AND APPLICATION

Previous studies have examined relationships among median type, access density, and other design and operational attributes on safety. Methodologies and sample attributes have varied among studies. In general, past studies have found that crash rates tend to increase when access density or signal density increases. Some have found that crash rates increase as volume increases, but crash rates are lower on higher speed roadways. The literature reports that multilane roadways with restrictive medians (raised or depressed) have the lowest crash rates, multilane roadways with no median have the highest crash rates, and those with two-way left-turn lanes fall in between.

This research project examined relationships among crash rates, cross section design elements, and other operational attributes of multilane urban and suburban roadways in Arkansas. Data were collected to compare crash rates for four cross section categories: roadways with no median (None), roadways with occasional left-turn lanes (None+LTL), roadways with continuous two-way left turn-lanes (TWLTL), and roadways with raised or depressed (Rais+Dep) medians. Freeways were excluded from the analysis. An elaborate process was used to screen the data, and hopefully improve the quality of the analyses. Periods during which construction activities were indicated to have occurred on study segments were excluded from the analyses. To be included in the analyses, the length of a segment had to be at least 0.3 mi, and within that length, characteristics such as posted speed and cross section characteristics had to remain constant. Segments were videotaped, and the tapes were viewed in the office to obtain and verify roadway attributes. The final data set included 326 segments, with slightly over half being the TWLTL type.

Crash histories were related to cross section types, speed limits, volumes, widths of through lanes, presence of curb or shoulder, outer shoulder widths, median widths, and the densities of various types of access.

SUMMARY OF FINDINGS

The outcomes of some tests may have been affected by uneven distributions of some variables across the range of the data, or by sample size limitations. For any particular attribute examined, it was not uncommon to find a statistically significant relationship between the attribute and crash history, but find that the relationship with the fatal+significant crash rate was statistically insignificant. That this occurred repeatedly leads to speculation that if there were more fatal+significant crashes in the data set, some of these relationships might have been significant.

The following sections summarize the outcomes of many of these analyses.

Median Type

Crash rates of four median types were examined. The None+LTL median type had the highest mean crash rate, followed by the TWLTL median and the None median. The Rais+Dep median had the lowest mean crash rate.

Speed Limit

Within the range of 30 through 50 mph, the speed limit had a statistically significant inverse relationship with crash rate and with the subset of fatal+significant crash rate. As the posted speed limit increased, both the crash rate and the fatal+significant crash rate decreased significantly.

Volume

Within the range of 2,333 vpd and 36,000 vpd, the crash rate had a statistically significant relationship with volume, but the fatal+significant crash rate did not. As the volume increased, the crash rate increased significantly.

Lane Width

From this analysis of crash rates on roadways with lane widths between 8.5 and 13 ft, it was concluded that lane width had a statistically significant inverse relationship with crash rate. As the lane width increased, the crash rate decreased significantly.

Presence of Curb or Shoulder

The average crash rate for segments with curbs was significantly higher than the crash rate for segments with shoulders.

Outer Shoulder Width

As the outer shoulder width increased, both the crash rate and the fatal+significant crash rate decreased, but these relationships were not statistically significant.

Median Width

Among the TWLTL and Rais+Dep segments, median widths ranged from 8 to 84 ft. For the width of the median on TWLTL and Rais+Dep roadways, there was an inverse relationship with both crash rate and fatal+significant crash rate. As the median width increased, both rates decreased. The relationship for crash rate was statistically significant, the rate for fatal+significant was not.

Left-Turn Lane Density

After removing two outliers from the None+LTL set, the crash rate on the remaining 30 segments did not have a statistically significant relationship with density (i.e., frequency) of left-turn lanes.

Median Opening Density

Evaluating segments with raised or depressed medians, the median opening density had a statistically significant positive relationship with crash rate. As the median opening density increased, the crash rate increased significantly. A marginally significant relationship exists between median opening density and fatal+significant crash rate.

Signal Density

Traffic signal densities in the study ranged from 0.0 to 13.49 signals per mile. As the signal density increased, the overall and the fatal+significant crash rates increased significantly. The graphs of the relationships showed a marked increase in the crash rate as the signal density increases.

Access Density

Among the 326 segments, access densities ranged from 0.0 to 137.70 access points per mile, counting both sides of the roadway. As the access density increased, both the overall and the fatal+significant crash rates increased. Both relationships were statistically significant.

Commercial+Industrial Access Density

For the segments in this study, the density of the combined commercial and industrial access types ranged from 0 to 101.7 points per mile, counting both sides of the roadway. Both the overall and the fatal+significant crash rates had statistically significant positive relationships with C+I access density.

Correlations

During the investigations, it became apparent that certain traits were not evenly distributed across the full range of the trait's descriptors. For instance, even though signal densities ranged from 0 to almost 13.5 per mile, most segments had fewer than 5 signals per mile.

A number of the independent variables were correlated. Certain traits or features were not evenly distributed across a full range of other traits or features. Just from observations, one can deduce that in urban areas, multilane state highways with shoulders adjacent to the travel lanes are usually found at the edge of the urban area, where development is less dense. As one moves into the more densely developed parts, multilane state highways are likely to have curbs adjacent to the traveled lanes..

For another example, the majority of Rais+Dep median type segments were found where there were lower access densities. The average access density for the Rais+Dep types was less than half of that for any of the other three types.

There were disproportionately fewer TWLTL segments with wider lanes (in the 12-13 ft range). There were only about ¼ as many TWLTL segments with lane widths in this wider group as would be expected.

These uneven distributions and correlations have a real potential to distort an analysis of the data.

Complex Negative Binomial Model

A negative binomial model was developed with backward elimination to relate crash rates on multilane roadways in urban and suburban areas to a number of geometric and operational attributes. The model included statistically significant traits and interactions. However, the predictive equation produced some suspect outcomes, especially for values of some attributes near the edge or limit of a range. It was suspected that uneven distributions and correlations were distorting the model, and that a simpler model would be preferable.

Simple Negative Binomial Model

Simplified negative binomial models relating volume, access density, and the four cross section types to the number of crashes, not the crash rate, were developed. The models were developed using a constrained range of variables that were better populated with data points. The resulting models appeared to produce more consistent and better behaved equations that did the previous complex models.

These simple models predict that for multilane urban and suburban roadways with attributes in the ranges of those studied, Rais+Dep roadways have the least number of crashes, with TWLTL second best, and None+LTL third. The None type was predicted to have the highest number of crashes. Greater differences were associated with the number of access points per mile; as access density increases, the number of crashes increases. As one would expect, the models predict the number of crashes to increase as the volume increases, but this increase is not linear, indicating a higher crash rate with a higher volume.

APPLICATION

Exhibit 5-1 ranks the four median types by their crash rates associates with the listed traits or features. This shows that for many traits of features, a lower crash rate was found to exist on the Rais+Dep segments.

EXHIBIT 5-1 Crash rate ranking by median type

	Crash rate ranking by median type			
	None	None+LTL	TWLTL	Rais+Dep
Median type	2	4	3	1
Speed limit (30 – 50 mph)	1	3	4	2
Volume (6,000 – 26,000 per day)	4	3	2	1
Lane width (8.5 – 13 ft)	2	4	3	1
Signal density (0.35 – 5 per mile)	4	3	2	1
Access density (5 – 60 per mile)	2	4	3	1
Simple multi-factor model	4	3	2	1
Composite sum	19	24	19	8

NOTE: “1” indicates lowest crash rate, “4” indicates highest.

Based on analyses of crash data from operating roadways, the simple model predicts that lower access densities will produce safer roadways. A restrictive median will offer a somewhat safer roadway than will the other three cross section designs (None, None+LTL, TWLTL) analyzed.

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