AHTD TRC TRANSPORTATION RESEARCH COMMITTEE

TRC0103

Rural Highway Median Treatments

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Final Report

2003

RURAL HIGHWAY MEDIAN TREATMENTS

TRC 01-03

for the
Arkansas State Highway & Transportation Department
and
Federal Highway Administration

by

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January, 2003

RESEARCH

RURAL HIGHWAY MEDIAN TREATMENTS

PROJECT OBJECTIVES

The objective of this study was to examine the safety effects of different rural and suburban four-lane highway cross-section alternatives. The frequency or density of access points (e.g., cross streets, driveways) was also considered. Fully controlled access roadways were not included in the study.

Various databases were examined to identify those roadway segments having four or more lanes and posted speeds of 40 mph or above. When entering an urban area, the segments were normally terminated when the first traffic signal or stop sign was encountered. Crash data from three years were used.

The median types encountered included depressed, raised, flush, and no median (i.e., just a marked centerline). Within the "flush" category, types included two-way left turn lane (TWLTL) and narrow (i.e., less than 8 feet wide).

FINDINGS

The crash rates of a number of combinations of cross section and other design features were determined. In some instances, there were too few roadways having a certain combination of cross section elements to allow an analysis. These findings were taken from rural and suburban roadways with volumes ranging from 1,800 to 26,000 veh/day.

- ✓ Crash rates for the roadway segments having a median were less than the rates for those without medians.
- ✓ As the width of the median increased, the crash rate decreased.
- ✓ Crash rates for the roadway segments having an inner shoulder were less than for those without an inner shoulder.
- ✓ As the width of inner shoulder increased, the crash rate decreased.
- ✓ 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.
- ✓ As the width of outer shoulder increased, crash rate decreased.
- ✓ As the traffic volume (ADT) increased, the crash rate increased.
- ✓ As the access density increased, the crash rate increased.
- ✓ On the roadways with lower access density (< 20 access points per mile), roadways with depressed medians had the best safety record.
- ✓ On the roadways with medium access density (20 – 40 access points per mile), roadways with no median had the worst safety record. Although depressed median roadways had the best safety record, the small sample size limited inferences from this dataset. Further investigation revealed that the comparison between roadways with Narrow medians and those with TWLTLs was somewhat skewed by the fact that the roadways in the dataset with Narrow medians had lower volumes, wider average lanes 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 TWLTL sample size was small.
- ✓ On roadways with high access density (> 40 access points per mile), the TWLTL group had a much better safety record than did roadways with no median.

Although it was not an objective of this research, the analysis suggests that there may be a correlation between median type and other factors that influences crash rates. In other words, some cross section types may tend to be installed in certain situations and environments that are less safe, and therefore that cross section option is found to have a higher crash rate. Additional research would be required to investigate this issue.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle RURAL HIGHWAY MEDIAN TREATMENTS		5. Report Date JANUARY 2003 6. Performing Organization Code 0402-30095-21-0000
7. Authors J. L. GATTIS, Ph.D., P.E., R. BALAKUMAR, L. K. DUNCAN		8. Performing Organization Report No.
9. Performing Organization Name and Address CIVIL ENGINEERING DEPARTMENT UNIVERSITY OF ARKANSAS 4190 BELL ENGINEERING CENTER FAYETTEVILLE, AR 72701		10. Work Unit No. (TRAIS) 11. Contract or Grant No. AHTD TRC 01-03
12. Sponsoring Agency Name and Address ARKANSAS STATE HIGHWAY & TRANSPORTATION DEPARTMENT P. O. BOX 2261 LITTLE ROCK, AR 72203		13. Type of Report and Period Covered FINAL REPORT JUL. 2000 -- JAN. 2003 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The objective of this study was to examine the safety records of different rural and suburban highway (other than fully-controlled access roadways) cross-section alternatives in Arkansas. This study attempted to assess the safety effects of the lack of or inclusion of various median types.

Various databases were examined to identify those roadway segments having four or more lanes and posted speeds of 40 mph or above. When entering an urban area, the segments were normally terminated when the first traffic signal or stop sign was encountered. Crash data from three years were used.

The analyses produced a number of relationships relating crash frequency to median, shoulder, volume, and access frequency attributes. Crash severity and crash type were also examined.

The roadways with depressed medians and shoulders had the lowest crash rates, while the roadways with no median (i.e., painted line) and no shoulder had the worst safety record.

17. Key Words MEDIAN, ROADWAY DESIGN, SAFETY, CROSS SECTION, RURAL, SUBURBAN	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 Class. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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CHAPTER 1
INTRODUCTION

In 1998, the Arkansas State Highway and Transportation Department (AHTD) revised the design of its typical rural cross-section, replacing a narrow 1.22 m to 1.83 m (4 ft to 6 ft) flush median with a wider flush median, marked as a continuous two-way left turn lane (TWLTL). In some cases, the needed width for the wider median was obtained by narrowing through-traffic lanes and shoulders. Although this decision was based on research performed in other states, AHTD wanted to obtain additional information, and decided to examine the effects of median width choices on roadways in Arkansas.

The objective of this study was to examine the safety records of different rural and suburban highway (other than fully-controlled access roadways) cross-section alternatives in Arkansas. This study attempted to assess the safety effects of the lack of or inclusion of various median types, in conjunction with lane widths and shoulder widths. This research attempted to answer the following questions.

- Question 1: Do similar median types have different safety records in rural vs. suburban areas? Does a median type that performs well in a rural area also perform well in a suburban area?
- Question 2: How are various types and severities of crashes affected by different median design alternatives?
- Question 3: Does the TWLTL design present problems under certain circumstances?
- Question 4: What multilane cross-section and median type (or no median) is appropriate for a given multilane rural or suburban highway situation?

MEDIAN TYPES

Figure 1.1 shows different types of medians. Medians were classified as being either "flush", "raised", or "depressed". Any of these three types having a raised barrier were placed in another category, "barrier". Roadways with only yellow centerline markings were classified as "no median". (Note that fully controlled, limited-access highways were not included in the study.)

Flush medians were further divided into three types: "two-way left turn lane" (TWLTL), "wide" median (greater than 2.44 m or 8 ft), and "narrow" median (width less than 2.44 m or 8 ft). No wide median roadways were encountered during the study.

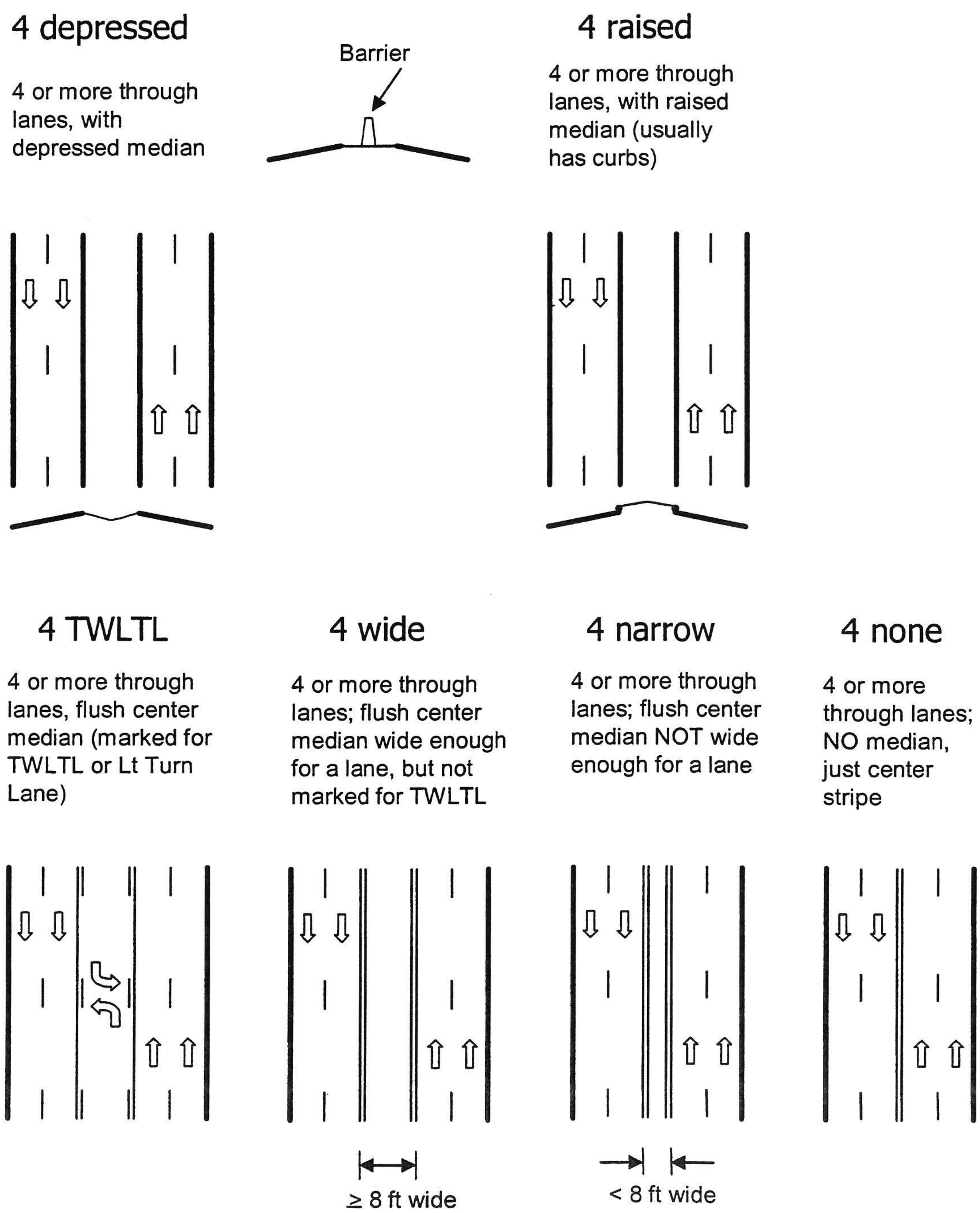

FIGURE 1.1 Roadway Median Types

CHAPTER 2
BACKGROUND

Chapter 4 of the *Green Book* (*A Policy on Geometric Design of Highways and Streets*, 2001) defines a median as "the portion of a highway separating opposing directions of the traveled way." Possible functions of a median include:

- separating traffic traveling in opposing directions,
- providing a recovery area for out-of-control vehicles,
- providing a stopping area in case of emergencies,
- providing a place for left-turn and U-turn speed change and storage lanes,
- providing a separation to minimize headlight glare,
- providing width in which to install future lanes, and
- provide an open green space in urban area.

The *Green Book* categorizes medians by elevation of the median with respect to that of the main traveled lanes: raised, depressed, or flush. Median width is expressed as the dimension between the through-lane edges and includes the left shoulders, if any.

A literature search produced several studies on the influences of median features on traffic operations and on crash rates. The following literature review is divided into sections on "Operations" and on "Safety". Note that the use of terms such as "suburban" and "urban" vary among the different studies.

REVIEW OF OPERATIONS LITERATURE

Operational topics address how drivers operate vehicles and how traffic affects drivers. An example of this is the amount of delay caused or eliminated by a median. There is necessarily some overlap between "Operational" studies and "Safety" studies.

Ohio Study

A study (Nemeth 1976) was conducted to develop the guidelines for the application of continuous two-way left-turn lanes. The objectives of this study were to synthesize existing information on continuous TWLTLs, conduct a nationwide expert opinion survey, and to conduct before-and-after field studies to evaluate the effectiveness of TWLTLs as an access control measure. In addition, a small-scale simulation study was conducted.

The field studies were conducted in Painesville (US-20), Cincinnati (US-264), Youngsfield (US-224), and Mansfield (US-42) in the state of Ohio. The average daily traffic (ADT) ranged from 12,940 to 18,070. From the study, the author concluded the following about operational aspects of TWLTLs.

- Almost without exception, where installed, the TWLTL has noticeably improved traffic flow. The study sites initially had no median and 2 to 4 through lanes.
- The value of a TWLTL in reducing congestion on roadways operating at or near maximum capacity becomes questionable, due to the lack of gaps of sufficient size in the approaching traffic stream that would permit left turn movements. However, for cases in which direct left turn access must be provided but signalization cannot be utilized to favorably alter the gap size or the distribution to accommodate left-turning vehicles, then left turn storage of some type becomes even more necessary. So perhaps the TWLTL should not be dismissed as inappropriate for high-traffic volume locales, since investigation may show that it still offers the best left turn storage alternative.

Harwood's Suburban Study

Harwood (1986) compared the safety, operational, and cost characteristics of selected multilane design alternatives for suburban highways. He combined the findings from the literature with data analyses to provide a comprehensive description of the advantages, disadvantages, and the potential applicability of a particular design alternative.

The following factors were considered in the review: median width and type, shoulder presence, access to roadside development, right-of-way requirements, capacity, operational characteristics, and accident experience. Any highway meeting the following criteria was considered a suburban arterial highway.

- Traffic volume over 7,000 vpd.
- Speeds between 56.3 and 80 km/h (35 and 50 mph).
- Spacing of at least 0.4 km (0.25 mi) between signalized intersections.
- Direct driveway access from abutting properties.
- No curb parking.
- Location in or near populated area.

The author concluded that the four-lane undivided (4U) design alternative is the most effective for residential and light commercial areas on suburban highways classified as collectors and minor arterials. The four-lane divided (4D) and five lane with center two-way left turn lane (5T) design alternatives, if physically feasible, would be more desirable than the 4U design alternative on highways that have dense commercial development, have heavy left turn volumes, or are classified as, or could become, major arterials. The 4U design alternative may also be appropriate as the first stage toward construction of a wider roadway with a median treatment.

The 4D design alternative is best suited for use on major arterials with high volumes of through traffic and less than 45 driveways per mile. The 4D design alternative is operationally preferable to the 4U design alternative only for sites with peak hour flow rates over approximately 1,000 vph in one direction, although this alternative could be used at lower flow rates where offsetting benefits, such as improved safety, land use control, or preservation of through traffic capacity, are expected. The 4D design alternative is not well suited to highways with strip commercial development and may be used to discourage such development from occurring. However, the 4D design alternative is better suited than the 5T design alternative to serve suburban highways with isolated major traffic generators having widely spaced, high volume driveways.

The 5T design alternative is most appropriate for suburban highways with commercial development, driveway densities greater than 45 driveways per mile, low-to-moderate volumes of through traffic, high left-turn volumes, and/or high rates of rear-end and angle accidents associated with left turn maneuvers. The installation of 5T design alternative on an undivided facility is expected to reduce the accident rate by 19 to 35 percent, on the average, with even greater reductions possible for highly congested facilities.

The five-lane continuously alternating left-turn lane (5C) design with a raised median is similar in traffic operations and safety to 4D design alternative, although more frequent median openings are provided. The use of 5C design alternative is not recommended where 5T design could be adopted.

Nebraska Study

A Nebraska research study (McCoy and Ballard 1986) developed guidelines for the use of TWLTL medians on urban four-lane roadways. Objectives of this research were:

- to evaluate the safety and operational effectiveness of the TWLTL medians on urban four-lane roadways,
- to develop a methodology for evaluating the cost-effectiveness the TWLTL, and
- to apply this methodology to develop guidelines for the cost-effective use of TWLTL medians on urban four-lane roadways.

Four-lane roads were reviewed to identify those which either were undivided or had TWLTL medians. All other sections were eliminated from further consideration. For each pertinent section, following information was recorded.

- Median type (none, TWLTL)
- Adjacent land use (strip commercial, CBD, industrial, residential, park, rural)

- Number of driveways
- Number of intersections (signalized and unsignalized)
- Parking condition (none, one-side, both sides)
- Curb condition (curbed, no shoulder, uncurbed, unpaved shoulder, uncurbed, paved shoulder)
- Lighting condition (none, one-side, both-sides, median, intersection only)

Four TWLTL sections were examined. Based on the results of a computer simulation study, it was concluded that:

- installing TWLTL medians on urban four-lane undivided roadways reduced stops and delays over a wide range of traffic volumes, left-turn percentages, and driveway densities;
- the magnitude of these reductions was an exponential function of traffic volume, left-turn volume, and driveway density.

Tennessee Suburban Study

A study (Mukherjee et al. 1993) was conducted in Tennessee on choosing between a median and a TWLTL for suburban arterials. The authors examined existing models and conducted a survey. Analysis of a few existing models and procedures dealing with accidents and delay to left-turning vehicles on arterial highways with nontraversable medians and TWLTLs showed that these empirical models based on different data sets yielded different results.

They distributed questionnaires to all the state DOTs in the United States except those in Hawaii, Tennessee and Alaska. The instrument included three hypothetical case studies. The following questions were asked.

- Does your state have formal guidelines for when to use median and TWLTL design?
- Have you ever changed a TWLTL to a median design or vice versa? Why?
- Have you ever conducted a before-and-after study of changing a design from a TWLTL to a median or vice-versa, or have you ever conducted a comparative analysis of the two cross-sections?
- What is your practice/experience with the following relating to medians: typical and desired median widths?
- If you have experienced problems with U-turns at signalized intersections on median sections, how have you addressed them?
- Have you ever used a TWLTL cross-section on a highway where current travel speeds are 72.4 km/h (45 mph) or higher? What has been your experience with these sections with accidents, traffic flow, and adjacent land access?

Descriptions of the three case studies follow.

- Case 1 described a two-lane highway in a rural area that is expected to develop into a suburban area.
- Case 2 was a four-lane undivided highway in an existing suburban area that needs upgrading because of accident and delay problems. The absence of mid-block turn lanes has created an unsafe situation.
- Case 3 dealt with a road section passing through a low-density, high-income residential area.

In each case the respondents were asked to select a cross-section feature related to median treatments.

The survey found that state highway engineers differed in their assessment of medians and TWLTLs. In the first case, that of an undeveloped area, most of the engineers choose a nontraversable median. The authors noted that it has not been proven whether there is a causal relationship between land development pattern and roadway geometrics. Many factors are involved with land development other than roadway geometrics. The authors concluded that initially using medians before the development of adjacent land would be a prudent policy to pursue, because it would provide the opportunity to manage driveways and land access in a more orderly fashion. Further, a change to TWLTL can be made later since sufficient right-of-way would already exist.

The second case dealt with a situation where a strip commercial development already exists, and most of the highway engineers chose a TWLTL. This choice can be justified based on the consideration that a TWLTL would better accommodate left turns to and from adjacent driveways. Another rationale used by some highway engineers is that a TWLTL requires less right-of-way in an already built-up area. It should be pointed out that the specified existing ADT of 25,000 vehicles was high. The authors found that some highway engineers believed that as traffic volume increases beyond certain levels, left turns become increasingly difficult and unsafe. It should also be noted that when traffic volume is high enough to warrant three through lanes in each direction, the situation would be significantly different.

The third case dealt with a residential area. Residential areas are more sensitive to environmental factors such as traffic noise than commercial areas. Residential areas do not generate as much traffic as commercial areas. The highway engineers did not show any clear consensus in this case. The authors reported that nearly one-third of the engineers did not even respond to this case, and the remaining engineers were almost evenly split among a median, a TWLTL, and other alternatives such as an undivided four-lane section.

Comparing Flush Medians with Two-Way Left-Turn Lanes in Texas

Differences in operation and safety between flush medians and two-way left turn lanes (TWLTL) were studied on four-lane rural highways in Texas (Fitzpatrick and Balke 1995). They found that, for all practical purposes, there was no difference in the way drivers used highways marked with TWLTLs and highways marked with flush medians.

Four sites were selected for this study. Three of them were located on US-69 west of Lufkin, Texas and the fourth one was located on US-59/Loop 224 on the outskirts of Nacogdoches, Texas. No mention was made about the widths of the median.

The number of drivers found using the flush median as a storage area and as acceleration lane was approximately equal to the number of drivers observed using TWLTLs for those maneuvers. Authors recommended the following.

- In order to promote uniform application of traffic control devices, flush medians should be used only in situations where the driveway location and spacing permits a left-turn bay at every driveway location. This would provide an area for drivers to decelerate and store vehicles when making a left turn from the highway.
- If median openings at every driveway are not possible, then a TWLTL should be used. Using TWLTLs in these situations would promote the uniform application of pavement markings in situations where left turns are permitted to adjacent properties.

However, if there is an operational or safety reason to prohibit left turns from the median, then some form of physical barrier (such as a raised or a depressed median island, or a median barrier) should be used to physically prohibit drivers from using the median area. Flush medians should not be used to control access to adjacent properties unless strict enforcement can also be provided.

Harwood's Recommendations on Median Design

An effort was made (Harwood et al. 1995) to recommend median width parameters and design criteria for intersections on rural and suburban divided highways with partial or no control of access. The following criteria were used to define suburban divided highways in this research.

- Divided highway traffic volume of more than 7,000 veh/day
- Speed of 56 to 80 km/hr (35 to 50 mph)
- Spacing of at least 0.40 km (0.25 mi) between signalized intersections
- Direct highway access from abutting properties
- No curb parking present
- Location in or near populated area

In this study, divided highways outside of populated areas with volumes lower than 7,000 veh/day or speeds higher than 80 km/h (50 mph) were generally defined as rural. Some 88-km/h (55-mph) sites located on developed arterials were classified as suburban areas. Divided highways with speeds below

56 km/hr (34.8 mph) with spacing between signals of less than 0.40 km (0.25 mi) or having curb parking were defined as urban and were excluded from this research.

This study produced the following findings.

1. At rural, unsignalized intersections, the frequency of undesirable driving behavior (e.g., side-by-side queuing, angle stopping, and encroaching on the through lanes of the major road) decreased as the median width increases.
2. At suburban, unsignalized intersections, the frequency of undesirable driving behavior increased as the median width increases.
3. The frequency of undesirable driving behavior increased as median opening length increases at rural intersections and decreases as median opening length increases at suburban intersections.
4. Most undesirable driving behavior at divided highway intersections arose from the competition for limited space on the median roadway between drivers traveling through the median in the same direction.
5. Vehicle delay at signalized intersections on divided highways increased as the median width increases. Thus, increasing the median width at signalized intersection reduces the level-of-service.

The following recommendations were developed based on the above conclusions by the authors (Harwood et al. 1995).

1. At rural unsignalized intersections on divided highways, medians should generally be as wide as practical and certainly should be wide enough to accommodate turning and crossing maneuvers by a selected design vehicle, as well as any needed left-turn treatments.
2. At suburban unsignalized intersections, medians generally should not be wider than necessary to provide whatever left-turn treatment is selected.
3. At signalized intersections, medians generally should not be wider than necessary to provide whatever left-turn treatment is selected. Signalized intersections on divided highways with medians wider than 31 m (100 ft) may require separate signal installations on both the roadways of the divided highway.
4. Wider medians at suburban unsignalized intersections are associated with higher accident frequency and increased delays.
5. At rural, unsignalized intersections with median width of more than 31 m (100 ft), a double yellow centerline should be used to separate the two directions of travel on the crossing roadway within the median.

6. At unsignalized intersections with median widths of approximately 18 m (60 ft) or less, dashed pavement marking that extends the left edge line of the divided highway across the intersection can be helpful to drivers in defining the boundaries of the median roadway. Markings of this type should help to minimize encroachment on the through lanes of the divided highway by vehicles stopped on the median roadway.

REVIEW OF SAFETY LITERATURE

Safety research literature spanning a period of over three decades was evaluated.

Relationship Between Median Openings and Crash Rate

A study in North Carolina (Cribbins et al. 1967) considered 92 definite sites which were as nearly homogeneous as possible, selected from the 624.3 km (388 miles) of divided, non-access controlled highways. This study on the relation between median openings on divided highways and crash rates and level-of-service indicated that the average daily traffic volume and roadside access, combined with the frequency and type of median openings, accounted for most of the variation in crash rates.

A significant finding was that changes in crash rates due to changes in the addition of median opening and type of median openings can be determined and evaluated. Other findings also indicated that rear-end collisions account for 33 percent of all accidents on four-lane non-access controlled highways. Numbers of rear-end collisions were less when a storage lane for the left turning vehicles was provided.

Kentucky Median Research

Research done in Kentucky (Garner and Deen 1973) to compare the accident histories of different median types used data acquired from the Kentucky State Police. The sections studied were along I-64, I-65, I-75, Kentucky Turnpike, Western Kentucky Turnpike, Mountain Parkway, and Bluegrass Parkway. Median types and median widths varied; some had full access control.

The findings showed a great decline in accident rate with increasing median width. A breaking point or "leveling off" seemed to occur at median widths between 9.1 and 12.19 m (30 and 40 ft). As the median width increased, there was a statistically significant decrease in the percentage of total median-involved accident vehicles that crossed the median.

The beneficial effects of wide medians can be completely negated by steep slopes. The adverse effects of steep 1V:4H and 1V:3H (formerly 4:1 and 3:1) cross slopes of 36-ft, deeply depressed medians were clearly indicated. The deeply depressed median resulted in a disproportionate number of vehicle overturnings. Raised medians seemed to have a higher number of cross-median accidents. (Both raised median types had a sod curb a few feet from the edge of the pavement.) Many drivers were found to hit this curb and overreact.

Raised medians also do not provide storage area for snow removal. Moisture from a damp raised median can bleed onto the roadways for days. In cold weather, this allows hazardous ice spots to form. The authors recommend that the medians should be a minimum of 9.1-12.19 m (30-40 ft) wide for high-speed facilities. For medians with width less than 18.29 m (60 ft), the slope should be 1V:6H or flatter, even though this will require some special drainage considerations.

Nemeth's TWLTL Study

Nemeth (1976) reached the following conclusions about TWLTL safety.

- When replacing two and four lane sections which have no median, the TWLTL has almost without exception noticeably reduced the incidence of left-turn related accidents, and perhaps more importantly, lessened the severity of accidents.
- Throughout the literature, TWLTL justification is based on such factors as "high incidence of rear-end, sideswipe and other left-turn related accidents", the existence of "heavy strip commercial development", the demand for "high access to abutting properties and heavy through traffic movement" and other generalized conditions.
- Literature states that the appropriate operating speeds of TWLTLs range from 40 to 80 km/h (25 to 50 mph). Concern has been expressed that in environments with speeds exceeding these, the TWLTL would have increased accident potential, and at speeds lower than these impatient drivers may use the median lane to pass slower vehicles. Neither concern has been sufficiently supported by data to rule out the applicability of TWLTLs for a wider range of speeds.
- Throughout the literature, before-and-after accident evaluations demonstrate the accident reduction potential of the TWLTL. Even at the least successful Painesville site, a field study revealed a 22% reduction in braking conflicts. These results combined to produce an overwhelming picture of the TWLTL as an innovative traffic control measure which provides a substantial improvement in safety, despite deficiencies in application, utilization, and evaluation which have detracted from its performance.

Effects of Installation of TWLTL Medians on Urban Four-Lane Undivided Roadways

McCoy and Ballard (1986) analyzed crash data to arrive at the following conclusions regarding the safety effects of the installation of TWLTL medians on urban four-lane undivided roadways.

- TWLTL medians were associated with lower accident rates.
- The reduction in accidents that resulted from the installation of a TWLTL were dependent on the ADT and the driveway density involved.

- TWLTL medians were associated with increased accident severity.
- TWLTL medians were associated with a significant reduction in percentage of rear-end accidents. Sideswipe, left-turn, and head-on accident percentages on TWLTL medians were not significantly different from those on four-lane undivided sections. The percentage of "other" accidents was significantly higher with TWLTL median.

Bahar's Study on Single Vehicle Accidents

Bahar (1987) showed that single vehicle overturning accidents were mainly caused by lack of driving experience, lack of concentration, or both, usually accompanied by high speed. The roadside and median surfaces were not always safely traversable by vehicles and objects were situated too close to the roadway, giving drivers less chance of controlling or stopping their errant vehicles.

Accident Comparison Between Raised Median and TWLTL

Squires and Parsons (1989) compared crashes on 50 TWLTL sections and 32 raised median sections. The parameters used for selection were:

- ADT at least 9,500 vpd,
- located on a state route,
- constant four-or six-through lane cross-section, and
- free access to the road at grade (uncontrolled access).

Comparisons were made for local and midblock crashes, four and six-lane sections, crashes per million vehicle miles (MVM), and crashes per mile per year, as well as injury, fatal, and all crashes occurring. The total crashes per MVM was considered to give the best indication of the relative safety of a median type. The comparison of crashes occurring on six-lane sections showed, with a low statistical error, raised medians to be safer than TWLTLs. The crash comparison for four-lane sections also showed raised medians to be safer, but with a higher statistical error.

For four-lane sections, raised medians were always safer than TWLTLs. However, the difference in rates was found to decrease with increasing number of signals per mile. For six-lane sections, raised medians were again found to be safer, except under certain conditions. TWLTLs were safer when all the following conditions were met: high number of driveways per mile (at least 75), low number of signals per mile (2 or fewer), and low number of approaches (unsignalized intersections) per mile (a maximum of 5 or 6, depending on signals per mile).

Crash Rate as a Function of Median Width

Analyses done in Utah and Illinois (Knuiman et al. 1993) on the association of median width and highway accident rate, were restricted to:

- two-way, four-lane, rural and urban Interstate, freeway, and major highway road sections of length exceeding 0.11 km (0.07 mi),
- posted speed limits of at least 56.3 km/hr (35 mi/hr), and
- no median, or an unprotected median no wider than 33.5 m (110 ft).

The findings generally indicated that the crash rates decreased with increasing median widths. On the other hand, there was very little decrease for the first 9.1 m (30 ft) of median width. The data also indicated that the safety benefits of the medians increased until widths of 18.3 m to 24.4 m (60 to 80 ft) were reached. While it is difficult to determine the exact width where safety effect is lost, the data suggest that decreasing an existing median to less than 6.1 to 9.1 m (20 to 30 ft) of width to enhance the capacity may decrease the level of safety.

Comparison of Safety Effects Between TWLTL and Raised Median

A case study (Bretherton 1994) was done in Gwinnett County, Georgia to compare the safety effects of a raised median and a TWLTL. The ADTs ranged from 39,000 to 50,000 vehicles per day (vpd).

The crash data showed that retrofitting a TWLTL with a 0.254 m (10-in) concrete raised median was beneficial. However, the benefits were not as great as with the 0.91 m (3-ft) high temporary New Jersey raised median.

The report had the following conclusions and recommendations.

- Retrofitting the raised median barrier, in places where a TWLTL was present, reduced accidents.
- Should additional TWLTL retrofitting projects be considered, the analysis recommended retrofitting with a raised median.
- Consideration should be given to alternative raised median designs to minimize object-struck accidents, while minimizing the opportunity to illegally cross the median.
- The land use type, traffic volume, and median design are significant variables in the optimum raised median design. Consideration should be given to emergency vehicles crossing needs, while still eliminating motorists' opportunity to illegally cross the raised median.

Benefits of TWLTL

A research project (Heikal and Nemeth 1994) done to measure the potential benefits from TWLTLs suggested an approach to determine the degree of congestion along arterials with midblock turning movements. The research produced a procedure to determine the potential benefits from the introduction of an arterial section (a roadway strip where the center flush median is marked as a TWLTL) with a midblock turning problem.

The procedure utilized the average number of stops per vehicle in the inside lane. Three zones were recommended to represent the flow conditions without a TWLTL and potential benefits from the introduction of TWLTLs (the choice of zone limits was based on professional judgment).

1. Fewer than 0.3 stops per vehicle in the inside lane – potential benefits are marginal or negligible.
2. Between 0.3 and 1.0 stops per vehicle – potential benefits are significant and TWLTLs should be considered depending on cost of adding a new lane.
3. More than 1.0 stops per vehicle – benefits are significant and the TWLTL addition should be considered. If not feasible, prohibition of midblock left turns needs to be investigated.

Based on these zones, a nomograph was generated using an ARTSIM (arterial simulation) model. This nomograph can be used as a guideline to determine if a TWLTL is applicable. The real value of the model was as a tool by which individual cases could be studied, using real driveway locations and representative turning volumes.

Negative Binomial Analysis of Safety Effects

Hadi et al. (1995), in estimating safety effects of cross-section design for various highway types using negative binomial regression, showed a significant relationship between median types and crash experience. This study quantified the effects of cross-section design elements on total, injury, and fatality crash rates for various types of rural and urban highways using data from Florida at different traffic levels. The study was conducted by stratifying the roadway samples by location, access type, and number of lanes into nine categories. These categories and ADT range used in analyzing each category were as follows.

- Rural freeways (5,000-60,000 vpd)
- Four-lane rural divided roads (1,145-40,000 vpd)
- Two-way, two-lane rural roads (200-10,000 vpd)
- Four-lane urban freeways (4,260-136,800 vpd)
- Six-lane urban freeways (20,000-200,000 vpd)
- Two-way, two-lane urban collectors (904-38,640 vpd)
- Four-lane urban divided roads (10,000-50,000 vpd)
- Six-lane urban divided roads (10,000-100,000 vpd)
- Four-lane urban undivided roads (5,000-40,000 vpd)

It was found that the safety of the median type decreased in the following order: flush-unpaved median (grass), raised curb, crossover resistance or barrier median, and TWLTL. However, the differences in median width between median types should be noted. Depending on the highway type investigated, increasing lane width, median width, inside shoulder width, and/or outside shoulder width were effective in reducing crashes.

Safety Relationship Associated with Cross-Sectional Roadway Elements

Zegeer and Council (1995) considered the effects of median design on safety relationship associated with cross-sectional roadway elements. The work included only multilane Interstate and parkway roads in rural areas.

They found no differences in the number of injury accidents, rollover accident occurrence, or in overall accident severity between raised and depressed median designs. However, a significantly lower number of single-vehicle median-involved crashes were found on sections with depressed medians as compared to raised medians. The authors concluded that mildly depressed median provided more opportunity for encroaching vehicles to return safely to roadway.

Harwood's Findings on Roadway Medians

Research on median intersection design (Harwood et al. 1995) found that wider medians at suburban, unsignalized intersections were associated with higher accident frequencies. This study resulted in the following findings on safety.

1. At rural, unsignalized intersections, the frequency of accidents decreased as the median width increased.
2. At suburban, unsignalized intersections, the frequency of accidents increased as the median width increased.
3. At suburban, signalized intersections, the frequency of accidents increased as the median width increased.

Safety Analysis of TWLTLs and Raised Medians

As a part of larger research effort (Margiota and Chatterjee 1995) to develop guidelines for the design of arterial roads in areas undergoing suburbanization, a safety analysis of median design was undertaken using Tennessee data. This research investigated the relationship of raised medians and TWLTLs with accidents.

Accident data were compiled from the Tennessee Roadway Information Management System (TRIMS) on selected highway segments located throughout the state. All segments had four through lanes. Accident data was from 1984 to 1988. At least three years of data were available for all segments. The ADT for the segments were within the range of 10,000 – 40,000 vehicles per day (VPD).

The variability of accident-rates for the high-volume roads (greater than 32,500 VPD) led the researchers to focus on highways with ADTs less than or equal to 32,500 VPD. For this volume range, the study concluded that raised medians were generally safer than TWLTLs, based on the analysis of covariance and separate regression models that were fit to the data.

Authors found that TWLTLs were safer at places with high driveway densities and low to medium traffic volumes. Regression analysis revealed that driveway density is an important contributor to accidents for roadways with medians but not for TWLTLs. A possible explanation for this occurrence is the increased number of U–turns on median sections for drivers who would be making left turns into and out of driveways on TWLTL sections.

SUMMARY OF LITERATURE REVIEW

From the literature review, the following conclusions were made about median types, traffic operations, and safety.

- The TWLTL has noticeably improved traffic flow on all the study sites that initially had no median and two to four through lanes.
- The value of a TWLTL in reducing congestion decreases on the roadways that are operating at or near maximum capacity. This is due to the unavailability of gaps in the approaching traffic of sufficient size to allow left turn movement.
- Installing TWLTL medians on urban four-lane undivided roadways reduced stops and delay over a wide range of traffic volumes, left-turn percentages, and driveway densities. The magnitude of these reductions was an exponential function of traffic volume, left-turn volume, and driveway density.
- The TWLTL design alternative is appropriate for suburban highways with commercial development, driveway densities greater than 45 driveways per mile, low-to-moderate volumes of through traffic, high left-turn volumes, and/or high rates of rear-end and angle accidents associated with left turn maneuvers.
- For four-lane sections having higher ADTs (around 40,000 vpd), raised medians were always safer than TWLTLs. The TWLTL design alternative is safer at places with high driveway densities and low to medium traffic volumes (less than 32,500 vpd).
- The four-lane divided design alternative is suited for use on major arterials with high volumes of through traffic and less than 45 driveways per mile.
- The safety of the median type decreases in the following order: flush-unpaved median (grass), raised curb, crossover resistance or barrier median, and TWLTL.
- For non-traversable medians, depressed medians seem preferable to raised medians.

- Incorporating some type of median that reduces a left turning vehicle's exposure to rear end collision seems to produce benefits in a wide range of situations.
- Increasing lane width, inside shoulder width, and/or outside shoulder width will result in reduced crash rates.
- The accident relationships are unclear for median widths of less than 6.1 m (20 ft), and the decline in crash rate was very little for the first 9.1 m (30 ft) of median width, suggesting that when constructing new highways, medians need to be at least 9.1 m (30 ft) wide to have a positive safety effect. The safety benefits of the medians increase until widths of 18.3 m to 24.4 m (60 to 80 ft) are reached. It is difficult to determine the exact width where the safety effect is lost. Decreasing the existing median width to enhance the capacity may decrease the level of safety.

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CHAPTER 3

RESEARCH METHODOLOGY

A number of different types of data were identified as needed for this research. These include roadway descriptive data, crash data, volume data, construction time-period data, and street and driveway intersection data.

DEFINING USABLE ROADWAY SEGMENTS

An initial and involved step of the research process was to identify those roadway segments that could be used for this analysis. For a segment to be deemed "usable", it had to meet a number of criteria.

Since the research effort was confined to "rural and suburban" multilane roadways, criteria to distinguish between "rural or suburban" and "urban" roadway sections had to be established. When considering a given roadway segment, the following criteria were employed to define when a roadway was no longer "rural or suburban" and therefore exclude it from further consideration.

- The speed limit was less than 64 km/h (40 mph).
- When approaching an urban area, segment terminated when the first traffic signal or stop sign was encountered. When departing an urban area, segment began upon passing the last traffic signal or stop sign. Some exceptions were made to this rule, based on judgment, in areas where it was felt that a suburban roadway environment did exist in the area between an outlying traffic signal and an urban area.

The segments that were judged to be rural or suburban were then evaluated to further identify homogeneous segments. The following roadway attributes defined the limits of homogenous roadway segments.

- Length of the section must be at least 0.8 kilometer (0.5 mile).
- Median type must remain the same throughout the section.
- Presence or absence of shoulders must be the same throughout the section (i.e., if a shoulder terminated, then that segment terminated at the same location).
- Presence or absence of curbs must be the same throughout the section.
- Presence of a school speed limit did not affect homogeneity of the section.

IDENTIFICATION OF RURAL AND SUBURBAN MULTILANE ROADWAYS

A number of involved steps were required to produce a list of rural and suburban multilane roadways.

Initial List of Multilane Roads

A list of state highways with four or more lanes (excluding ones with full access control) as of January 1, 1999 was obtained from the Arkansas State Highway and Transportation Department (AHTD) headquarters. This list contains information sorted by the county number, then by route, then by section, and then by the beginning log mile of the segment. It also contains the length of the multilane segment, and number of lanes present in the subject segment.

Verification of the Data Received

The route and section locations identified by AHTD were then marked on maps for each of the ten districts. These maps were sent to each AHTD district headquarters for verification. The responses from the district headquarters contained a few corrections, which were incorporated into the list.

Preliminary List

Based on information furnished by AHTD, a preliminary list was prepared in spreadsheet format. This list contained the location of multilane roads throughout Arkansas sorted by route, then by section, and then by the estimated end-mile points. Each section was entered on its own row. The list also had columns with county number, county names, and the district numbers. This list, which was sequentially updated with the subsequent data collection, served as the master list for this research.

Preliminary Maps

The county maps of all the counties were downloaded from the AHTD website. Using photo-editing software, the routes and sections that might have usable segments were enlarged and printed for future reference.

AHTD Video Database

The AHTD Planning and Research Division makes and files videotapes showing the roadway of all the routes and sections in the state. The previously-mentioned preliminary list was sent to the AHTD to obtain the tape number and the beginning frame number of each route and section on this preliminary list. These numbers were added to the list.

Frequent trips were made to AHTD headquarters in Little Rock to view the videos of the routes and sections. A video log form was prepared to help record pertinent roadway features while watching the videotapes at AHTD headquarters.

The log kilometer of roadway details such as median type, presence or absence of curb or shoulders, and any changes of these were recorded. Other features recorded as each tape was viewed included school zone details with their beginning and ending speed limits, median opening locations in case of divided highways, intersections, traffic signals, railroad crossings, the presence of turn lanes, speed limits, stop signs, yield signs, beginning and end points of bridges, interchange ramp intersections, and signs at county lines. Also, the date the video was made, direction of travel, tape number, frame number where the multilane section begins, county number, county name, district number, route and section numbers, and the date when the video was viewed were recorded on the video viewing form. The log kilometer was converted to log mile. This information later served as a guide while videotaping the usable segments.

IDENTIFICATION OF STUDY LOCATIONS

The previously assembled data was examined closely to refine the listing of potentially usable study segments.

Finding Usable Segments

Using the previously stated guidelines, the preliminary list was searched for usable segments. Some roadway sections had more than one usable segment, some had just one, and some had no usable segments. The end points of the usable segments were entered on video log forms.

Master List Formed

After expanding and updating the preliminary list with the details obtained from the video log forms, a master list was created having a separate row for every usable segment. More columns were added to incorporate the segment details such as the presence or absence of curb (presence denoted by 1 and absence denoted by 0), median type, beginning and ending mile points, length of the segment, the average daily traffic of the segment, and the name of the nearby town.

PRESENTATION OF INTERIM FINDINGS

The highway segments available for study along with their crash histories were presented to the AHTD research project subcommittee for their approval to continue the research. The subcommittee determined that the available data were sufficient to continue with the study.

ADDITIONAL ADJUSTMENTS

The Master List was again revised and updated to reflect other factors. These included changes in the log mile system, construction on usable segments, and traffic volumes.

Log Mile Changes

The AHTD Planning and Research Division furnished information about roadway segments that had undergone changes in log mile numbers. All the segments that had change in mile points were also noted with the year the change was made.

Reference to State Highway Maps

The Arkansas state highway maps published from 1994 through 2000 were examined to see when the two-lane segments were changed to four-lane segments. All the changes found were incorporated in the master list.

Segments with Construction During Study Period

The Construction Division furnished a file listing state highway construction projects. From this list, those segments on which construction had occurred between 1995 and the present were noted. This information was important for two reasons.

1. It identified time periods during which certain construction activities occurred on multilane segments. Crashes during these time periods were excluded from the subsequent crash analyses.
2. Some construction projects involved converting a two-lane roadway to a multilane facility. Crashes that occurred before the conversion were excluded from the crash analysis.

The following examples illustrate the use of construction activity dates. If the most recent major construction changes, such as roadway widening on a segment, were completed in November 1998, the analysis of this segment was restricted to the crash data after November 1998.

If the widening was in the year 2000 or later, then the segment was excluded from the analysis. The segments were excluded because the traveled way dimensions that are measured now may not match the conditions prior to the construction changes, and hence the conditions under which the crashes had occurred prior to the construction changes would have been different. This occurred on US 65, section 9 between old log mile points 1.29 and 4.53 in Jefferson County. This segment had a raised median prior to 2001, and was changed to TWLTL. Since the cross-section dimensions that existed on this segment can no longer be measured, the crashes on this segment prior to 2001 cannot be analyzed as a function of lane and shoulder widths.

Volume Data

The volume data for all the usable segments for the years 1997 through 1999 were obtained from the AHTD.

CRASH DATA

Crash analyses were based on data for the three-year period between 1997 and 1999, obtained from AHTD. The database contained a summary listing of every crash occurring on every highway in Arkansas.

Extraction of Crash Data

To obtain the crashes for any given roadway segment, the database was queried by entering the county name and the route number as the query criterion. The results obtained were sorted by section and then by log mile.

A spreadsheet template was prepared with the required column headings. The required data were copied from each year's database and pasted into this crash template. A separate "crash" file for each segment was created.

Errors in the Data

In the early stages of examining the extracted crash data, many of what appeared to be erroneous entries were found. An effort was made to identify and either remove these erroneous entries or move them to a seemingly proper location. Although no effort was made to quantify this, it seemed that sometimes errors were not randomly distributed, but rather sometimes appeared in clusters at certain locations. Situations in which one road intersected another at two separate locations seemed problematic.

For example, a crash that was entered as having occurred at mile point 7.86 was entered with other location details that appeared to conflict with being at this location. Sometimes a crash that occurred in the previous section had been logged with the correct log mile, but in an adjacent section.

A specific example was Route 49, Section 8, in Brinkley (between US 70 and I-40), between log mile points 7.12 and 8.54. The search in the AHTD database found 34 crashes listed in 1998. But in addition to crashes logged as having occurred in Brinkley, the query for this route, section, and log mile produced crashes with the "city" listed as Blytheville, Clarendon, Holly Grove, Marvell, St. Charles, and a few others. Of these 34, 14 were logged as having occurred in a city. An estimated 10 crashes actually occurred in this segment. But in the 1999 database, no crashes were found in this segment. A change in one year from 10 crashes to no crashes seemed extreme. This segment was excluded from further analysis.

Crash Data Correction

To minimize the number of errors in the crash data set, the following processes were followed. Crash data for all three years were combined into a single file.

1. The subject location was found both on the Annual Average Daily Traffic Estimate (AADT) log mile books and the AHTD state maps. This helped to identify nearby cities and other features, to assess the validity of individual crash data entries in Step 7.
2. A check was made to see if there had been any construction work during that time interval.

3. The AHTD crash database was then queried by the route number and the county in which a particular roadway segment was located. The result was then sorted according to section and log mile.
4. The search results were copied into a spreadsheet for subsequent work.
5. The data copied into the spreadsheet were then sorted by route number and log mile. Mile point limits of the usable segment were extended by 0.8 km (0.5 miles) at each end, in order to help detect any crashes that might actually be located within the roadway segment but had incorrect log miles assigned to them.
6. Data within these mile points were copied and pasted into the crash template file.
7. The data was visually inspected to find any apparent typographical errors. A crash at log mile 3.4 could have been entered as 3.40 or 034.
8. Maps from the AHTD website were downloaded, and location details such as street intersection were checked to verify they were actually within the log mile limits of the segment. Sometimes, maps from commercial services such as Expedia or Yahoo were also used to verify the accuracy of the entries.
9. The AHTD database was queried by route number and section number to see if any crashes had been overlooked. This list was compared with the previous list. The likelihood of finding an incorrect county listing was less than that of finding an incorrect section listing, but sometimes a crash entry with an incorrect county was found by this route-and-section query.
10. The list of crashes within a given roadway segment was visually reviewed, to identify and eliminate seemingly incorrect entries. For example, a segment on Route 1, Section 11, in Forrest City (St. Francis County) between mile points 4.24 and 5.39 had two entries that were seemingly incorrect. A 1997 crash entered at log mile point 5.17 also had a notation that it happened 1.77 km (1.1 miles) south of Forrest City. From the other available sources, it was confirmed that 1.77 km (1.1 miles) south of Forrest City should have a log mile somewhere in the vicinity of 4.0. Another such crash on SH 1 had been coded as happening at the intersection with St. Francis Street, Forrest City, but the St. Francis Street intersection is in Section 12. So neither crash was included with the other crashes for this segment.

FIELD DATA COLLECTION

Equipment used during field data collection included 8mm camcorders, a measuring wheel, a tape measure, and two-way radios. Figure 3.1 shows field data collection in process.

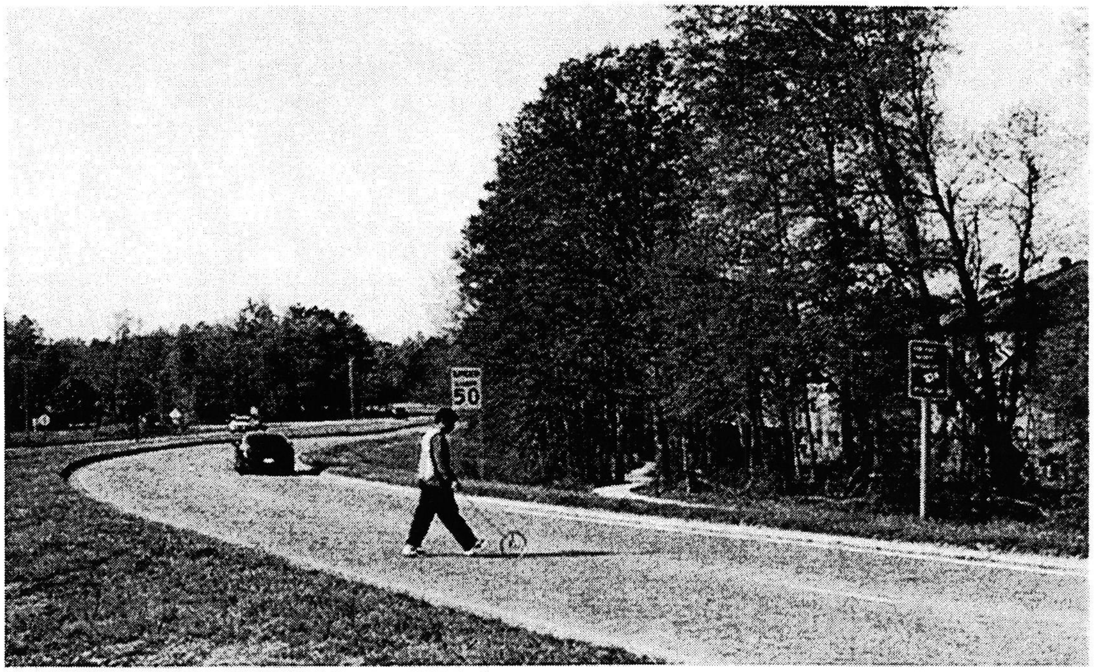

Figure 3.1 Field Data Collection

Videotaping

Trips were made to all of the usable segments identified to record the roadway features and intersection details. A team of two, one person to drive the vehicle and the other person to operate the video camera, was sent to the usable segments. The camera was normally aimed toward the roadside, with the right side of the road ahead visible in the left edge of the view. Separate runs were made for each side of the roadway. The following guidelines were followed for the videotaping.

After reaching the usable segment, the conditions on the field were verified with the data on the video log form. If there were any bridges present on or near the segment, the mile point on the mile marker of the bridge was matched with the mile point on the video log form or the AADT book.

Before the videotaping began, the route and section numbers, the beginning and ending log mile point of the segment, the length of the segment, the county in which the segment was located, the nearest city, the direction of travel, the median type, and the presence or absence of curb or shoulders were noted.

- Just before videotaping began, the car trip odometer was reset to zero. While driving, every tenth of the mile was called out.
- The land use type served by the driveways and the names of the intersecting streets and highways were called out.

- The mile markers present on bridges and along the highways were called out.
- Median openings were called out when encountered on a raised or depressed median segment.
- Ramp junctions were called out if encountered.
- Occasionally, the camera view was panned to the center of the roadway when there were no intersecting driveways or streets.

Field Measurements

A field data cross-section form was prepared to enter the details recorded on the field. The widths of the through lanes, shoulders, turn lanes (if present), and the median were measured at intervals. Two-way radios were used by the two member team to communicate while making the measurement, where one person walked across the roadway, made measurements, and communicated them to the other person who recorded the measurements on the field data cross-section form.

OFFICE DATA REDUCTION

Videos made in the field were viewed in the office to count the number and types of driveways and intersecting roadways on every segment. A traffic counting board was used for this purpose.

A driveway data cross-section form was prepared to assimilate data from the various sources. Field data include the intersection details and traveled way details. The driveway intersections were categorized as serving one of the following land uses.

- commercial and government
- industrial, warehouse, factory
- schools
- churches and funeral homes
- apartment and mobile home parks
- single family residential
- recreational areas or parks
- open area, fields, or forests

The following roadway access features were recorded.

- median openings
- ramp junctions
- side street or roads

The traveled way details include the following.

- shoulder width
- through lane width

- turn lane width
- median width

Crash data include crash severity, relation to junction, and type of collision. Crash severity details include the following.

- fatality or incapacitating injury
- non-incapacitating injury or possible injury
- property damage only

The relation-to-junction details include the following.

- intersection or intersection related and
- driveway or alley related

The type-of-collision categories include the following.

- single vehicle crash
- head on collision
- rear end collision
- right angle collision
- side swipe collision along the same direction
- side swipe collision along the opposite direction
- backing collision
- other types
- unknown

The volume data reflected the average daily traffic for the years from 1997 through 1999.

This process produced a reduced listing of roadway segments that were both rural/suburban and homogeneous, on which to perform subsequent data analysis.

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CHAPTER 4

DATA ANALYSIS AND RESULTS

Data for each segment were reviewed to identify any needed changes. An initial analysis was made of the data that had been combined into the single form. More rigorous statistical analyses were then performed.

ADJUSTMENTS TO DATA

A review of the data indicated two types of adjustments that were needed to achieve more homogeneous roadway segments: eliminating segments with cross-section variability (segments that were too unsymmetrical), and subdividing a segment with variation in the access point density along the highway.

All the segments identified as having too much variability in the cross-section dimensions were omitted from analysis. An example of such elimination would be Route 1, Section 10 located south of Haynes between mile points 6.27 and 7.87. The width of the outer shoulder on the northbound direction is 2.74 m (9 ft) while the width on the southbound direction is 1.22 m (4 ft). Considering this big difference, the segment was omitted from the analysis.

The segment on Route 63, Section 9 at Poinsett County was split into three separate segments, even though the roadway cross-section features were homogenous. This was done to account for the perceivably high variation in the access point density along the highway. Driveway density was less from mile points 0.00 to 4.10 and from 4.80 to 10.14. Density was high near the City of Tyronza, between mile points 4.10 to 4.80.

INITIAL SUMMARY DATA ANALYSIS

The list contained 112 usable roadway segments. Segment lengths ranged from 0.82 km (0.51 mi) to 20.18 km (12.54 miles). For these segments, the average ADT for the 3 years ranged from 1,800 to 25,667.

The number of crashes per segment ranged from 0 to 319 crashes. Crash rates ranged from 0 to 5.03 crashes per million vehicle kilometers (MVKm) of travel or 0 to 8.09 crashes per million vehicle miles (MVM) of travel. Table 4.1 displays the summary data, categorized by median type and presence of either a shoulder or a curb immediately adjacent to the traveled-way edge. The few roadways having a curb on the outside of the shoulder were placed in the "with shoulder" category.

Table 4.1 Initial Summary Data

	Median Type					
	Barrier	Depressed	Raised or Curb	TWLTL	Narrow	None
Total Number	1	22	5	42	17	25
With Shoulder	1	22	3	19	16	13
Avg. Crash Rate (MVKm)	0.29	0.48	0.84	0.87	0.63	0.97
Avg. Crash Rate (MVM)	0.46	0.78	1.35	1.40	1.02	1.56
Vol. Range (1000)	10	5 - 23	9 - 26	4 - 19	4 - 19	2 - 22
With curb -- (i.e., w/o Shoulder)	0	0	2	23	1	12
Avg. Crash Rate (MVKm)	na	na	1.34	1.22	1.34	2.35
Avg. Crash Rate (MVM)	na	na	2.15	1.96	2.15	3.78
Vol. Range (1000)	na	na	9 - 13	6 - 23	7	4 - 15

ADJUSTMENTS MADE FOR STATISTICAL ANALYSES

After consulting with the statistician, the format of the file of the usable segments was modified to facilitate analysis with the statistical software. Whenever a segment with a signalized intersection was encountered, then the part of the roadway within 0.16 km (0.10 mi) of the signalized intersection was excluded from the crash analysis. This adjustment was done in order to eliminate crashes related to signalized intersections from the analysis.

An example of this was Route 7, Section 14 in Russellville (Pope County) between mile points 0.29 and 2.45. A tenth of a mile was subtracted from both the ends of the segment, which has a signalized intersection with State Highway (SH) 247 at mile point 0.29 on the south end of the segment, and a signalized intersection with SH 325 at mile point 2.45 on the north end of the segment. So the crash data for the segment were collected between mile points 0.39 and 2.35.

This subtraction was not performed when calculating density of access points. The driveways were counted from the beginning to the end of the usable segment (e.g., between mile point 0.29 and 2.45).

CRASH RATES AS A FUNCTION OF CERTAIN ROADWAY FEATURES

An initial step in the analysis of data sets was a test for normality, or testing to determine if the data were normally distributed. If the data were normally distributed, then a t-test could be performed to determine if there were differences between two features, such as roadway "with" and "without" medians. If the data set did not follow the normal distribution, then a non-parametric test such as the Wilcoxon Sign-Rank test (also know as the Mann-Whitney U-test) was called for.

Crash Rate for Presence or Absence of Non-traversable Median

All roadways were assigned to one of two groups, either with (barrier, depressed, or raised) or without (none, narrow, or TWLTL) a non-traversable median. Neither set was found to be normally distributed.

Figure 4.1 shows a boxplot (also known as a "box and whiskers" plot) of the crash rate for the two median groups. The boxplot, a graphical means of displaying statistical data, employs these conventions.

- a symbol such as a "+" or a heavy single point denotes the mean value
- the lower box shows the spread of data values from the 25th percentile reading to the median, and the upper box shows the spread of data values from the median to the 75th percentile value
- the boundary between the two boxes is the median value
- the single lines extending from the boxes show the range of values from the 25th percentile value to the minimum value, and from the 75th percentile value to the maximum value

Thus, at a quick glance, a boxplot allows a viewer to see the mean value, the values of the bulk of the data, and the values and limits of the outliers. This plot displays the difference between the means of roadway having a median (mean crash rate = 0.6 crashMVKm or 0.97 crash/MVM) and those without a non-traversable median (mean crash rate = 1.2 crash/MVKm or 1.88 crash/MVM). Using the Wilcoxon Rank Sum test, the means were significantly different from each other at a value less than $\alpha = 0.002$.

Crash Rate for Median Width

The crash rates associated with various median widths were examined for a dataset consisting of all roadways. Figure 4.2 shows that as the median become wider, the crash rate gradually declines.

The analysis found that although the width of a median was not by itself a strong influence on crash rate, the relationship was statistically significant. The equation with all median widths, including "no median" or width equals 0, had an R^2 value of 0.09.

Crash rate in MVKm = 1.28 – 0.055 (median width in meters)

Crash rate in MVM = 2.0604 – 0.0269 (median width in ft)

The slope of the regression line for the median width was significantly different from zero at a value less than $\alpha = 0.01$.

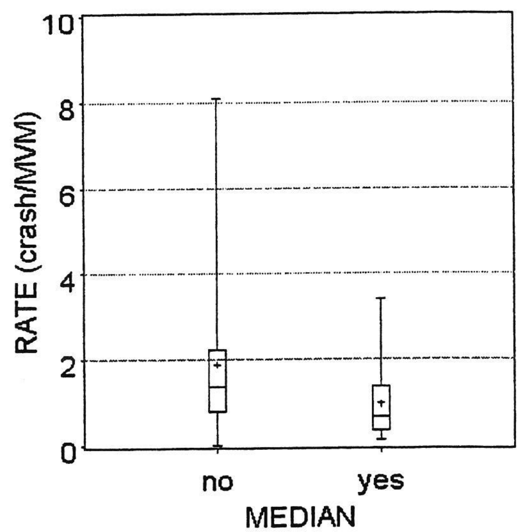

Figure 4.1 Non-traversable Median Presence Crash Rate Boxplot

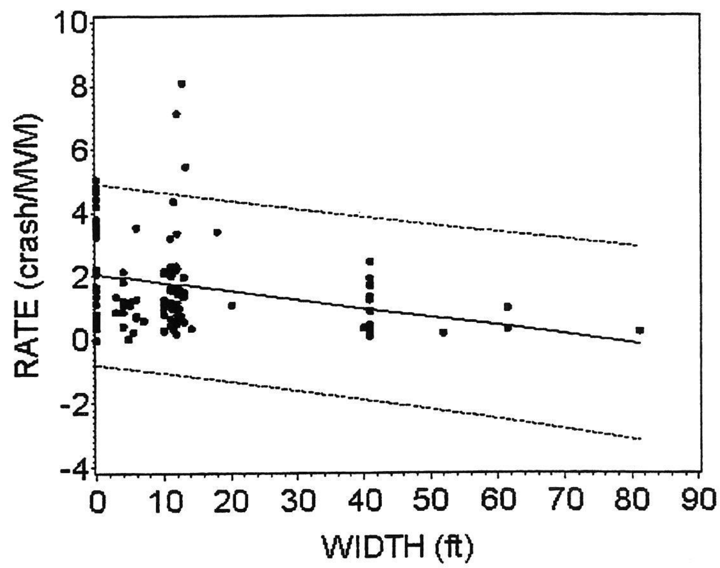

Figure 4.2 Median Width Crash Rate Regression (including width = 0)

Figure 4.3 graphically displays the equation excluding those with "no median", or width equals 0.

Crash rate in MVKm = 1.05 – 0.017 (median width in meters)

Crash rate in MVM = 1.798 – 0.0190 (median width in ft)

The R^2 value was 0.05. The slope of the regression line for the median width was significantly different from zero at a value less than $\alpha = 0.03$.

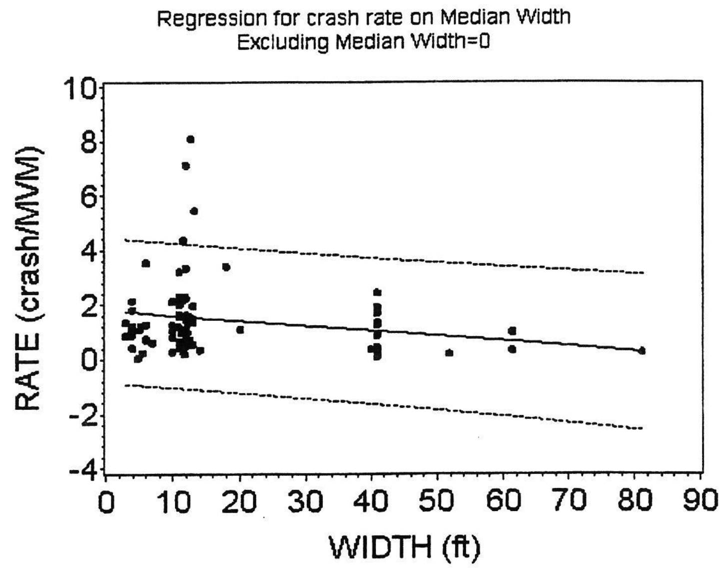

Figure 4.3 Median Width Crash Rate Regression (excluding width = 0)

Crash Rate for Presence or Absence of Inner Shoulder

Figure 4.4 shows a boxplot for crash rate by presence or absence of inner shoulder. The "absence of an inner shoulder" would include roadways with no median, or with a curb adjacent to the inside through lane. This plot displays the difference between the mean crash rates of roadways having an inner shoulder (mean crash rate = 0.52 crashes/MVKm or 0.84 crash/MVM) and those without a shoulder (mean crash rate = 1.20 crashes/MVKm or 1.90 crash/MVM). Using the Wilcoxon Sign-Rank test, the means were significantly different from each other at a value less than $\alpha = 0.001$.

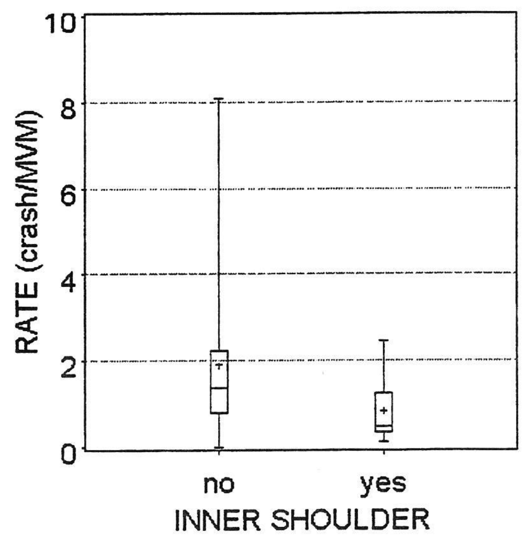

Figure 4.4 Inner Shoulder Presence Crash Rate Boxplots

Crash Rate for Inner Shoulder Width

The crash rates associated with the inner shoulder widths were examined for a dataset consisting of all roadways. Figure 4.5 shows that as the inner shoulder width decreases, the crash rate gradually increases.

The analysis found that although the width of inner shoulder was not by itself a strong influence on crash rate, the relationship was statistically significant. The equation had an R^2 value of 0.0956.

Crash rate in MVKm = 1.18 – 0.46 (inner shoulder width in meters)

Crash rate in MVM = 1.8923 – 0.224 (inner shoulder width in ft)

The slope of the regression line for the inner shoulder width was significantly different from zero at a value less than $\alpha = 0.01$.

Figure 4.6 shows the line whose the equation for crash rate as a function of inner shoulder width (excluding those with no shoulder) was

Crash rate in MVKm = 0.99 – 0.33 (median width in meters), or

Crash rate in MVM = 1.593 – 0.1641 (median width in ft).

The R^2 value was 0.12. The slope of the regression line for the inner shoulder width was significantly different from zero at a value less than $\alpha = 0.08$.

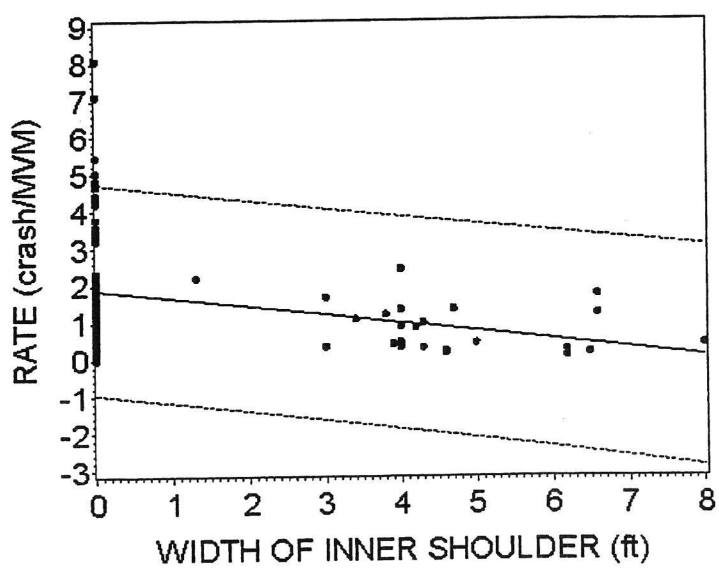

Figure 4.5 Inner Shoulder Width Crash Rate Regression (including width = 0)

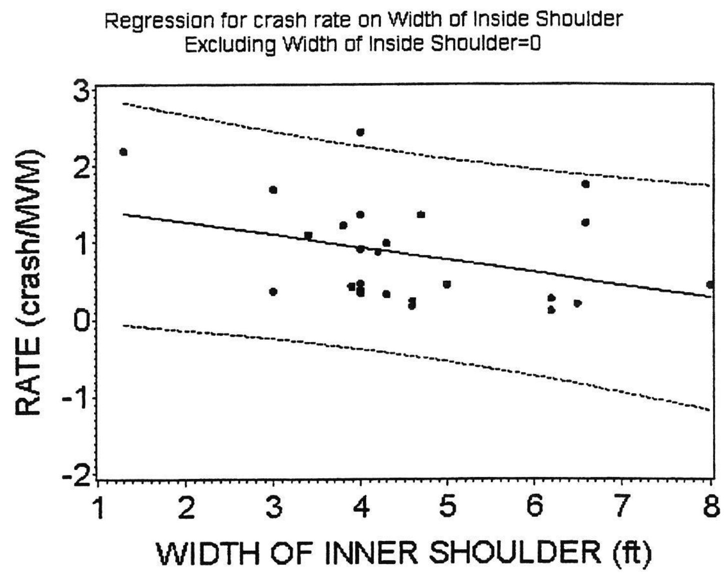

Figure 4.6 Inner Shoulder Width Crash Rate Regression (excluding width = 0)

Crash Rate for Lane Width

Figure 4.7 displays a plot of crash rate as a function of through lane width. The regression equations shows some decrease in crash rate with wider through lanes. The R^2 value was 0.02. The slope of the regression line for the inner shoulder width was significantly different from zero at a value less than $\alpha = 0.15$.

Crash rate in MVKm = 3.37 – 0.664 (lane width in meters)

Crash rate in MVM = 5.42 – 0.326 (lane width in ft)

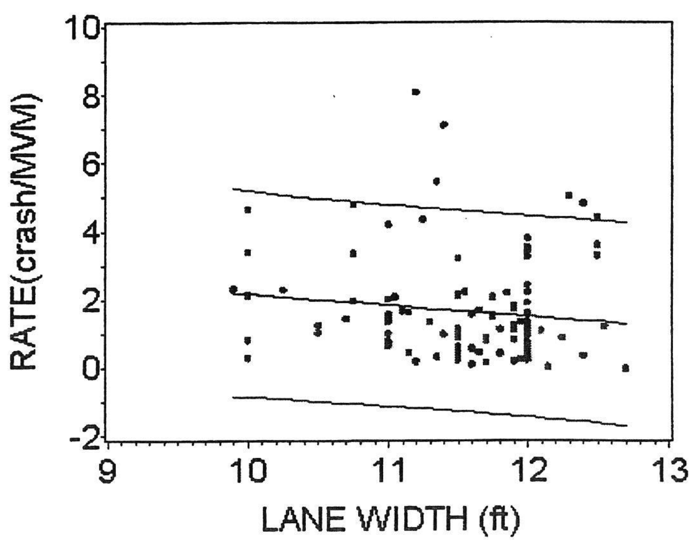

Figure 4.7 Lane Width Crash Rate Regression

Crash Rate for Presence or Absence of Curb on the Outside of The Road

Figure 4.8 shows a boxplot for crash rate by presence or absence of curb to the right of the outer through lane. If a curb were present to the outside of a shoulder, it was considered a "no curb" situation. This plot displays the difference between the mean crash rates of roadways having a curb (mean crash rate = 1.63 crash/MVKm or 2.62 crash/MVM) and those without a curb (mean crash rate = 0.72 crash/MVKm or 1.16 crash/MVM). The means were significantly different from each other at a value less than $\alpha = 0.001$.

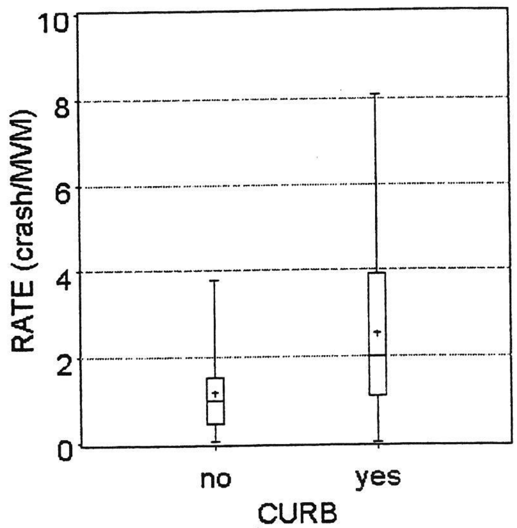

Figure 4.8 Curb Presence Crash Rate Boxplot

Crash Rate for Outer Shoulder Width

The crash rates associated with various outer shoulder widths were examined for a dataset consisting of all roadways. Figure 4.9 shows that as the outer shoulder width decreased, the crash rate gradually increased.

The analysis found that although the width of shoulder was not by itself a strong influence on crash rate, the relationship was statistically significant. The equation (including roadways with outer shoulder width equal to 0) had an R^2 value of 0.2489.

Crash rate in MVKm = 1.61 - 0.35 (outer shoulder width in meters)

Crash rate in MVM = 2.5883 - 0.1696 (outer shoulder width in ft)

The slope of the regression line for the outer shoulder width was significantly different from zero at a value less than $\alpha = 0.01$.

The equation (see Figure 4.10) for outer shoulder width crash rate (excluding roadways with outer shoulder width equal to 0) had an R^2 value of 0.08.

Crash rate in MVKm = 1.29 – 0.23 (outer shoulder width in meters)

Crash rate in MVM = 2.070 – 0.1117 (outer shoulder width in ft)

The slope of the regression line for the outer shoulder width was significantly different from zero at a value less than $\alpha = 0.02$.

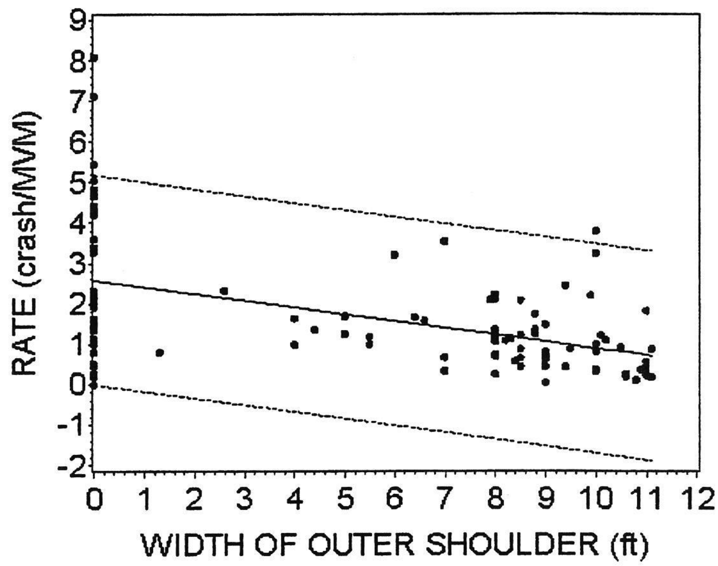

Figure 4.9 Outer Shoulder Width Crash Rate Regression (including width = 0)

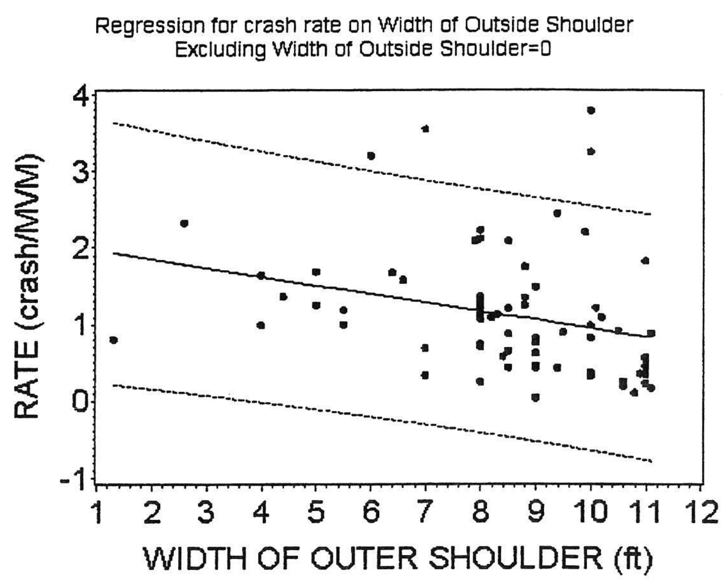

Figure 4.10 Outer Shoulder Width Crash Rate Regression (excluding width = 0)

Crash Rate for Traffic Volume

The crash rates of traffic volumes ranging from 1,800 to 26,000 ADT were examined for a dataset consisting of all roadways. Figure 4.11 shows that as the traffic volume increased, the crash rate gradually increased.

The analysis found that although the traffic volume was not by itself a strong influence on crash rate, the relationship was statistically significant with a α value of 0.01. The equation

Crash rate in MVKm = 0.65 + 0.0000327 (ADT), or

Crash rate in MVM = 1.0412 + 0.0000526 (ADT)

where ADT is the average daily traffic, had an R^2 value of 0.0339.

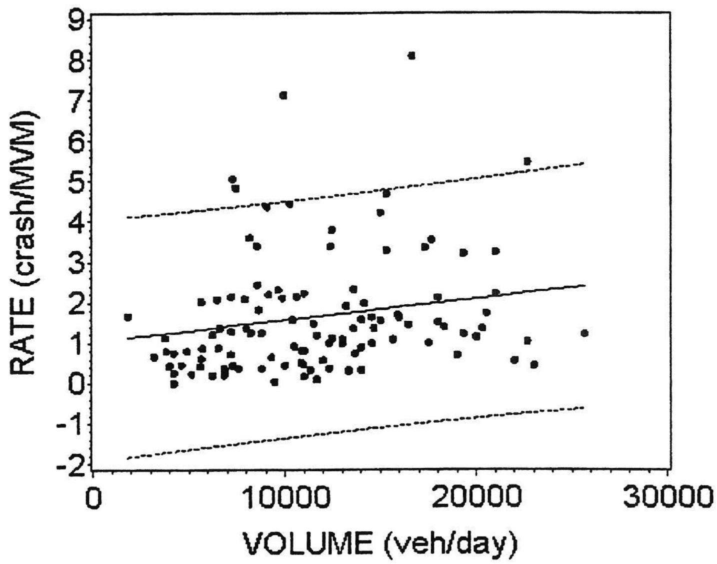

Figure 4.11 Traffic Volume Crash Rate Regression

Crash Rate for Access Point Density

The crash rates associated with access point density were examined for a dataset consisting of all roadways. Figure 4.12 shows that as the access density increases, the crash rate gradually increases.

The analysis found that although the access density was not by itself a strong influence on crash rate, the relationship was statistically significant. The equation

Crash rate in MVKm = 0.55 + 0.024 (access points per kilometer), or

Crash rate in MVM = 0.8899 + 0.0242 (access points per mile)

had an R^2 value of 0.1218. The slope of the regression line for the access point density was significantly different from zero at a value less than $\alpha = 0.01$.

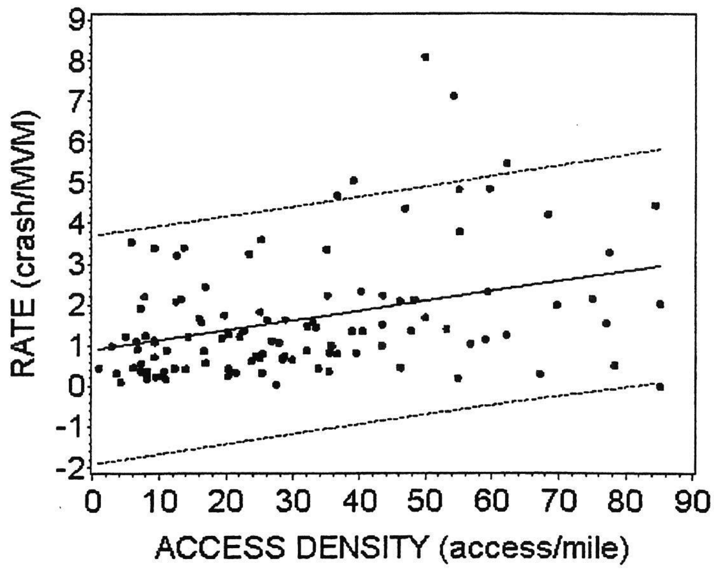

Figure 4.12 Access Density Crash Rate Regression

CRASH RATES ANALYZED WITH POISSON AND NEGATIVE BINOMIAL MODEL

The crash rates were converted and rounded to integers after multiplying the rate by 100. The Poisson model was fit to the converted rates with eight variables (presence or absence of a median, median width, width of the inside shoulder, lane width, presence or absence of a curb, presence or absence of a shoulder, volume or average ADT, and access density) as predictors. The Pearson and deviance statistics indicated that the Poisson model did not adequately describe the data. Therefore, the negative binomial model was fit.

The non-significant terms removed from the negative binomial model were lane width, curb, width of inside shoulder, median presence, and access density. The significant terms retained were presence or absence of outer shoulder, ADT, and width of median. The p-values of non-significant and significant variables are listed in Tables 4.2 and 4.3 respectively. Models from the analysis follow. ADT is the average daily traffic, and WMED is median width.

- with Curb (i.e., without Shoulder)

  WMED in meters, Crash Rate in MVKm $= 0.01\,(e^{4.176 + 0.674 - 0.050\,(WMED) + 0.000\,028\,89\,(ADT)})$

  WMED in feet, Crash Rate in MVM $= 0.01\,(e^{4.653 + 0.673 - 0.0152\,(WMED) + 0.000\,028\,93\,(ADT)})$

- with Shoulder

  WMED in meters, Crash Rate in MVKm $= 0.01\,(e^{4.176 - 0.050\,(WMED) + 0.000\,028\,89\,(ADT)})$

  WMED in feet, Crash Rate in MVM $= 0.01\,(e^{4.653 - 0.0152\,(WMED) + 0.000\,028\,93\,(ADT)})$

Table 4.2 p-values of Non-significant Terms Removed from the Negative Binomial Model

Lane width	0.68
Presence or absence of Curb	0.37
Width of inner shoulder	0.18
Presence or absence of Median	0.22
Access density	0.36

Table 4.3 Significance of Terms Retained in the Negative Binomial Model

Presence or absence of shoulder	<0.0001
Width of median	0.0013
Average daily traffic	0.0421

The negative binomial model indicated that the crash rates were significantly higher on the roadway segments with curbs compared to roadway segments with shoulders. As the width of the median increased, the crash rate decreased significantly. As ADT increased, the crash rate also increased. However, the p-value associated with ADT suggested that the relationship between ADT and crash rate was not as strong as that of the other two variables with crash rate.

CRASH SEVERITY AND COLLISION TYPES

Table 4.4 presents crash severities and type of collision by six combinations of median and shoulder types. Median and shoulder type combinations for which sample sizes were small were not included in this table. For crash severities, fatal and more-serious injury crashes were grouped (injury codes 1 and 2), as were the two minor injury categories (codes 3 and 4). The property damage only (PDO) category (code 5) was not aggregated. Under "Collision Type", only those types which occurred more frequently were listed in the table.

Differences Among Crash Severity

The four lane roadways with depressed medians and shoulders had the lowest crash rates in all three severity groupings. Among roadways with other medians types and with shoulders, the order of ranking was narrow median, TWLTL, and no median.

In all crash severity categories, roadways with no median or shoulder had a much higher crash rate than did roadways in the other categories. Although roadways with a depressed median and shoulders had the greatest percentage of all crashes in the "3 or 4" severity category, this group had the lowest rate.

Table 4.4 Crash Severity and Collision Type by Median Type

Median Type	Total # of Crashes	Crash Severity 1 or 2	3 or 4	5	Type of Collision 0	9 or 19	16	17	18
Depressed w/Shoulder	852								
Fraction		15.5%	28.2%	56.3%	25.8%	3.4%	30.4%	24.9%	5.8%
Rate/MVKm	0.49	0.08	0.14	0.27	0.13	0.02	0.15	0.12	0.03
Rate/MVM	0.78	0.12	0.22	0.44	0.20	0.03	0.24	0.20	0.05
TWLTL w/Shoulder	596								
Fraction		17.1%	21.1%	61.7%	21.1%	4.4%	25.8%	31.4%	8.9%
Rate/MVKm	0.87	0.15	0.18	0.54	0.18	0.04	0.23	0.27	0.08
Rate/MVM	1.40	0.24	0.30	0.87	0.30	0.06	0.36	0.44	0.12
TWLTL w/o Shoulder	1133								
Fraction		11.7%	25.9%	62.5%	11.9%	4.2%	23.7%	39.8%	14.1%
Rate/MVKm	1.22	0.14	0.32	0.76	0.15	0.05	0.29	0.49	0.17
Rate/MVM	1.96	0.23	0.51	1.23	0.23	0.08	0.47	0.78	0.28
Narrow w/Shoulder	262								
Fraction		19.5%	24.0%	56.5%	30.2%	5.3%	23.3%	26.3%	5.7%
Rate/MVKm	0.63	0.12	0.15	0.36	0.19	0.03	0.15	0.17	0.04
Rate/MVM	1.02	0.20	0.25	0.58	0.31	0.05	0.24	0.27	0.06
None w/Shoulder	375								
Fraction		13.3%	24.3%	62.4%	18.9%	2.1%	37.6%	20.0%	9.9%
Rate/MVKm	0.97	0.13	0.24	0.61	0.18	0.02	0.37	0.19	0.10
Rate/MVM	1.56	0.21	0.38	0.98	0.30	0.03	0.59	0.31	0.15
None w/o Shoulder	518								
Fraction		11.0%	26.4%	62.5%	10.4%	6.4%	29.3%	30.5%	8.7%
Rate/MVKm	2.35	0.26	0.62	1.47	0.25	0.15	0.69	0.72	0.20
Rate/MVM	3.78	0.42	1.00	2.37	0.39	0.24	1.11	1.15	0.33

NOTES:
Crash Severity 1 = Fatal; 2, 3, 4 = Injury; 5 = Property Damage Only
Crash Type 0 = Single Vehicle Crash; 9 = Head On or 19 = Side Swipe / opposite direction; 16 = Rear End; 17 = Right Angle; 18 = Side swipe / same direction

Differences Among Collision Type

The roadways with no median or shoulder had the highest crash rate in each of the five categories of collision type listed in the table. In some cases the rate was many times higher than that of other median and shoulder types. Especially surprising was that the no median or shoulder roadway crash rate for single vehicle crashes was about double that of the depressed median with shoulder group.

Not surprising was that the two groups without shoulders had higher rates of same direction sideswipe crashes. Among the two groups of roadways with no shoulders, the TWLTL group had a crash rate almost half that of the "no median" group. Note that the no median crash rates for "head on" plus"opposite direction sideswipe" crashes, and for "rear end" crash types, were many times greater than for the TWLTL roadways.

COMPARISON OF SAFETY RECORDS

The number of crashes according to median type were further subdivided into three different groups based on the access density: low access group (less than 20 access points per mile), medium access group (20 – 40 access points per mile), high access (more than 40 access points per mile). The low and the medium access groups are categorized as rural and the high access group is categorized as suburban. Each group is further divided into two subgroups, with and without shoulder. The one case of "barrier" median had a crash rate of 0.46 per MVM, and was not included in the table.

Table 4.5 lists crash rates for the different median types, sorted by the presence of shoulder or curb adjacent to the traveled way, and by number of access points per mile. It suggests that, for the types of roadways examined, the roadways with an outer shoulder were safer than the roadways with a curb. The barrier median group was not included, since there was only one segment in this group. Although the "Raised or Curbed Median" group was included in the table, the number of samples was so small as to make any conclusions about this type very tentative. The following observations were also made about the safety effects of the median types with respect to the access density.

- The crash rates associated with the median type on the roadways having less access density (less than 20 access points per mile) increased in the following order: depressed median, no median, narrow median.
- The crash rates associated with the median type on the roadways having medium access density (between 20-40 access points per mile) increased in the following order: narrow median, TWLTL, and no median.
- The crash rates associated with the median type on the roadways having higher access density (greater than 40 access points per mile) increased in the following order: TWLTL , and no median.

Table 4.5 Crashes by Median Type, Shoulder Presence, and Access Density

	Median Type				
	Depressed	Raised or Curb	TWLTL	Narrow	None
Total Number of Segments	22	5	42	17	25
ACCESS DENSITY					
Number < 20 per mile	17	5	3	7	6
Avg. Crash Rate (per MVKm)	0.44	1.03	1.40	0.84	0.83
Avg. Crash Rate (per MVM)	0.71	1.65	2.25	1.35	1.33
Number With Shoulder	17	3	3	6	5
Avg. Crash Rate (per MVKm)	0.44	0.84	1.40	0.82	0.59
Avg. Crash Rate (per MVM)	0.71	1.35	2.25	1.32	0.95
Number With Curb	0	2	0	1	1
Avg. Crash Rate (per MVKm)	na	1.34	na	1.34	2.11
Avg. Crash Rate (per MVM)	na	2.15	na	2.15	3.40
Number 20 - 40 per mile	3	0	17	10	9
Avg. Crash Rate (per MVKm)	0.33	na	0.76	0.47	1.32
Avg. Crash Rate (per MVM)	0.53	na	1.23	0.75	2.13
Number With Shoulder	3	0	10	10	6
Avg. Crash Rate (per MVKm)	0.33	na	0.61	0.47	1.03
Avg. Crash Rate (per MVM)	0.53	na	0.98	0.75	1.66
Number With Curb	0	0	7	0	3
Avg. Crash Rate (per MVKm)	na	na	0.91	na	2.56
Avg. Crash Rate (per MVM)	na	na	1.47	na	4.12
Number > 40 per mile	2	0	22	0	10
Avg. Crash Rate (per MVKm)	1.03	na	1.49	na	2.22
Avg. Crash Rate (per MVM)	1.66	na	2.33	na	3.58
Number With Shoulder	2	0	6	0	2
Avg. Crash Rate (per MVKm)	1.03	na	1.09	na	1.83
Avg. Crash Rate (per MVM)	1.66	na	1.75	na	2.95
Number With Curb	0	0	16	0	8
Avg. Crash Rate (per MVKm)	na	na	1.51	na	1.61
Avg. Crash Rate (per MVM)	na	na	2.43	na	3.70

Figure 4.13 presents these rankings in order, scaled across the page left to right.

ACCESS DENSITY (access/mile)	CRASH RATE (per MVM) 0 – 1.0			2.0	3.0	4.0
< 20	Dep	None	Nar			
Sample size	22	25	17			
Crash rates	0.70	1.30	1.30			
20-40	Nar	TWLTL		None		
Sample size	10	17		9		
Crash rates	0.75	1.23		2.13		
> 40				TWLTL	None	
Sample size				22	10	
Crash rates				2.33	3.58	

NOTE: Median type Dep = Depressed Nar = Narrow None = No Median
Rais = Raised or Curbed TWLTL = Two-Way Left Turn Lane

Figure 4.13 Ordered Effects of Medians and Access

Comparing Narrow Medians with TWLTLs

Figure 4.13 and Tables 4.4 and 4.5 showed the crash rate for the roadways with a narrow median to be less than that for roadways with a TWLTL. Since literature suggests that the reverse should be true, a closer examination of this crash data was requested.

The sample sizes of roadways categorized as "Narrow" (10) and "TWLTL" (17) were larger in the 20-40 access points per mile group. Table 4.6 presents data for only those roadways having a shoulder.

Table 4.6 Comparing 20 to 40 Accesses-per-Mile Roadways with Narrow and TWLTL Medians

	Crash Rate (per MVM)	Avg. ADT	Avg. Lane Width (ft)	Avg. Access Density (per mi.)	Access Type: Commer. + Indus.	Single Family Res.	Open, Field
Narrow	0.75	7,090	24.0	25.6	16%	46%	20%
TWLTL	0.98	11,970	23.0	30.1	24%	40%	15%

NOTE: Commer. = commercial; Indus. = industrial; Res. = residential

It appears there was a correlation between median type and the surroundings. In this range, the higher crash rate of the TWLTL roadways was accompanied by higher volumes, narrower lanes, and greater access densities, all factors which were associated with higher crash rates. In addition, the access types shown for the two categories suggest the driveways that intersected the TWLTL roadways were of the type that produce more traffic.

In this access density category, nine of the ten Narrow roadways had an ADT between 3,000 and 10,000, while all but three of the 17 TWLTL had ADTs above this range. Within this volume range, the crash rates were as follows.

TWLTL 0.57 crashes/MVM

Narrow 0.64 crashes/MVM

Within the same volume range, the small number of TWLTL roadways had a lower crash rate than did the Narrow median roadways.

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CHAPTER 5
CONCLUSION

Research was conducted to determine the relationship between certain features on rural and suburban multilane roadways and crash rates. The following features were considered.

- presence or absence of median
- width of median
- presence or absence of shoulder or curb
- width of shoulder
- traffic volume (ADT)
- density of access points

Homogenous stretches of roadway segment were identified throughout the state of Arkansas and trips were made to these segments to record the intersection details on videotape (such as number and type of driveways, median openings etc.) and measure traveled way cross-section dimensions (such as median width, through-lane widths etc.). Volume data and crash data were obtained for the years from 1997 through 1999. Attempts to identify and correct errors encountered in these databases were made. All the videotaped segments were viewed and relevant details were recorded.

The final data set had 112 usable segments, of which 1 segment had a barrier median, 22 had depressed median, 5 had raised or curbed median, 42 had TWLTL, 17 had narrow median, and 25 had no median. Of these segments, 74 had shoulders and 38 had curbs (no shoulders) adjacent to the outer through lane.

A number of analyses were performed. An initial step in the analysis of data sets was a test for normality. If the data were normally distributed, then a t-test was performed; if not, a non-parametric test such as the Wilcoxon Sign-Rank test was performed.

FINDINGS

The analyses led to the following findings. These findings were taken from rural and suburban roadways with volumes ranging from 1,800 to 26,000 vpd.

- Crash rates for the roadway segments having a median were less than the rates for those without medians.
- As the width of the median increased, the crash rate decreased.
- Crash rates for the roadway segments having an inner shoulder were less than the rates for those without an inner shoulder.

- As the width of inner shoulder increased, the crash rate decreased.
- Crash rates for the roadway segments having an outer shoulder were less than the rates for those with a curb.
- As the width of outer shoulder increased, crash rate decreased.
- As the traffic volume (ADT) increased, the crash rate increased.
- As the access density increased, the crash rate increased.

CONCLUSIONS

From these findings, the following conclusions about selecting roadway design features for future construction, or reconstruction of existing roadways, can be made.

- 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 lanes 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.

Although it was not an objective of this research, the analysis suggests that there may be a correlation between median type and other factors that influences crash rates. In other words, some cross section types may tend to be installed in certain situations and environments that are less safe, and therefore that cross section option is found to have a higher crash rate. Additional research would be required to investigate this issue.

ANSWERING RESEARCH OBJECTIVES

From the preceding analyses, the original questions associated with this research project can be answered.

Question 1: Median Type Performance

Do similar median types have different safety records in rural vs. suburban areas? Does a median-type that performs well in rural area also perform well in a suburban area?

Using driveway density as a surrogate for rural or suburban, it can be concluded that similar median types perform differently in areas having different driveway densities.

Question 2: Effects of Median Upon Severity and Type of Crash

How are various types and severities of crashes affected by different median design alternatives? (One possible implication is that although an overall crash rate was higher, the severity was less.)

Six different groupings of roadways by median and shoulder type were examined. Although crash rates by severity and by collision type did not exactly mimic the total crash rate for any given group of median and shoulder type, there were no dramatic cases of high overall crash rate but low severity rate. Roadways with depressed medians and shoulders consistently fared well. The no median, curbed (i.e., no shoulder) group exhibited the worst crash rates in all severities and collision types; in some cases, the rates were many times worse than those of other median/shoulder groups.

Question 3: TWLTL Performance

Does the TWLTL design present problems under certain circumstances?

On the roadways with more than 40 access points per mile, the TWLTL median was much safer than no median. On roadways with access point density between 20 and 40 per mile, TWLTL median was safer than a no median, and had a higher crash rate than a narrow median. When this analysis was constrained to roadways within a range of similar volumes, the TWLTL were safer than a narrow median. The sample size was not sufficient to study the behavior of a TWLTL median on the roadways with less than 20 access points per mile.

Question 4: Selecting Appropriate Median Types

What multilane cross-section and median type (or no median) is appropriate for a given multilane rural or suburban highway situation?

For the roadways with less than 20 access points per mile, the depressed median was safer than the others. For the roadways with 20 to 40 access points per mile, the no median option had a higher crash rate. For the roadways with more than 40 access points per mile, the no median option was clearly inferior to the TWLTL.

COMPARISON WITH OTHER RESEARCH

The findings from this research support many conclusions made from the review of the literature.

- A negative binomial analysis of the safety effects on the median types (Hadi et al. 1995) concluded that depending on the highway type, increasing lane width, median width, inside shoulder width, and/or outside shoulder width is effective in reducing crashes. In another study on the safety effectiveness of highway design features (Zegeer et al. 1992), the authors concluded that the wider medians reduce crashes. Median widths in the range of 18.29 to 24.38 m (60 to 80 ft) or more appear to be desirable. This study agreed, concluding that increased median width, inner shoulder width and outer shoulder width was associated with reduced crash rates.
- On a study on TWLTLs (Nemeth 1976), it was concluded that almost without exception, when replacing four lane sections with no median, the TWLTL has noticeably reduced the incidence of left turn related accidents and, perhaps more importantly, lessened the severity of accidents. In this study, roadways with TWLTLs had a better safety record than the roadways with no median on medium and high access density roadways, thus agreeing with the conclusions found from the literature.
- While analyzing the safety records of TWLTLs and raised medians, authors (Margiota et al. 1995) found that raised medians were safer than TWLTLs on roadways with ADT less than 32,500 vpd. This research found that, for low access density roadways, the raised medians were safer than TWLTL, agreeing with the conclusions found from the literature.

In general, roadways with depressed median had the best safety record and roadways with no median had the worst safety record on rural and suburban multilane highways in Arkansas.

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APPENDIX A

Crash Data Extraction Form

THIS FILE REVIEWED BY:
STATUS:
ON (DATE)
Hwy
CURB
Sec
County
MEDIAN
BEGIN MP =
SHOULDER
END MP =

CRASHNUMBER	ATMOSPHERICCONDITIONS1	LIGHTCONDITIONS	RURALURBAN	ROADSURFACECONDITION	ROADSYSTEM	ROADSURFACETYPE	ROADWAYALIGNMENT	ROADWAYPROFILE	CRASHINCONSTZONE 2=NO	CONSTZONETYPE	CONSTZONEPROTECTED	REDUCEDROADWIDTH	ROADREPAIRMAINTENANCE	TRAFFICFLOW	NUMBEROFLANES	ROADWAYDEFECTS1	RELATIONTOJUNCTION	TYPEOFTRAFFICCONTROL	CONTROLFUNCTIONING	TYPEOFCOLLISION	FIRSTHARMFULEVENTOCCURRED	FIREOCCURRENCE	CRASHDATE	WEEKDAY	CRASHTIME	HITRUNCRASH	COUNTY	INCITY 1 = IN CITY	CITY	DISTANCEFROMNEARESTCITY	DIRECTIONFROMNEARESTCITY	ROUTE	SECTON	LOGMILE	NHSCODE	HPMSCODE	POPULATIONGROUP	ATINTERSECTINGSTREET	REFERENCEPOINT	INSERT COLUMN	DISTFROMNEARESTINTERSECT	DIRFROMNEARESTINTERSECT	RAILROADIDNUMBER	CRASHSEVERITY	NUMBEROFFATALITIES	NUMBEROFINJURIES	NUMBERINVOLVED	NUMBEROFVEHICLES	FUNCTIONALCLASS	ALCOHOLINVOLVED	INVESTIGATINGAGENCY

APPENDIX B

Field Data Cross-Section Form

Route ______
Section ______
Section Length ______ miles

County: ______
City: ______
Date: ______

Median Type: ______

Curb: ______

Shoulder: ______

Note: ______

Shoulder | # of Thru Lanes / Thru Lanes | Left Turn Lane | Shoulder | Median | Shoulder | Left Turn Lane | # of Thru Lanes / Thru Lanes | Shoulder

REFERENCE END: ______

REFERENCE END: ______