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Statistical Relationship Between Vehicular Crashes and Highway Access

Access Management

Balancing Access and Mobility

Minnesota Local Road Research Board

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To fully apprize the Legislature of the potential impacts of access management, the Minnesota Department of Transportation (Mn/DOT) has gathered information and conducted research in order to make recommendations covering a wide range of interrelated land use planning, engineering, and legal practices to maximize the operational efficiency and safety of all functional categories of roadways.

The study focused on first identifying and then analyzing a random and statistically representative sample of roadways. The following highlights some of the study's conclusions:

- There is an observed positive relationship between access density and crash rates in 10 of 11 highway categories.
- Additional analysis of the crash data in each of the categories revealed that in all cases, roadway segments with the highest crash rates have high levels of access density and segments with the lowest crash rates have low levels of access density.
- A review of case studies of 11 access management-related projects (three in Minnesota and eight in Iowa) documented an average crash reduction of approximately 40 percent.
- A benefit-cost analysis was completed for the 11 roadway categories. The results are based on a range of estimated project costs and crash reductions and indicate that positive outcomes are possible in every category.
- Crash data was analyzed from two different perspectives; a comparison of crash rates on a random sample of the state+s highway system and a before/after comparison of crash rates from 11 case studies. The results from each approach suggest a strong and statistically sound relationship between levels of accessibility and crash rates.
- The final conclusion addresses the question: Is access management a legitimate public safety issue? All results of the various analyses suggest that yes; access management is a legitimate public safety issue.

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Between Vehicular Crashes and Highway Access

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Executive Summary

The Minnesota Department of Transportation (Mn/DOT) has undertaken a variety of new initiatives in an attempt to improve traffic operations and safety on the States 12,000 mile Trunk Highway System. One of the initiatives authorized by the legislature involves developing a process and a set of guidelines to take a more proactive approach to managing access from abutting properties.

In order to fully apprize the legislature of the potential impacts of access management, Mn/DOT has studied the legal issues associated with property rights and local land development regulations. In addition, Mn/DOT retained the services of BRW, Inc. to assist with conducting a traffic safety study to help determine to what extent a case can be made for suggesting that access management is a public safety issue.

Mn/DOT was aware of the potential safety implications of access management as a result of previous research (See figures 1-1, 1-2 and 1-3). However interesting this data appeared to be, Mn/DOT did not consider the information conclusive because the reports, respectively, did not actually document access density, did not consider different roadway types or the data was based on a very small sample size.

Mn/DOT placed a very high priority on having this study produce credible results with a very high level of statistical reliability. However, during the initial phase of the study it was determined that the data collection efforts associated with an analysis of the entire State Highway system was beyond Mn/DOT's time frame and budget. Therefore, the study focused on first identifying and then analyzing a random and statistically representative sample of roadways. The study concluded the following.

•The previously published safety research has suggested a link between access and crash rates. However, this research did not actually document access density, did not account for differences between various roadway types or the data was based on very small sample. In addition, none of the research used either access or crash statistics from Minnesota.

•This study is based on a representative random sample of segments from Minnesota's State Trunk Highway System. The samples were limited to the State System because of the availability of video log records, which greatly simplified the identification and counting of the access points.

•Eleven roadway segment categories (five rural and six urban) were selected to isolate the potential relationship between crash rates and access density.

•Characteristics of the study sample included: 432 roadway segments, 765 miles, 9,545 access points, and 13,700 crashes (over the three-year period from 1994 to 1996).

•The average density of access was approximately 8 per mile along rural highways and 28 per mile along urban highways.

•The most prevalent type of access along rural highways was residential driveways (38%), followed by public streets (28%). Commercial driveways accounted for only about 6% of the access in the rural sample.

•The most prevalent type of access along urban highways was public streets (40%), followed by commercial driveways (34%).

•The average crash rates for the sample segments was within 10% of the statewide average crash rate for ten of the eleven categories (there was a 20% difference in the urban 6-lane category).

•There is an observed positive relationship between access density and crash rates in ten of the eleven highway categories (i.e., higher levels of access density resulted in higher crash rates). Only the 6-lane category does not show this correlation and this may be due to the small number of segments in this category.

•Further analysis of the data suggests that there is no correlation between traffic volume and crash rates. The data also suggests that there is an inverse relationship between speed and crash rates. However, this may be due to Mn/DOT practicing some degree of access management on higher speed roadways, because the higher speed roadways in the sample also had lower levels of access density.

•Additional analysis of the crash data in each of the categories revealed that in all cases, roadway segments with the highest crash rates have high levels of access density and segments with the lowest crash rates have low levels of access density.

•The additional analysis also demonstrated an observed positive relationship between the density of commercial driveways and crash rates on urban roadways.

•A review of case studies of eleven-access management related projects (three in Minnesota and eight in Iowa) documented an average crash reduction of approximately 40%. In addition, the crash reductions in ten of the eleven cases were statistically significant at the 95% confidence level.

•A comprehensive package of statistical testing was performed. The results of this testing indicate that there were sufficient sample sizes in six of the eleven roadway categories to reach statistically reliable conclusions (RC2NLT, RC4, UC2NLT, UC4NLT, UC4LT and UE4) and there was a statistically significant access effect in five of the six categories (all but UC2NLT).

•A Benefit-Cost analysis was completed for each of the eleven roadway categories. The results are based on a range of estimated project costs and crash reductions and indicate that positive outcomes (a B/C ratio greater than 1) are possible in every category. However, the data also suggest that urban projects would likely result in greater crash reductions and therefore, greater benefits.

•Crash data was analyzed from two different perspectives; a comparison of crash rates on a random sample of the State's Highway System and a Before/After comparison of crash rates from eleven case studies. The results from each approach suggest a strong and statistically sound relationship between levels of accessibility and crash rates.

•The final conclusion addresses the key question identified in the Introduction. IS ACCESS MANAGEMENT A LEGITIMATE PUBLIC SAFETY ISSUE? All of the results of the various analyses suggest that yes; access management is a legitimate public safety issue.

1.0 Introduction

The Minnesota Department of Transportation has undertaken a variety of new initiatives in an attempt to improve traffic operations and safety on the States 12,000 mile Trunk Highway System. One of the initiatives authorized by the legislature involves developing a process and a set of guidelines to take a more proactive approach to managing access from abutting properties.

In order to fully apprize the legislature of the potential impacts of access management, Mn/DOT has studied the legal issues associated with property rights and local land development regulations. In addition, Mn/DOT retained the services of BRW, Inc. to assist with conducting a traffic safety study to help determine to what extent a case can be made for suggesting that access management is a public safety issue.

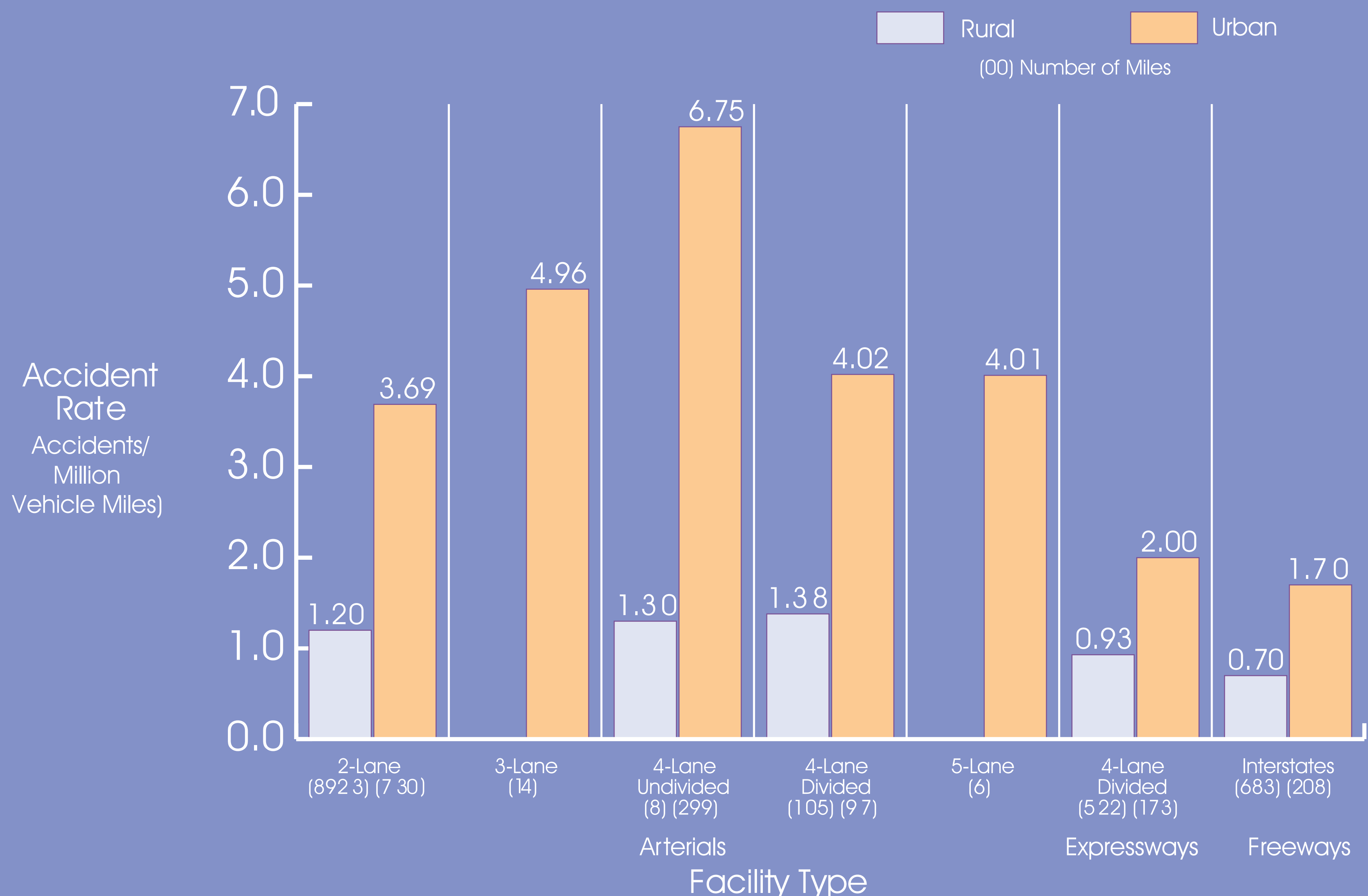
Mn/DOT was aware of the potential safety implications of access management as a result of previous research (See figures 1-1, 1-2 and 1-3). However interesting this data appeared to be, Mn/DOT did not consider the information conclusive because the reports, respectively, did not actually document access density, did not consider different roadway types or the data was based on a very small sample size.

Mn/DOT placed a very high priority on having this study produce credible results with a very high level of statistical reliability. However, during the initial phase of the study it was determined that the data collection efforts associated with a analysis of the entire State Highway system was beyond Mn/DOT's time frame and budget. Therefore the study focused on first identifying and then analyzing a random and statistically representative sample of roadways.

The key steps in the study process are listed below and then described in more detail in the following sections:

- Data Collection
- Document and Analyze Access and Crash Statistics
- Analyze Relationship with Traffic and Roadway Characteristics
- Review Minnesota and Iowa Case Studies
- Conduct Statistical Tests
- Calculate Expected Benefits vs. Costs

In summary, the purpose of this project is to provide a comparison to the results of previous access management research conducted elsewhere and then based on comprehensive analysis of Minnesota access and crash statistics, determine if access management is a legitimate public safety issue.



Roadway Segment Accident Rates by Facility Type

Source: Mn/DOT (1991-1993) Accident Data. Trunk Highways and Some Metro Area County Roads.

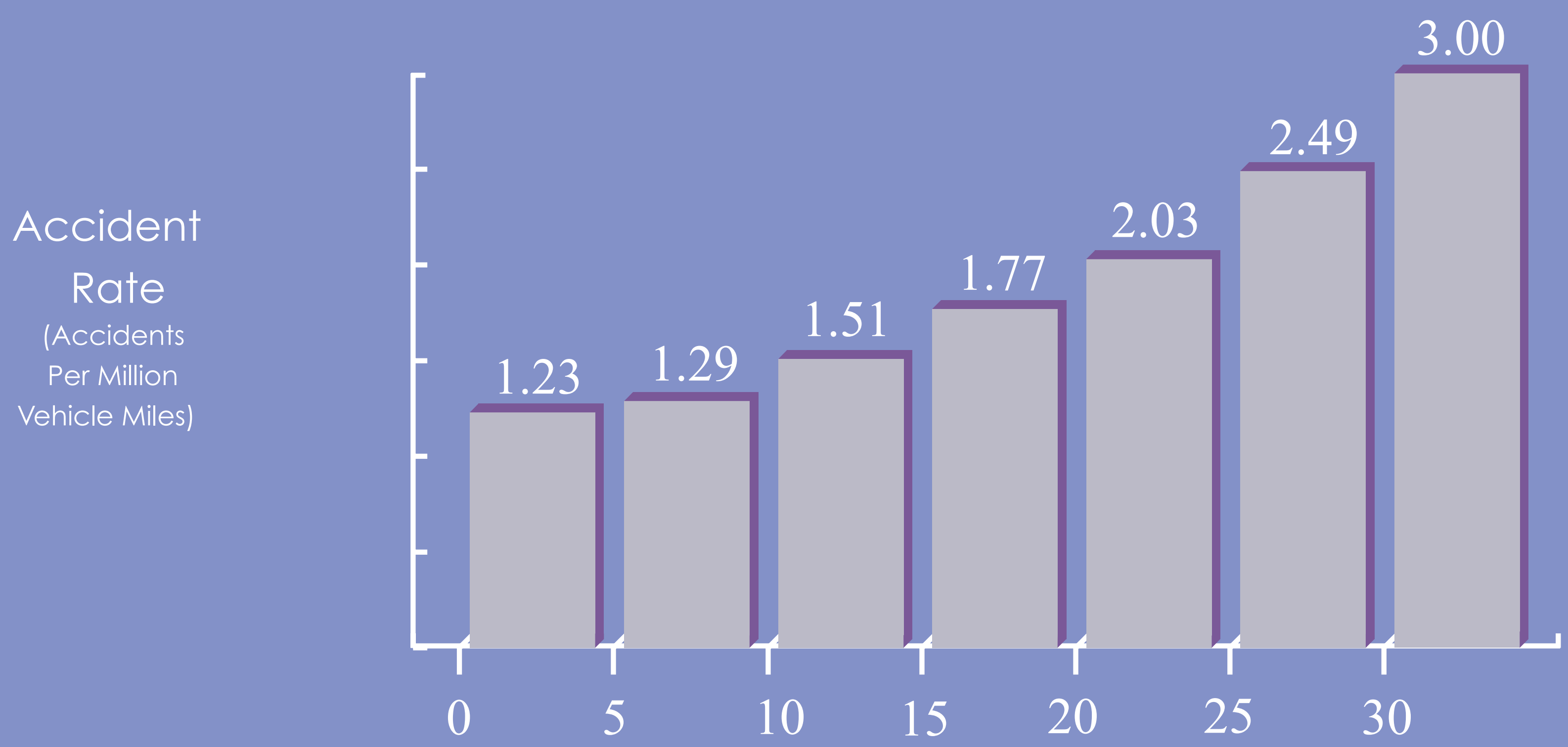
Figure 1-1

Average Daily Traffic	Access Points Per Mile: 0 - 3.9	4 - 7.9	8 - 11.9	12 - 15.9	16 - 19.9	20 - 23.9	24 - 27.9
	Accident Rates (Accidents Per Million Vehicle Miles)						
1000 - 1999	0.70	0.77	1.05	1.36	2.85	2.75	3.17
2000 - 2999	1.25	1.60	1.63	2.42	1.97	2.40	3.95
3000 - 3999	1.74	2.03	1.86	1.93	1.50	0.95	2.60
4000 - 4999		0.75		1.36	1.80	3.85	2.25

Accident Rates Related to Average Daily Traffic and Access Points Per Mile

Source: FHWA, Publication No. FHWA-RD-91-044 (Nov. 1992)

Figure 1-2



Accident Rates Relative to Number of Access Points

Figure 1-3

Source: FHWA, Publication No. FHWA-RD-91-044
(Nov. 1992)

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2.0 Data Collection

The purpose of this chapter is to document the initial project setup and data collection process. In any project dealing with data analysis the quality of the data is the major factor in determining the success of the project. As a result, considerable time and effort was expended to ensure a statistically reliable data set.

2.1 Category Selection

The first step in developing this project was to determine the different roadway classifications that will be analyzed for the effect of access on the crash rate. The Minnesota Department of Transportation categorizes its roadways based on five parameters. These parameters include:

- Roadway Environment (rural, suburban, or urban)
- Roadway Design (conventional, expressway, or freeway)
- Number of Through Lanes
- Type of Median Treatment (none or median)
- Type of left turn treatment (none, paint, and physical)

Breaking this down, there are 162 possible description combinations for a roadway in the State of Minnesota. Although many of these combinations are not used this is still too large a number of roadway types to analyze and some sort of consolidation is necessary.

The important factor in consolidating the different types of roadways was to come up with a manageable number of homogenous roadway categories that isolate the effects of access characteristics. With this in mind eleven different roadway categories were created. Table 2-1 gives a breakdown of how all the different types of conventional roads and expressways in Minnesota fall into these categories. The consolidation of the different types of roadways required several decisions involving the importance of different parameters. The basis for these decisions is described as follows:

1. Suburban and Urban Environments were merged into a single Urban/Suburban environment descriptor. This was done because Urban and Suburban roadways tend to have similar access characteristics. However it was also determined that Rural and Urban/Suburban roadways have sufficiently different characteristics and should remain separated.

2. Freeways were not classified and will not be analyzed as part of this project. This was done because freeways have no at-grade access and therefore would have no impact on the outcome of this study. It was also determined that expressways and conventional roadways have sufficiently different characteristics and should remain separated.

3. It was determined that the presence of a left turn treatment was the important characteristic not the type of left turn treatment.

As a result, eleven different roadway categories were selected for analysis. These roadway categories are listed in Table 2-2 along with a short definition of the category and an alpha descriptor. The alpha descriptor shown for each category in this table will be used in various Tables and Figures throughout this document as an abbreviation for the category definition.

2.2 Segment Selection

The definitive study of Mn/DOT's road system would have involve sampling all 4,645 segments and 10,868 miles of conventional roads and expressways in the state. However, this magnitude of data collection was considered beyond the scope of the project and therefore it was determined that a statistically reliable randomly selected sample was sufficient for this project. A preliminary investigation suggested that a minimum total of 500 crashes in each category should provide statistically reliable results. It was also determined that a minimum of 5% of a category's total segments should be sampled.

Using the criteria described above a sampling percentage of the total number of segments in each category was determined. This percentage combined with a randomly generated seed applied to the total population of each roadway category then determined the segments that were to be sampled. The comparison of this original study sample to the statewide population is shown in Table 2-3. This table shows that the original selection resulted in 317 sample segments with 674 total miles. Also the preliminary selection resulted in several categories having their entire statewide population sampled.

Once analysis of the data began it quickly became clear that there was not a sufficient number of sample segments in some of the roadway categories to provide the desired degree of statistical reliability. This led to combining the eleven roadway categories into six categories in order to get a sufficient number of segments in each category. Later statistical analysis and a review of the homogeneity of these combined categories indicated that the categories should not be combined. It was then determined that in order to get statistically reliable results additional sample segments needed to be obtained.

In the second iteration of segment selection the focus was placed on obtaining a minimum number of segments in the urban categories. This was done for two reasons. First, the original selection of segments focused on obtaining a minimum number of total crashes in each category. This resulted in a larger number of sample segments in the rural categories because lower volumes on rural segments required more segments and miles to be sampled in order to reach the minimum crash threshold. As a result, the sample size of the rural categories appeared sufficient for statistically reliable conclusions. The second reason for focusing the additional data collection efforts on urban categories was that initial analysis indicated that access management policies were likely to have the biggest effect in urban areas.

In the second selection of segments it was decided that a sample set of between 40 and 50 segments in each category was necessary in order to obtain statistically reliable results. As before, a sampling percentage of each category was determined and a randomly generate seed was created and applied to the total population in order to select the additional segments. In both iterations of segment selection it was necessary to remove some segments from the sample due to inconsistencies between data sources or because of the unavailability of video.

Table 2-4 shows the final distribution of sample segments by district. The table illustrates that the sampling process achieved the goal of obtaining segments from throughout the state. Table 2-5 shows the comparison of the revised sample set with the statewide population and highlights the categories in which additional sample segments were obtained. This table shows that the revised sample set includes 432 segments and 766 miles of roadway. Also with the revised segment selection four of the roadway categories (RC2LT, RC6, UC6, and UC2LT) have had their entire statewide population sampled. A complete list of all Minnesota road segments sampled is included in Appendix A.

2.3 Data Collection

The data collection involved three basic types of information:

- The number of access points in each segment
- The three year crash statistics for each segment
- The characteristics of each segment

The following sections describe the source and the process involved in obtaining the information for each segment.

2.3.1 Access Data

The most labor intensive and time consuming piece of data to collect was the number of access points in each segment. This information was obtained through the video logs the Minnesota Department of Transportation keeps for all its state highways. The data collection involved scrolling through 766 miles of state highway in order to account for approximately 9500 access points.

Figure 2-1 shows the access inventory worksheet used in the data collection of all the access points. This worksheet shows that the access points were broken down into five different types of access and that the side of street the access point appeared on was also noted. The five different types of access that were counted include:

- Public Street
- Commercial Driveway
- Residential Driveway
- Field Entrances
- Other Access (access points that could not be qualified)

Figure 2-2 shows the convention that was used for counting access. This convention counted access by the number of intersecting legs with the main roadway. Therefore a T-intersection with the main roadway would constitute one access point and a 4-leg intersection with the main roadway would constitute two access points. It should be noted that the counting of accesses was not affected by whether or not the access point had full access (i.e. open median) or partial access (i.e. closed median).

This counting convention was selected after checking with other researchers at the Federal Highway Administration and Iowa State University. It was determined that this counting convention was consistent with the methodology in other similar research studies.

2.3.2 Crash Data

The crash data used in this project was obtained from the Minnesota Statewide Crash Database. Crash information was obtained for the years 1994-1996. The collected data accounted for 13,700 crashes on all the sample segments between the years of 1994 and 1996. The following crash data was obtained for each individual segment sampled:

- Total Number of Crashes
- Crash Rate
- Total Number of Crashes for each level of severity
  (Fatal, Personal Injury A, B, and C, and Property Damage)
- Categorization of Crashes by Crash Type
- Categorization of Crashes by Diagram Type
- Wet Accident Statistics

And the following information was obtained for the entire statewide population by roadway category:

- Crash Rate
- Categorization of Crashes by Crash Type (from years 1995-1997)
- Categorization of Crashes by Diagram Type (from years 1995-1997)

2.3.3 Segment Data

The segment characteristics for each sample segment were obtained from the Minnesota Roadlog Database. The following segment characteristics were obtained for each individual segment sampled:

- Segment Length (miles)
- Segment ADT (Average Volume across segment from 1994-1996)
- Segment VMT (Vehicle Miles Traveled from 1994-1996)
- Speed Limit
- Segment Environment (Rural, Suburban, Urban)
- Segment Design (Conventional, Expressway, Freeway)
- Number of Through Lanes
- Median Treatment (none or median)
- Left Turn Treatment (none, painted, physical)

CATEGORY	ENVIRONMENT	DESIGN	LANES	DIVIDED	LT LANE
R1	Rural	Conventional	2-Lane	Median	None
	Rural	Conventional	2-Lane	No Median	None
R2	Rural	Conventional	2-Lane	Median	Physical
	Rural	Conventional	2-Lane	No Median	Paint
	Rural	Conventional	2-Lane	No Median	Physical
R3	Rural	Conventional	4-Lane	Median	None
	Rural	Conventional	4-Lane	Median	Paint
	Rural	Conventional	4-Lane	Median	Physical
	Rural	Conventional	4-Lane	No Median	None
	Rural	Conventional	4-Lane	No Median	Paint
R4	Rural	Conventional	6-Lane+	No Median	None
R5	Rural	Expressway	4-Lane	Median	None
	Rural	Expressway	4-Lane	Median	Paint
	Rural	Expressway	4-Lane	Median	Physical
U1	Urban/Suburban	Conventional	2-Lane	Median	None
	Urban/Suburban	Conventional	2-Lane	No Median	None
U2	Urban/Suburban	Conventional	4-Lane	Median	None
	Urban/Suburban	Conventional	4-Lane	Median	None
	Urban/Suburban	Conventional	4-Lane	No Median	None
U3	Urban/Suburban	Conventional	6-Lane+	No Median	None
U4	Urban/Suburban	Conventional	2-Lane	Median	Physical
	Urban/Suburban	Conventional	2-Lane	No Median	Paint
	Urban/Suburban	Conventional	2-Lane	No Median	Physical
U5	Urban/Suburban	Conventional	4-Lane	Median	Paint
	Urban/Suburban	Conventional	4-Lane	Median	Paint
	Urban/Suburban	Conventional	4-Lane	Median	Physical
	Urban/Suburban	Conventional	4-Lane	Median	Physical
	Urban/Suburban	Conventional	4-Lane	No Median	Paint
	Urban/Suburban	Conventional	4-Lane	No Median	Physical
U7	Urban/Suburban	Expressway	4-Lane	Median	None
	Urban/Suburban	Expressway	4-Lane	Median	Paint
	Urban/Suburban	Expressway	4-Lane	Median	Physical

Table 2-1

Mn/DOT Roadway Categories

CATEGORY	DESCRIPTION	ABBREVIATION
R1	2 Lane Rural Conventional Roadway with No Left Turn Lanes	RC2NLT
R2	2 Lane Rural Conventional Roadway with Left Turn Lanes	RC2LT
R3	4 Lane Rural Conventional Roadway	RC4
R4	6+ Lane Rural Conventional Roadway	RC6
R5	4 Lane Rural Expressway	RE4
U1	2 Lane Urban/Suburban Conventional Roadway with No Left Turn Lanes	UC2NLT
U2	4 Lane Urban/Suburban Conventional Roadway with No Left Turn Lanes	UC4NLT
U3	6+ Lane Urban/Suburban Conventional Roadway	UC6
U4	2 Lane Urban/Suburban Conventional Roadway with Left Turn Lanes	UC2LT
U5	4 Lane Urban/Suburban Conventional Roadway with Left Turn Lanes	UC4LT
U7	4 Lane Urban/Suburban Expressway	UE4

Table 2-2

Roadway Categories

CATEGORY	STATEWIDE POPULATION			STUDY SAMPLE		
	SEGMENTS	MILES	AVG. MILES/SEG	SEGMENTS	MILES	AVG. MILES/SEG
RC2NLT	2,710	9,020	3.3	120	412	3.4
RC2LT	14	20	1.4	14	21	1.5
RC4	79	142	1.8	36	68	1.9
RC6	7	7	1.0	7	7	1.0
RE4	202	577	2.9	25	80	3.2
RURAL SUBTOTAL	**3,012**	**9,766**	**3.2**	**202**	**588**	**2.9**
UC2NLT	1,166	702	0.6	51	33	0.6
UC4NLT	130	83	0.6	18	11	0.6
UC6	28	26	0.9	17	14	0.8
UC2LT	28	20	0.7	13	10	0.8
UC4LT	112	83	0.7	10	11	1.1
UE4	169	188	1.1	6	7	1.2
URBAN SUBTOTAL	**1,633**	**1,102**	**0.7**	**115**	**86**	**0.7**
TOTAL	**4,645**	**10,868**	**2.3**	**317**	**674**	**2.1**

Table 2-3

Original Sample Comparison

CATEGORY	STATEWIDE POPULATION			STUDY SAMPLE		
	SEGMENTS	MILES	AVG. MILES/SEG	SEGMENTS	MILES	AVG. MILES/SEG
RC2NLT	2,710	9,020	3.3	120	412	3.4
RC2LT	14	20	1.4	14	21	1.5
RC4	79	142	1.8	36	68	1.9
RC6	7	7	1.0	7	7	1.0
RE4	202	577	2.9	25	80	3.2
RURAL SUBTOTAL	**3,012**	**9,766**	**3.2**	**202**	**588**	**2.9**
UC2NLT	1,166	702	0.6	58	38	0.7
UC4NLT	130	83	0.6	48	29	0.6
UC6	28	26	0.9	17	14	0.8
UC2LT	28	20	0.7	20	14	0.7
UC4LT	112	83	0.7	42	33	0.8
UE4	169	188	1.1	45	50	1.1
URBAN SUBTOTAL	**1,633**	**1,102**	**0.7**	**230**	**178**	**0.8**
TOTAL	**4,645**	**10,868**	**2.3**	**432**	**766**	**1.8**

Table 2-4

Revised Sample Comparison

Category	Mn/DOT District								Total
	1	2	3	4	6	7	8	Metro	
RC2NLT	17	22	17	19	8	13	18	6	120
RC2LT	0	3	1	0	4	1	0	5	14
RC4	5	1	6	2	14	1	5	2	36
RC6	0	0	0	0	0	6	0	1	7
RE4	3	5	5	4	1	2	0	5	25
UC2NLT	1	6	15	8	7	7	8	6	58
UC4NLT	5	6	10	3	4	7	4	9	48
UC6	0	3	0	0	0	4	4	6	17
UC2LT	0	0	1	0	3	0	4	12	20
UC4LT	0	4	6	3	9	3	3	14	42
UE4	0	7	3	6	2	0	0	27	45
Total	**31**	**57**	**64**	**45**	**52**	**44**	**46**	**93**	**432**

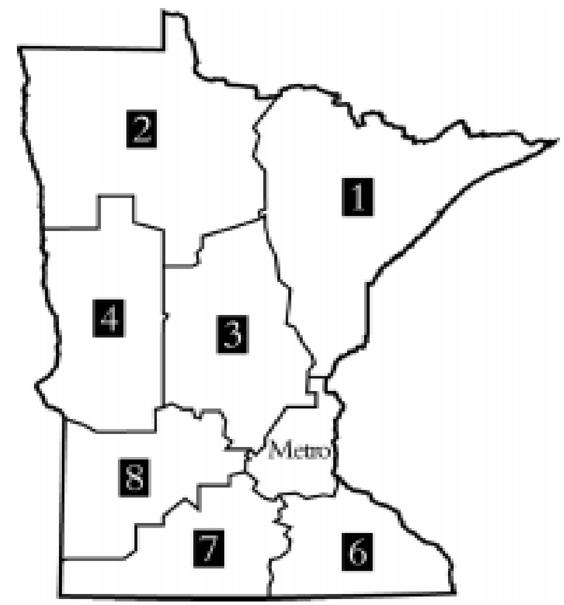

Table 2-5

Distribution of Sample Segments by District

Mn/DOT ROADWAY SEGMENT ACCESS INVENTORY WORKSHEET

Statistical Relationship Between Vehicular Crashes and Highway Access

CATEGORY:	
INDEX NUM:	
PAGE:	of

Mn/DOT DIST:	1 2 3 4 5 6 7 8 9
SYSTEM:	US TH
ROUTE NUM:	

START RP:	
END RP:	
DISTANCE:	

MILE POINT	**REFERENCE POINT**	**STREET**		**DRIVEWAY**							
		LEFT	**RIGHT**	**LEFT**				**RIGHT**			
				COMM	**RES**	**FIELD**	**OTHER**	**COMM**	**RES**	**FIELD**	**OTHER**

Figure 2-1

Mn/DOT Roadway Segment Access Inventory Worksheet

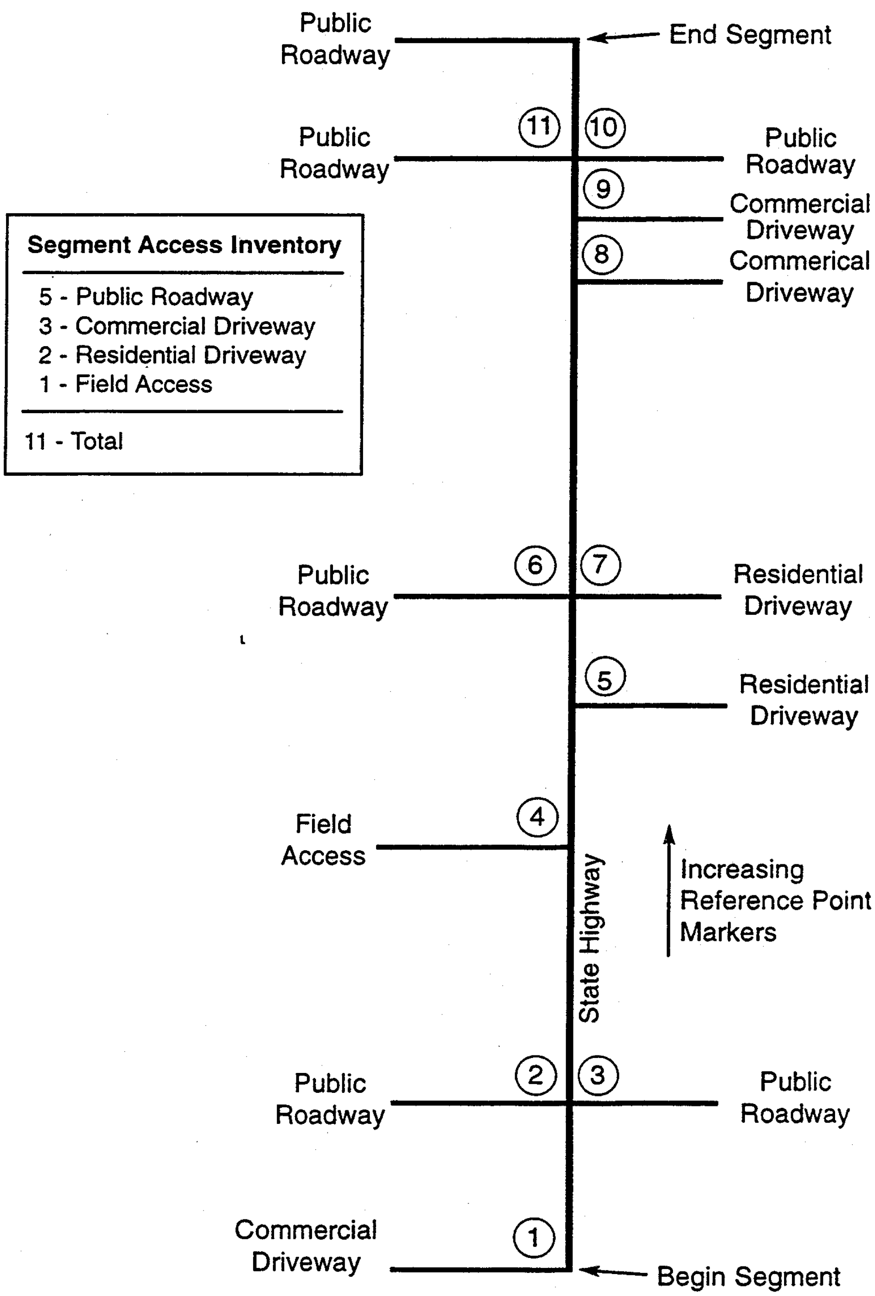

Figure 2-2

Access Counting Convention

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3.0 Technical Analysis

The purpose of this chapter is to document the findings of the crash and access statistics and discuss the observed trends in the data. This chapter also provides an initial assessment of the relationship between access density and crash rate.

3.1 Roadway Access Statistics

The statistic used throughout this project to describe the level of access on a segment of roadway is access density. Access density is simply the average number of accesses per mile. It is computed by taking the total number of accesses in a segment and dividing it by the length of the segment.

Figure 3-1 details the average access density for each rural roadway category and Figure 3-2 details the average access density for each urban roadway category. From these figures the average access density for all rural categories is approximately 8 accesses per mile and the average access density for all urban categories is approximately 28 accesses per mile. These figures also show that for similar types of roadway categories the urban category always has a higher average access density than the rural category.

Figure 3-3 shows the distribution of rural and urban access types. From this figure it can be seen that residential driveways (38%) are the most prevalent type of access in rural areas followed by public roads (28%), and field entrances (25%). Public roads are the most prevalent type of access in urban areas followed by commercial driveways (34%) and residential driveways (21%). This data suggests that the greatest opportunities to manage access involve public streets and residential driveways in rural areas and public streets and commercial driveways in urban areas.

3.2 Crash Statistics

The statistic used throughout this project to describe the level of crashes on a segment of roadway is the crash rate. Crash Rate is simply the number of crashes per million vehicle miles traveled. The number of vehicle miles traveled is calculated from the segment ADT, the segment length, and the period of time over which the crashes were observed.

The average crash rates for the sample segments are compared with the statewide average crash rates by roadway category in Figures 3-4 and 3-5. These figures illustrate that the crash rates for the sample segments are very similar to the crash rates of the statewide population. The data also shows that urban roadways have significantly higher crash rates than rural segments with similar design features.

Figure 3-6 shows the distribution of rural and urban crash types. The key piece of information in this figure is that there are significantly more single vehicle crashes on rural roadways than on urban roadways.

Figure 3-7 shows the distribution of rural and urban crash severity. The key piece of information in this figure is that the percentage of fatal crashes on rural roadways is three times the percentage on urban roadways.

3.3 Crash Rate / Roadway Access Relationship

The purpose of this section is to determine if there is a relationship between access density and crash rate. As stated in the introduction, previous research shows a positive relationship between access density and crash rate. This is supported by theoretical reasoning that suggests an increase in crash rate as access density increases. This reasoning is based on the belief that turning vehicles and the conflict points caused by these turning vehicles is a major cause of crashes. In addition, this line of reasoning also suggests that with more access points the number of possible conflict points increase and as a result the crash rate would be expected to increase as well.

Figures 3-8 through 3-18 document the crash rate / roadway access relationship for each of the eleven roadway categories by grouping sample segments within each category into different levels of access density. In keeping with the project goal of statistical reliability each of these charts was rated on an Expected Reliability scale. This was a discretionary scale based mainly on the sample size and number of crashes in each roadway category. The following is the basis for the level of Expected Reliability given to each figure:

1. High Expected Reliability
    - All Access Density Groups with approximately 100 crashes or greater.
    - All Access Density Groups with approximately 5 segments or greater.

2. Moderate Expected Reliability
   - Most Access Density Groups with approximately 100 crashes or greater.
   - Most Access Density Groups with approximately 5 segments or greater.

3. Low Expected Reliability
   - Few or No Access Density Groups with 100 crashes or greater.
   - Few or No Access Density Groups with 5 segments or greater.

Figures 3-8 through 3-18 show that in almost every category and that in all categories with a high expected reliability there is a strong positive observed relationship (increasing crash rate as access density increases) between access density and the crash rate. This relationship doesn't always appear between the different access density groups but it does always exist between the highest and lowest levels of access. Another interesting relationship was noticed when the average access density for each category was compared to these figures. In most cases the access density groups with crash rates lower than the category average also had access densities that were lower than the category average. The reverse was also true as most access density groups with crash rates higher than the category average had access densities higher than the category average.

3.4 Summary

The purpose of this chapter was to provide an initial assessment of the access density / crash rate relationship. The analysis of this chapter determined that a strong positive relationship (crash rate increases with increasing access density) was observed between access density and crash rate. In order to improve our understanding of this relationship and to assure that this relationship is not effected by other variables further analysis is required.

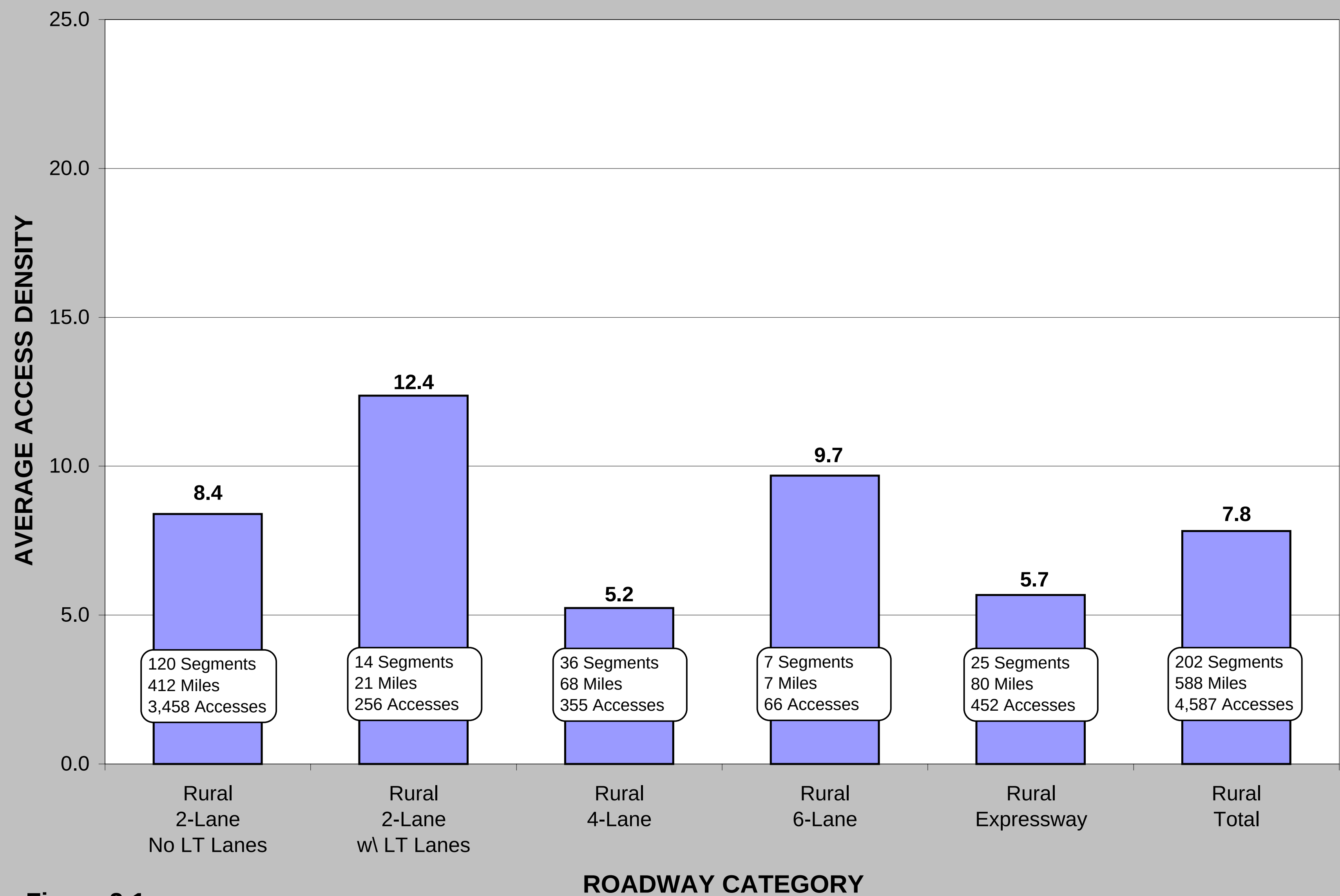


Figure 3-1

Rural Access Density Summary

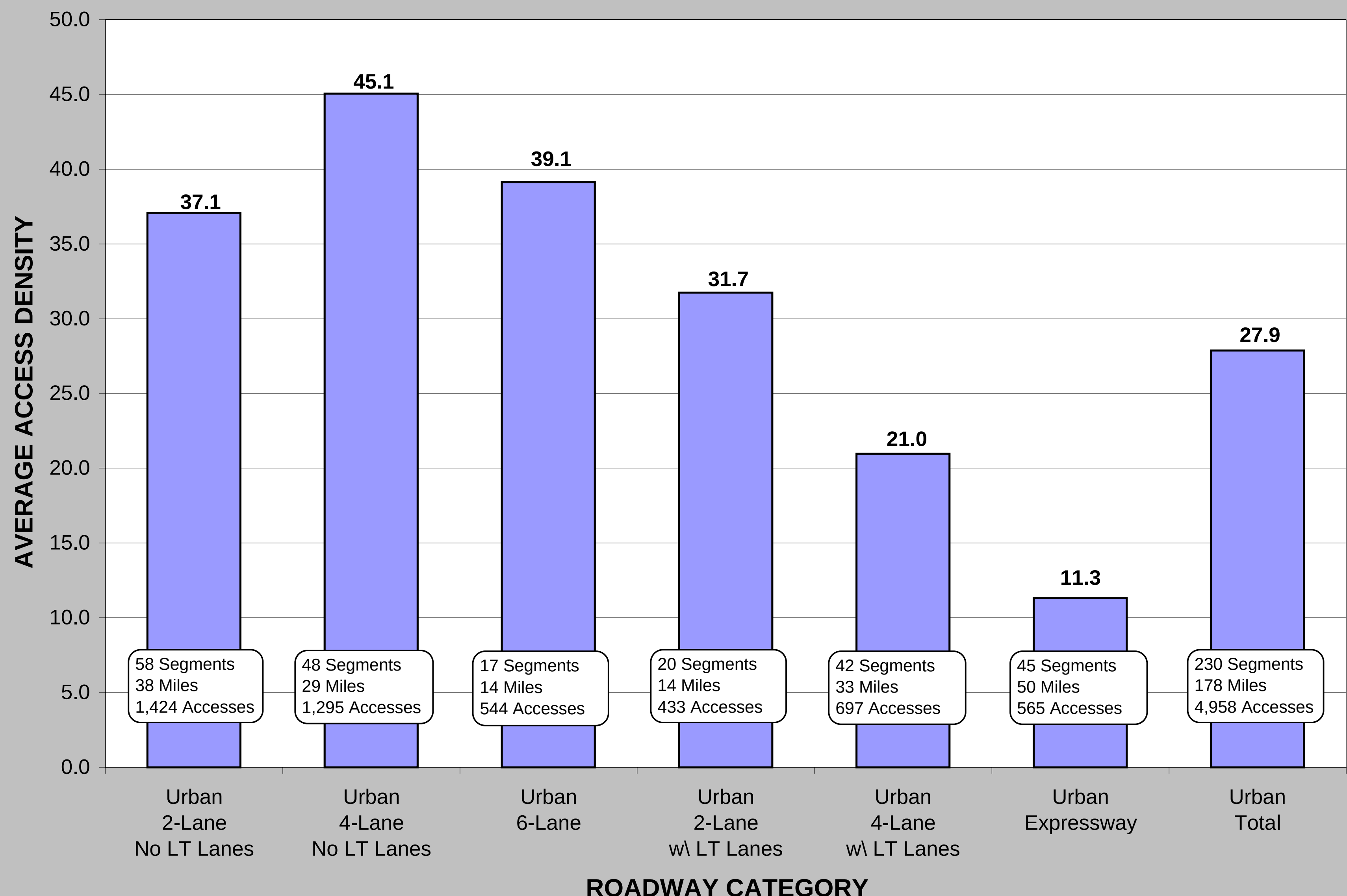


Figure 3-2

Urban Access Density Summary

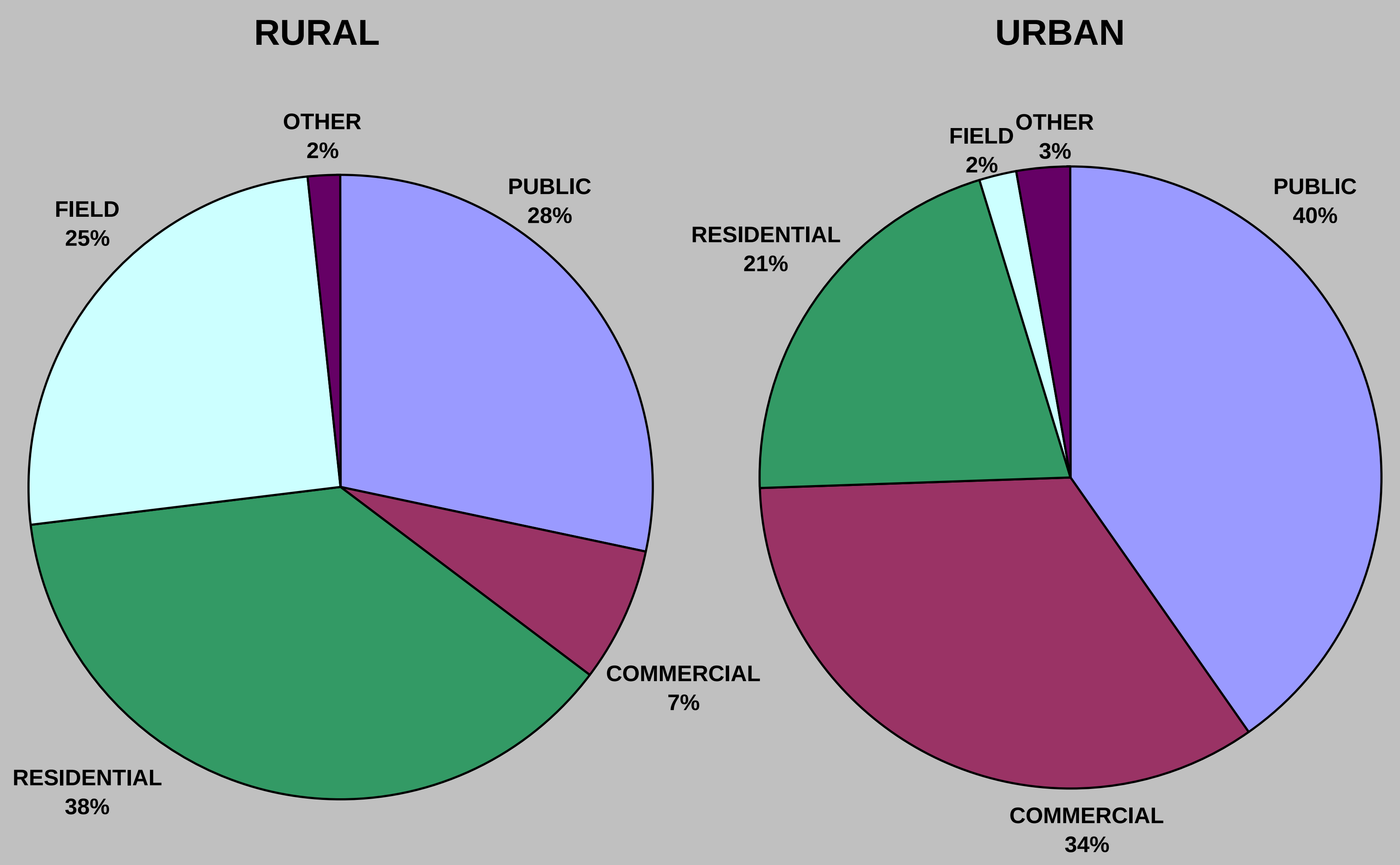


Figure 3-3

Distribution of Rural and Urban Access Type

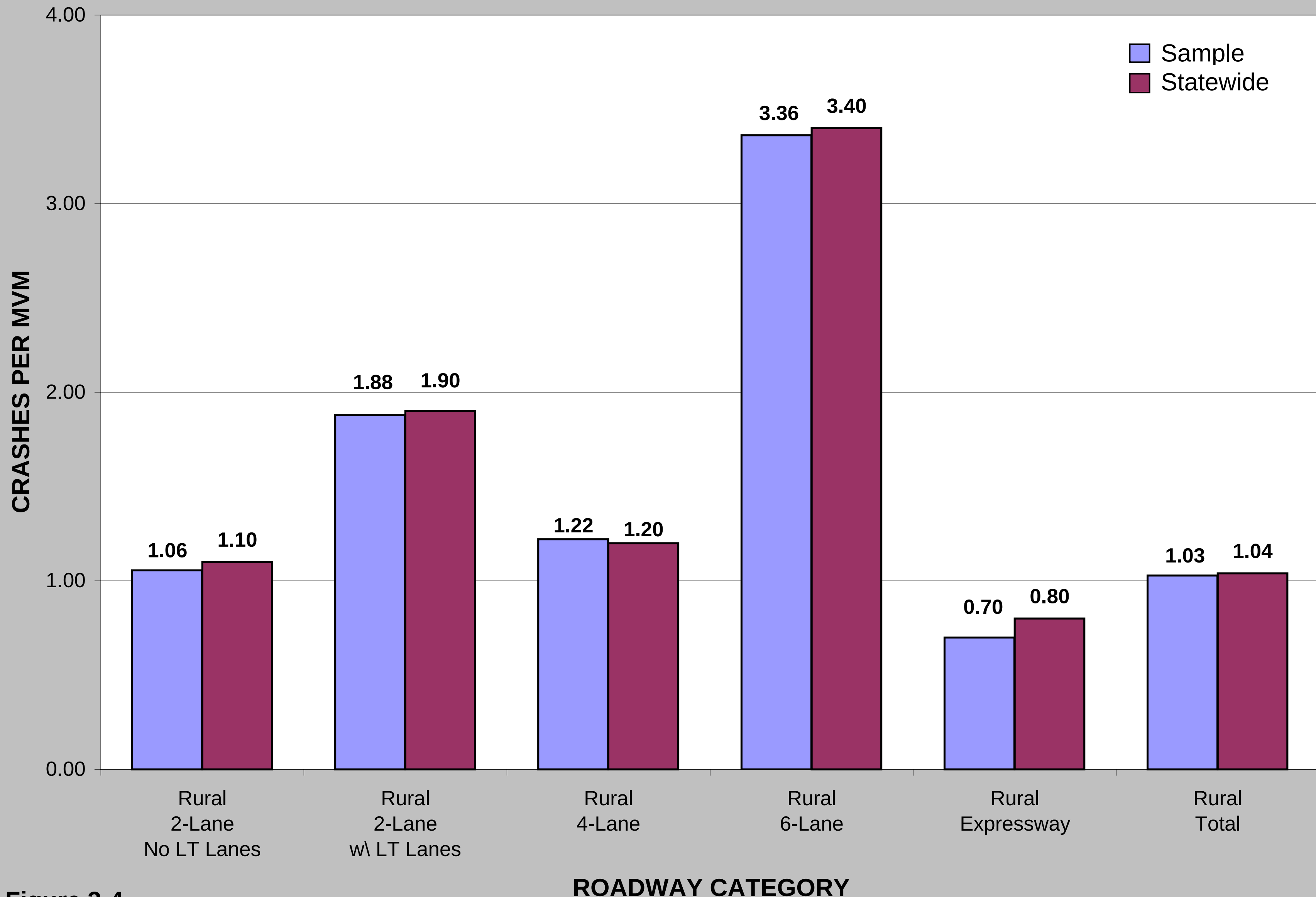


Figure 3-4

Crash Rates of Rural Roadway Categories

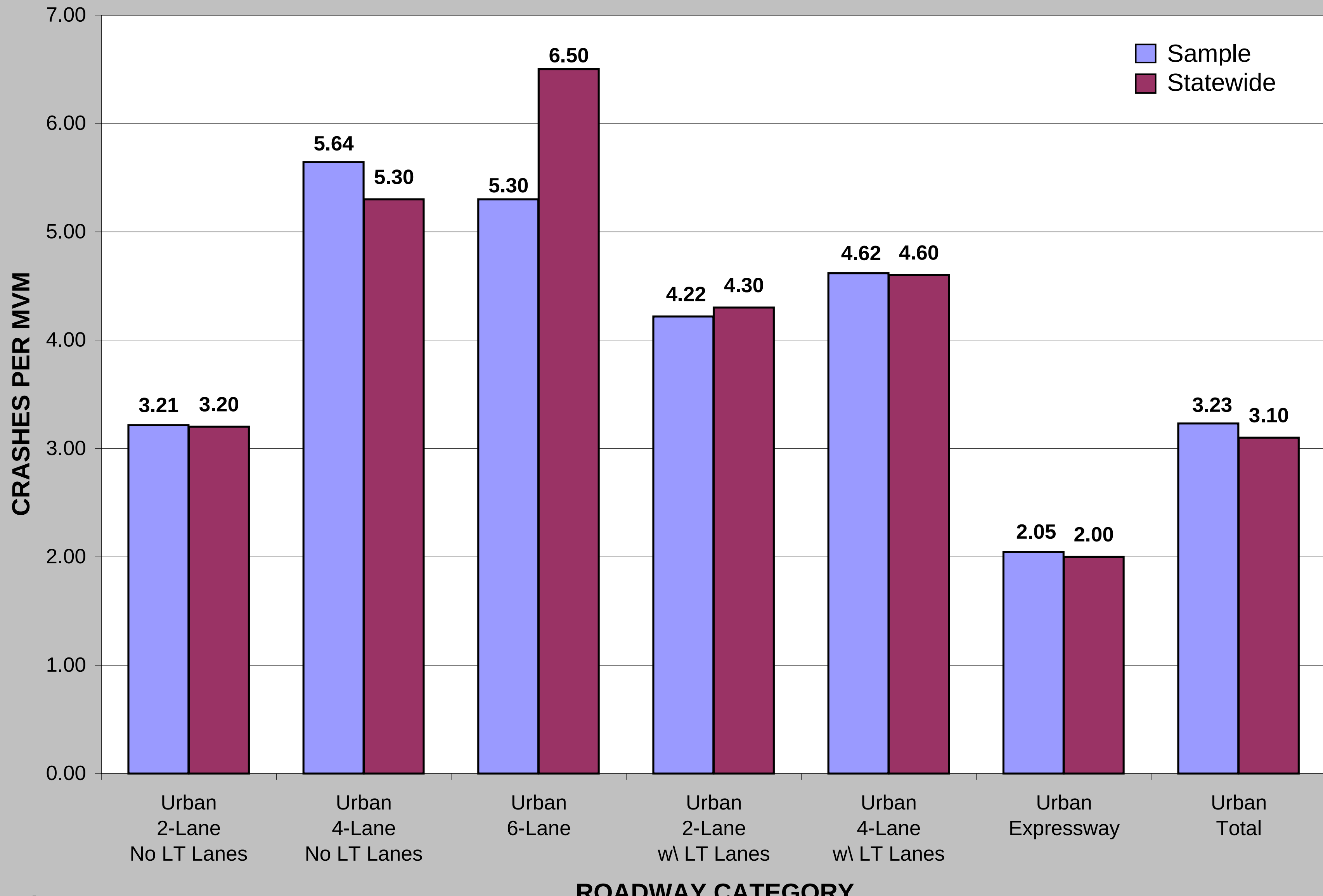


Figure 3-5

Crash Rates of Urban Roadway Categories

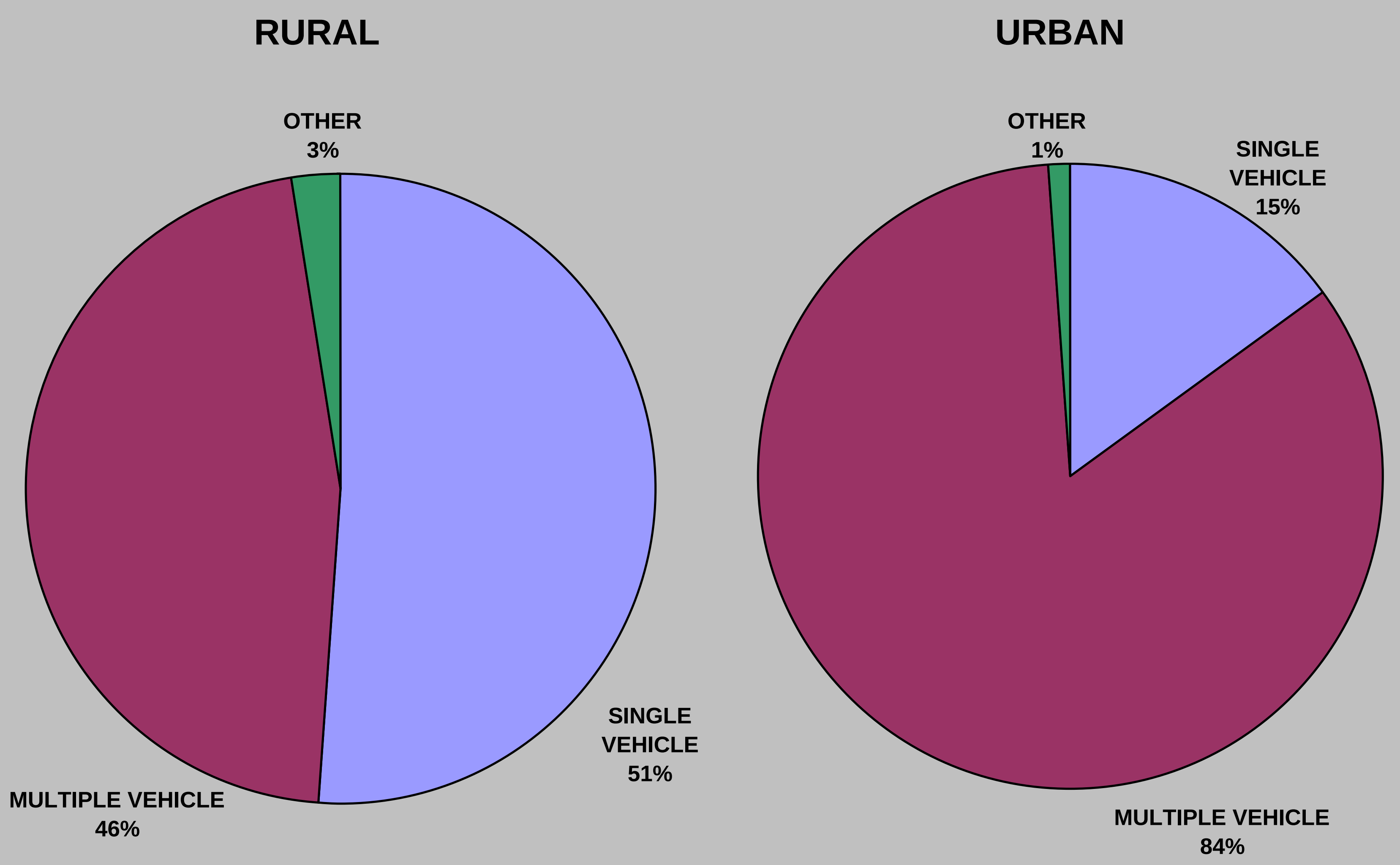


Figure 3-6

Distribution of Rural and Urban Crash Types

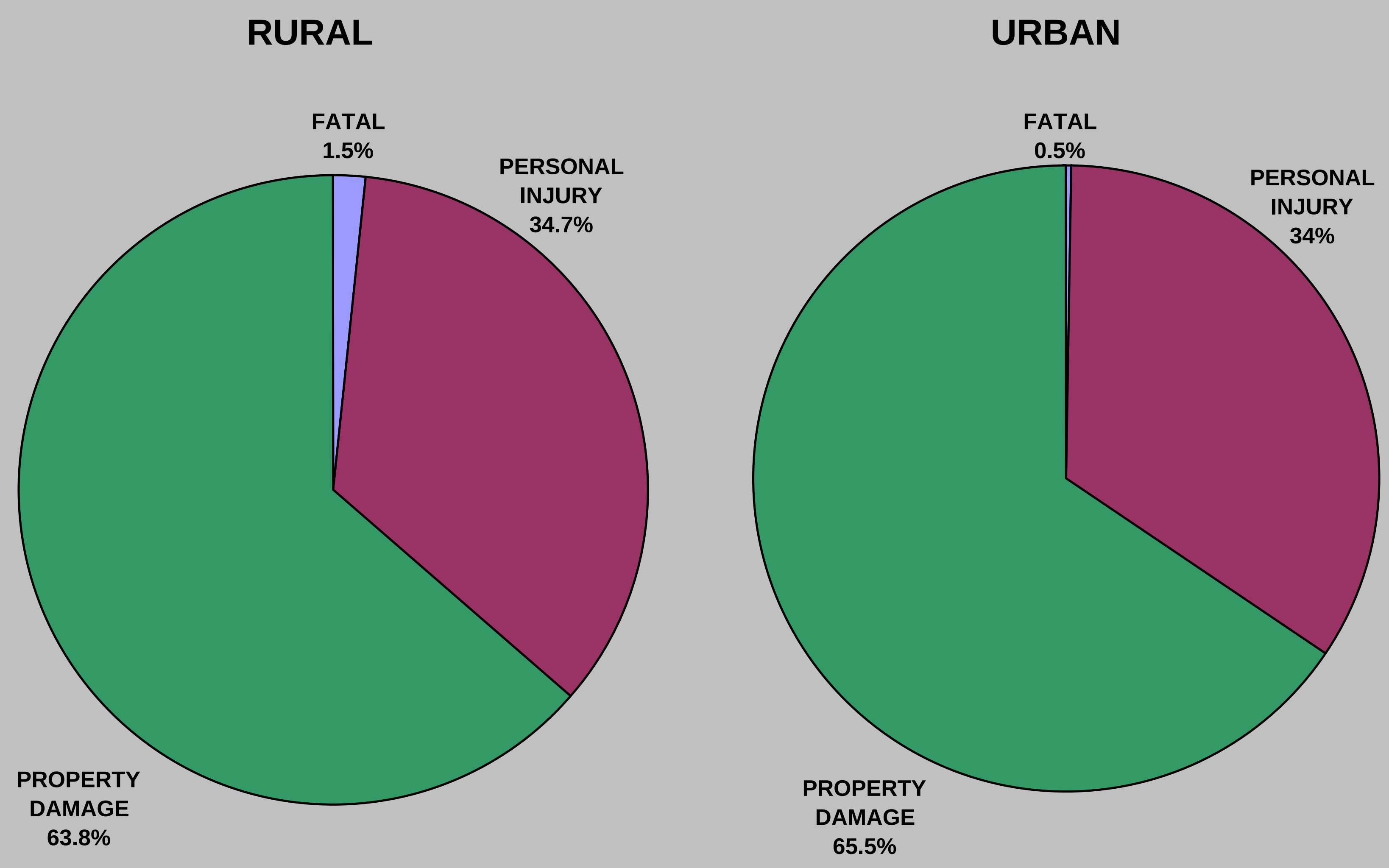


Figure 3-7

Distribution of Rural and Urban Crash Severity

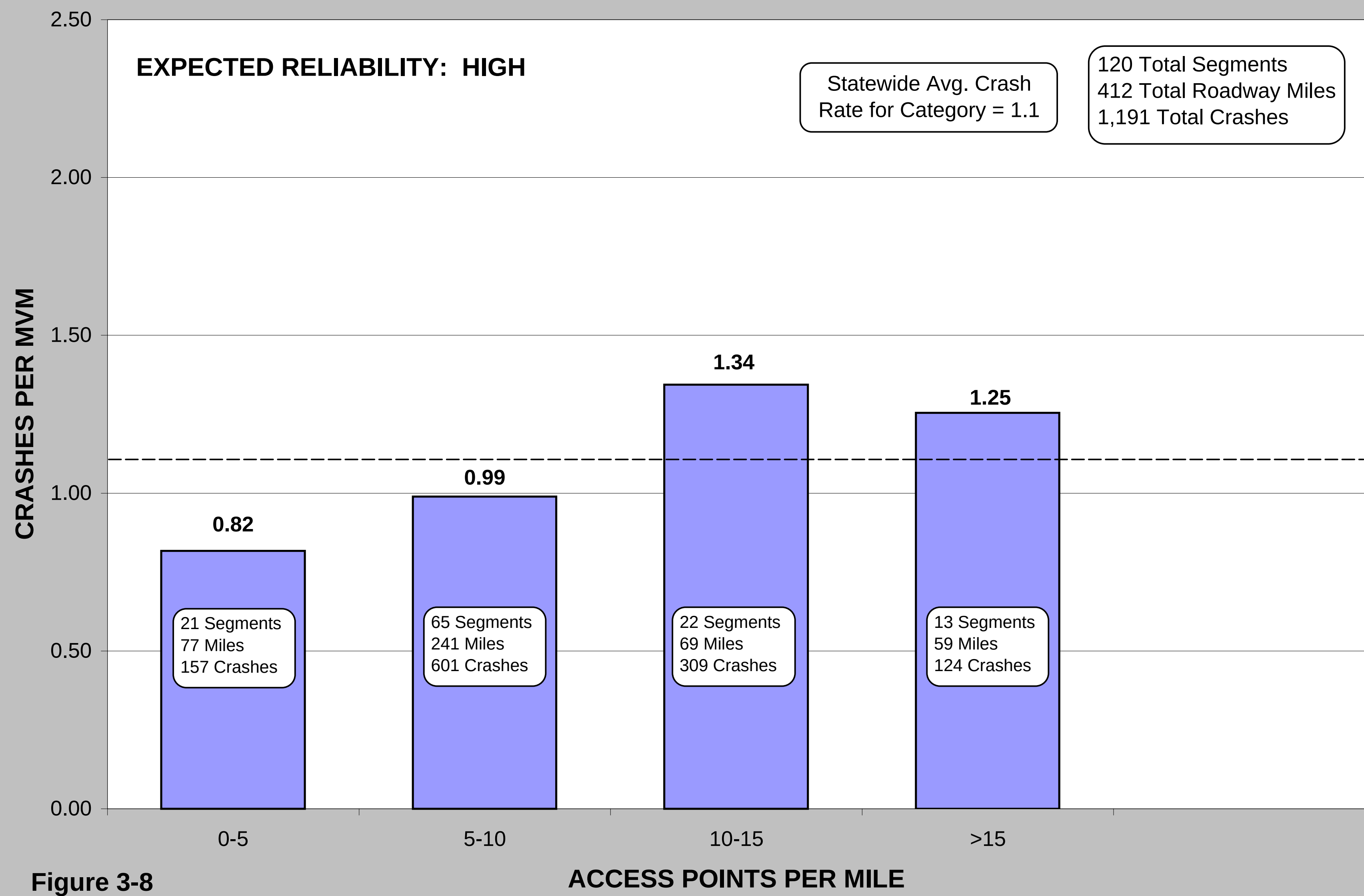


Figure 3-8

2 Lane Rural Conventional Roadways with No LT Lanes (RC2NLT)

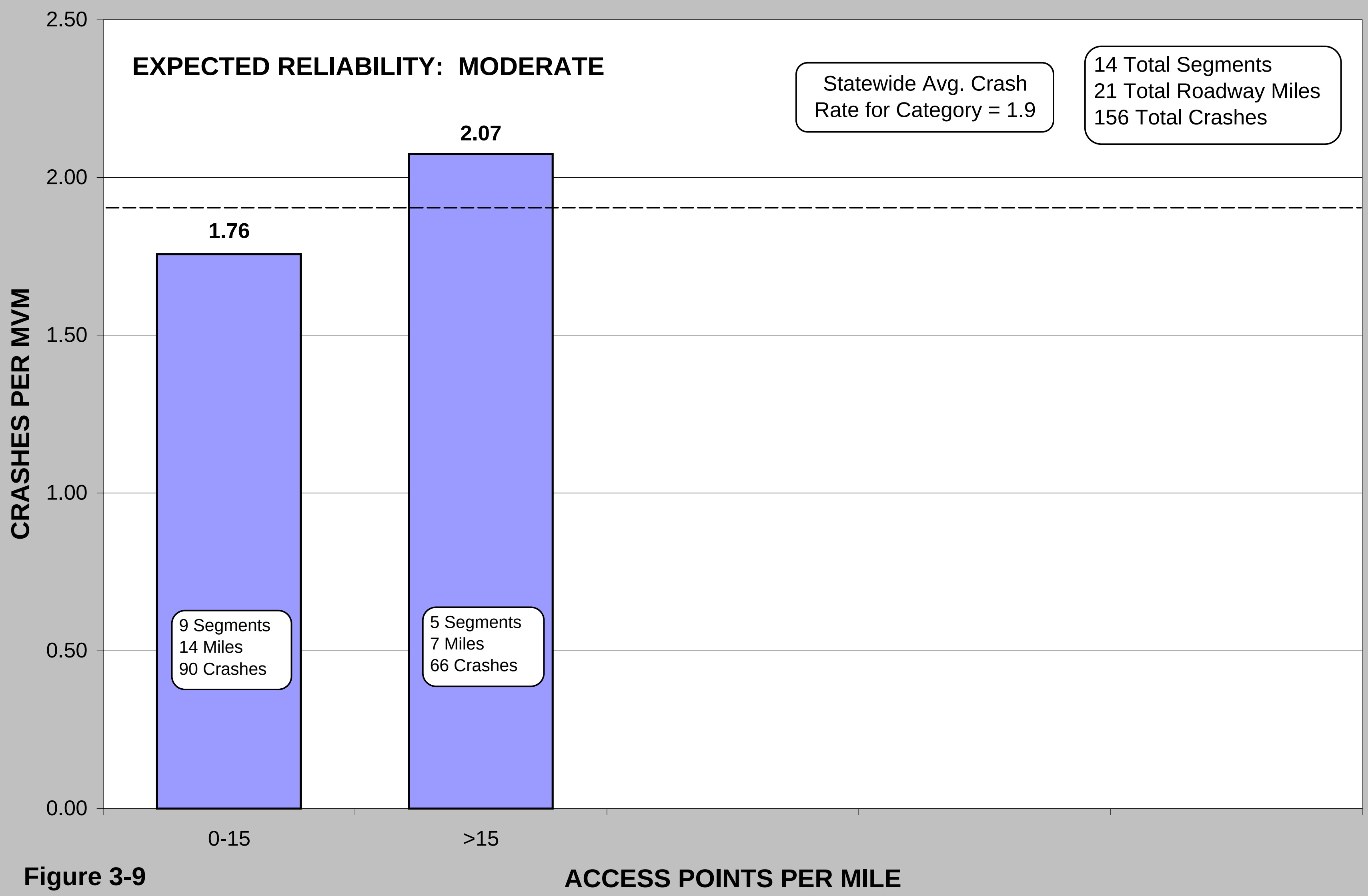


Figure 3-9

2 Lane Rural Conventional Roadways with Left Turn Lanes (RC2LT)

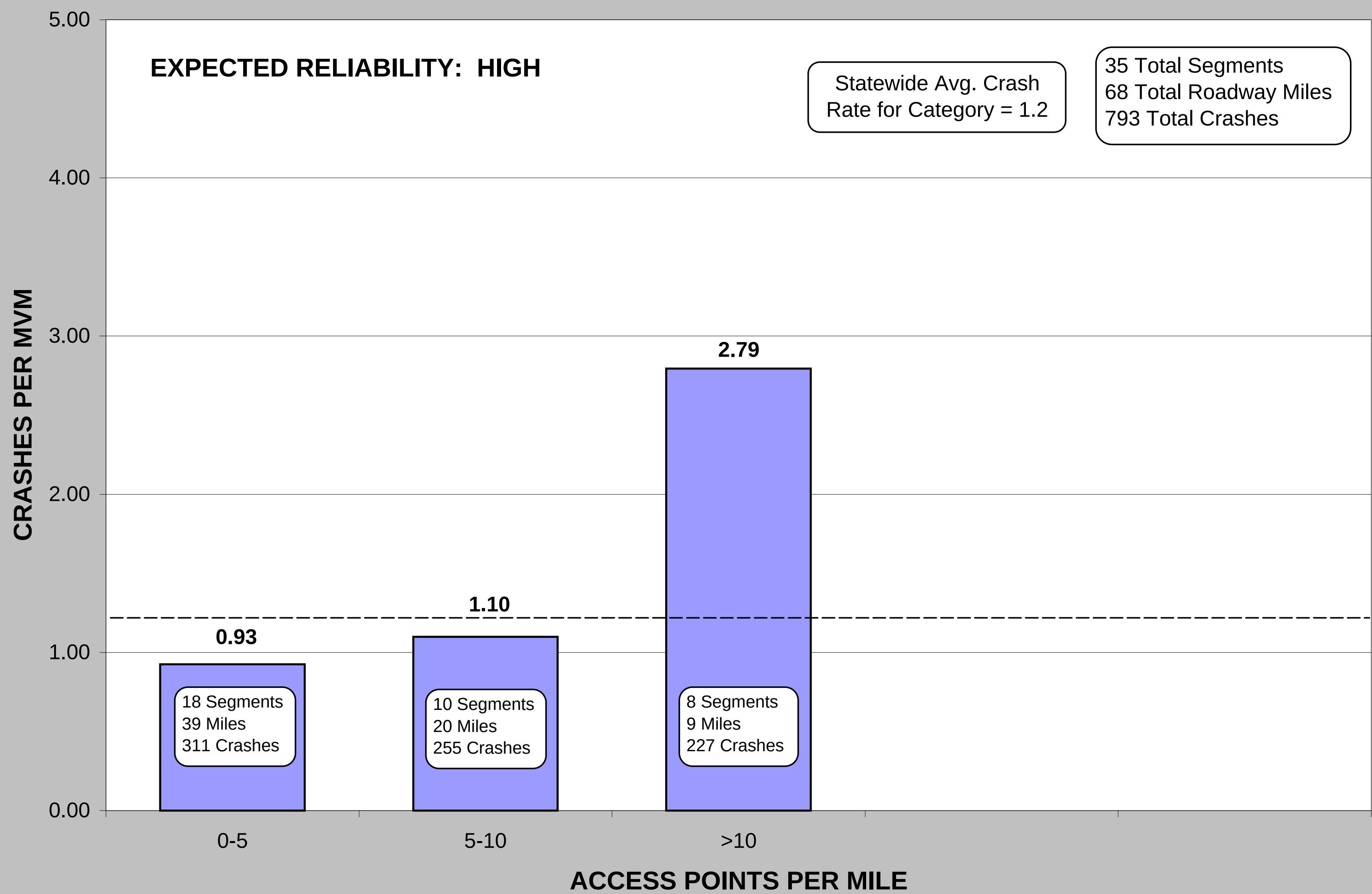


Figure 3-10

4 Lane Rural Conventional Roadways (RC4)

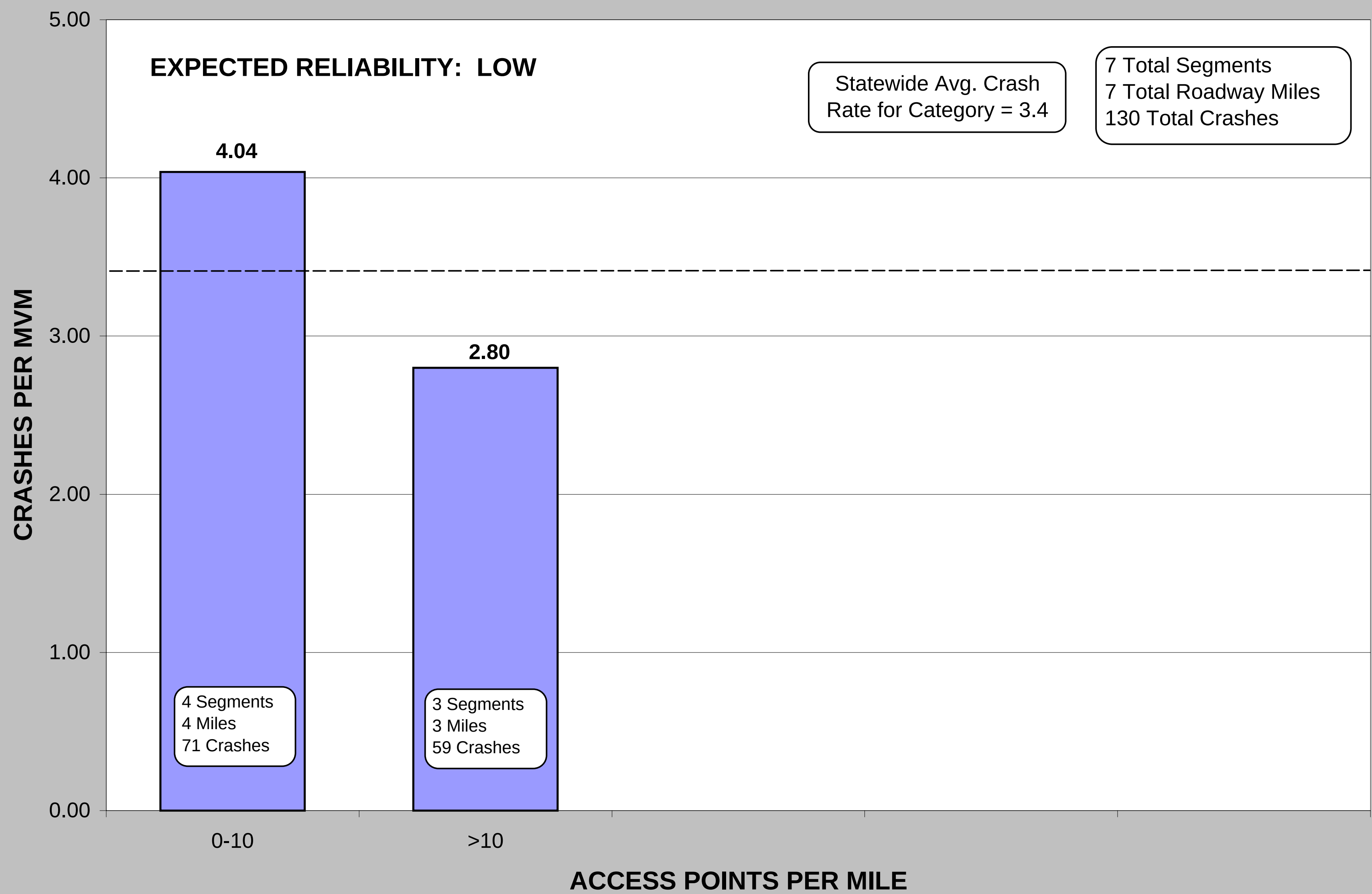


Figure 3-11

6 Lane Rural Conventional Roadways (RC6)

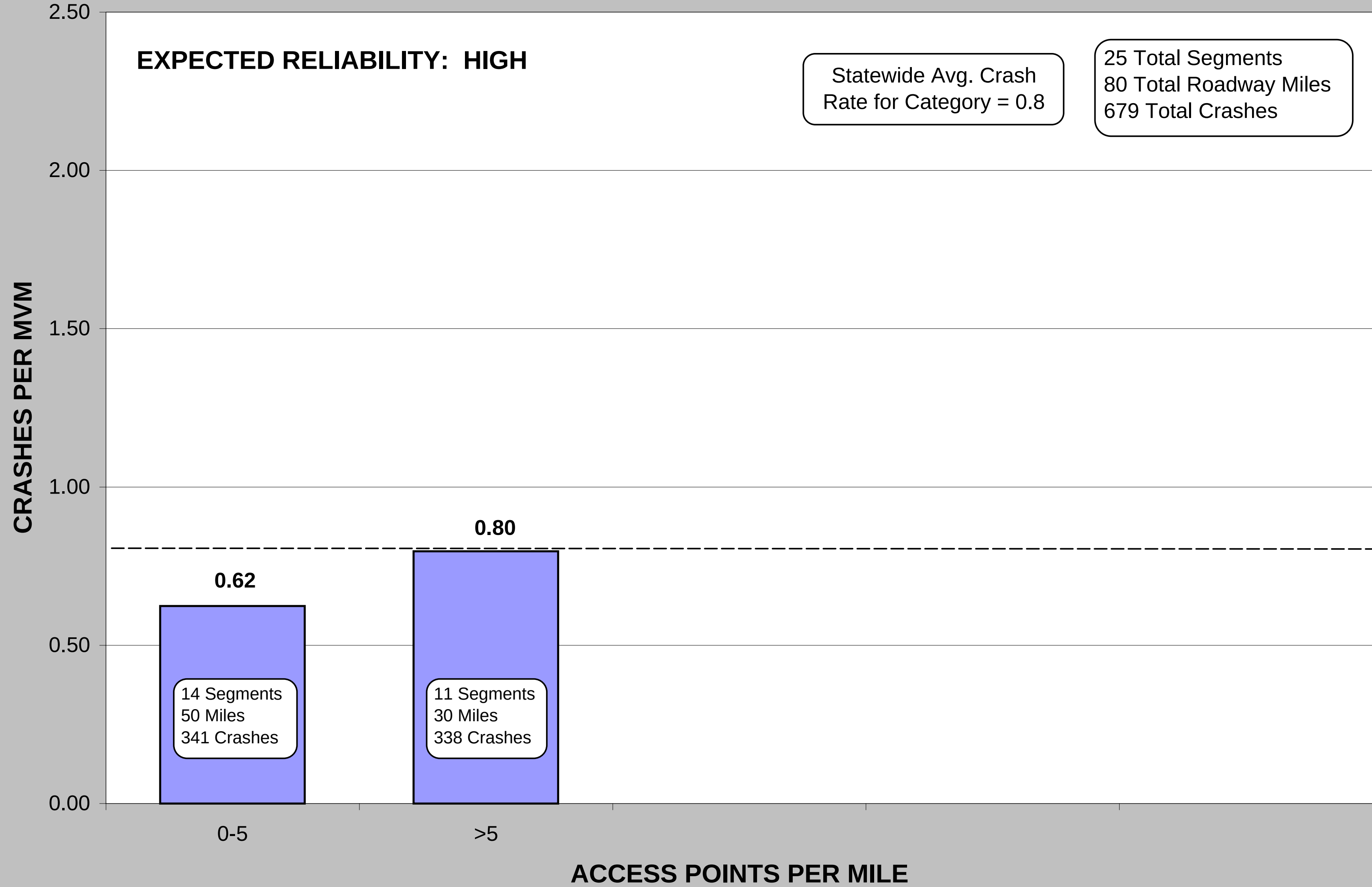


Figure 3-12

4 Lane Rural Expressway (RE4)

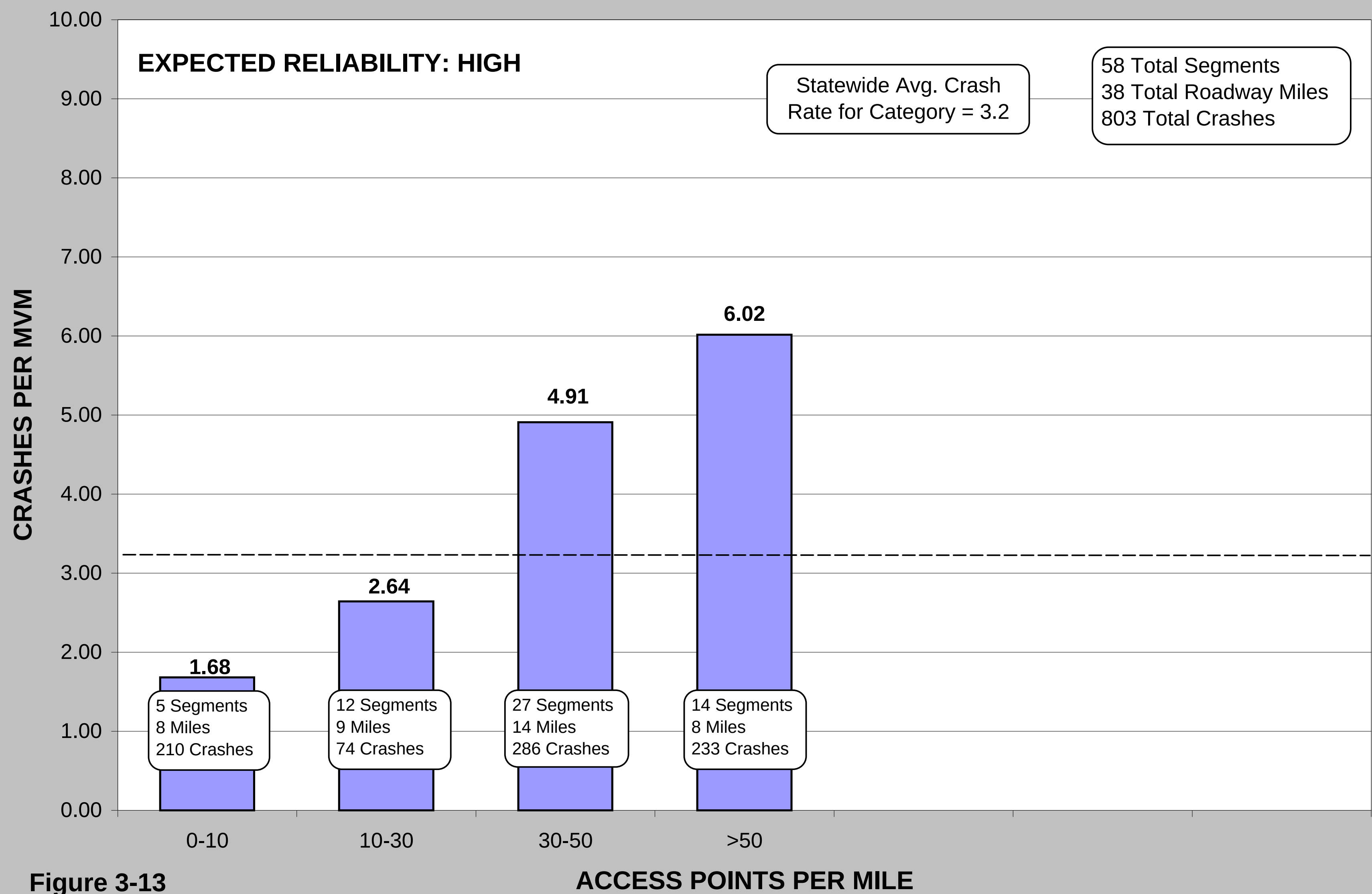


Figure 3-13

2 Lane Urban Conventional Roadways with No Left Turn Lanes (UC2NLT)

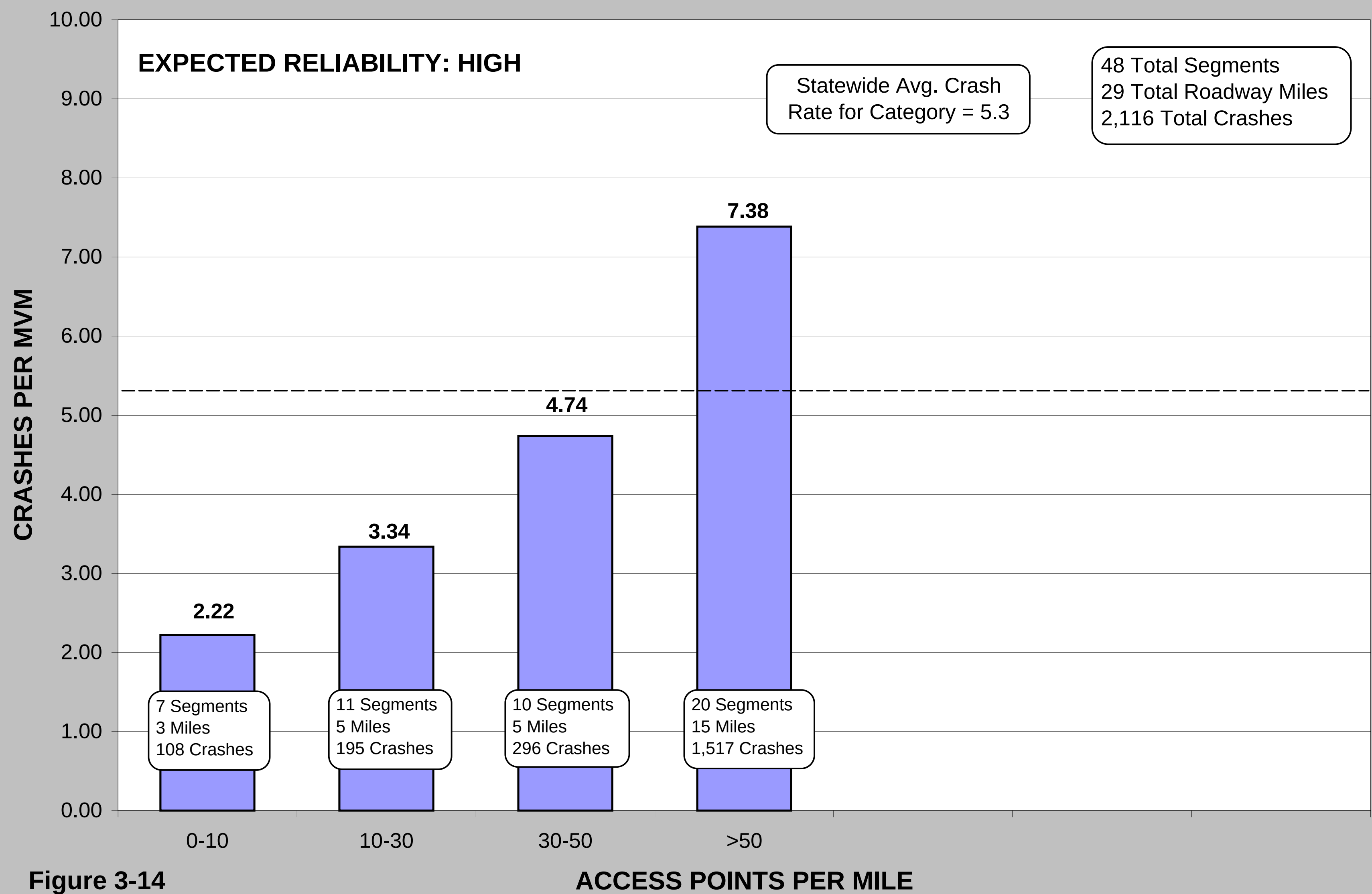


Figure 3-14

4 Lane Urban Conventional Roadways with No Left Turn Lanes (UC4NLT)

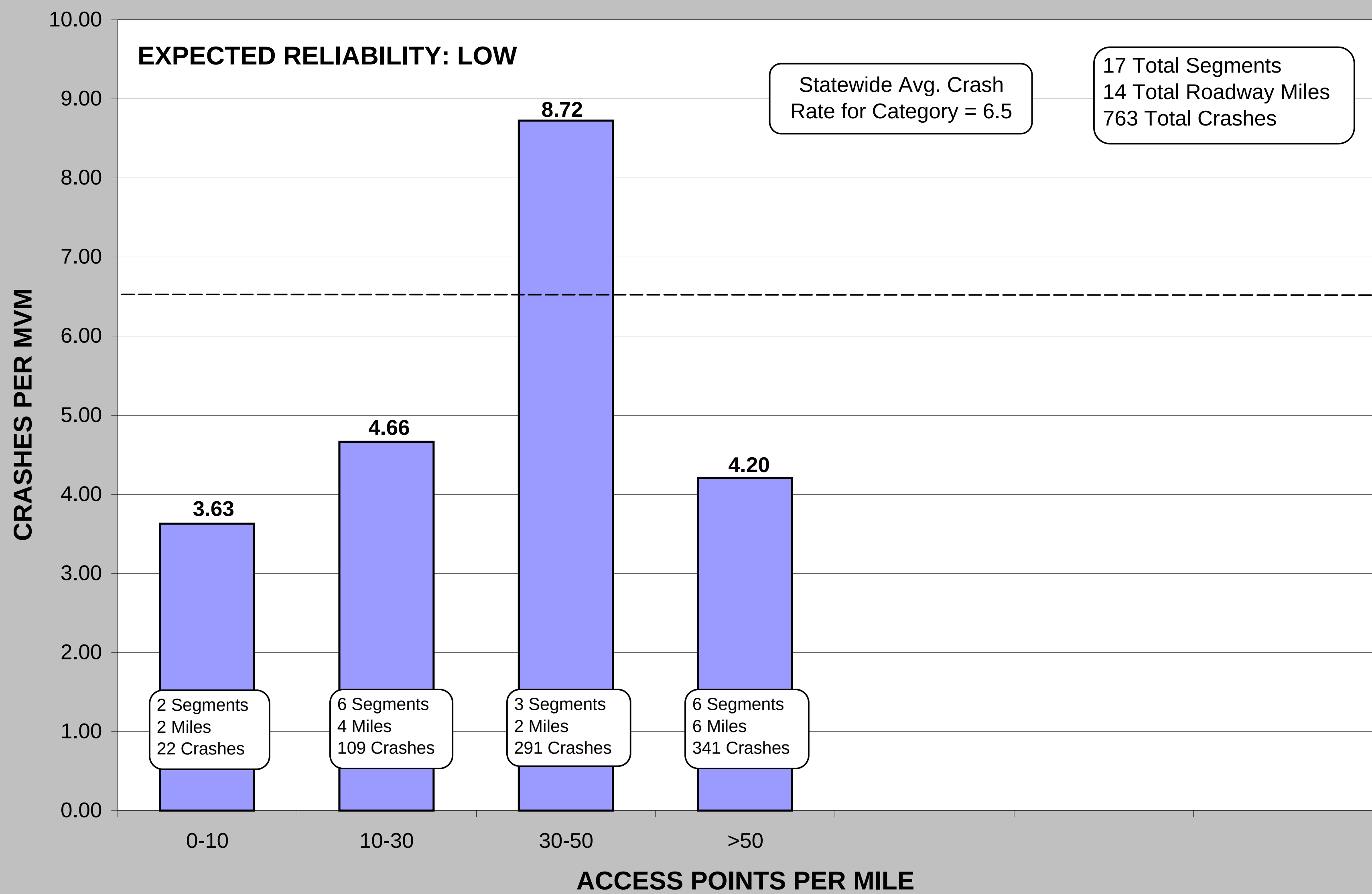


Figure 3-15

6 Lane Urban Conventional Roadways (UC6)

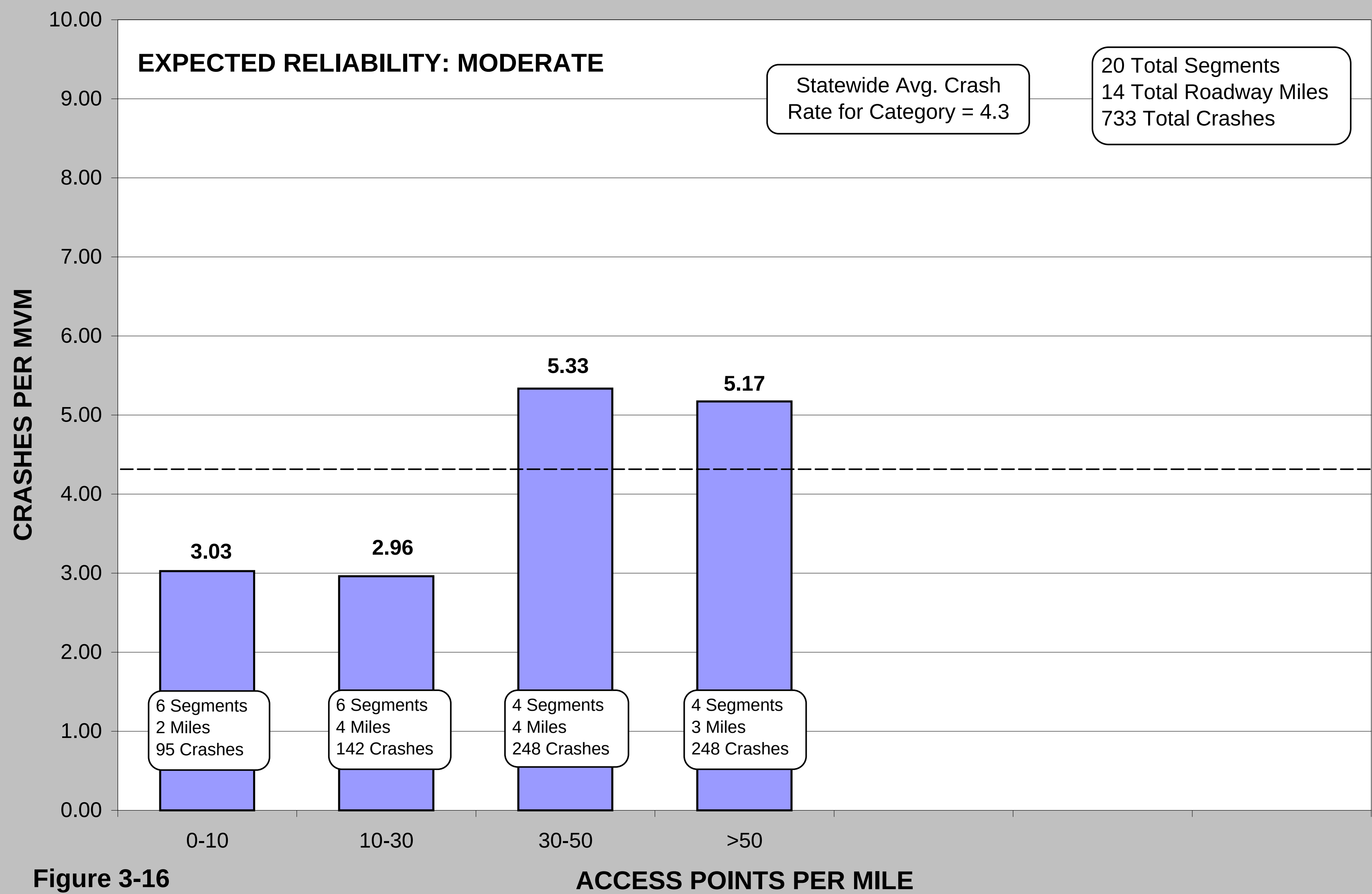


Figure 3-16

2 Lane Urban Conventional Roadways with Left Turn Lanes (UC2LT)

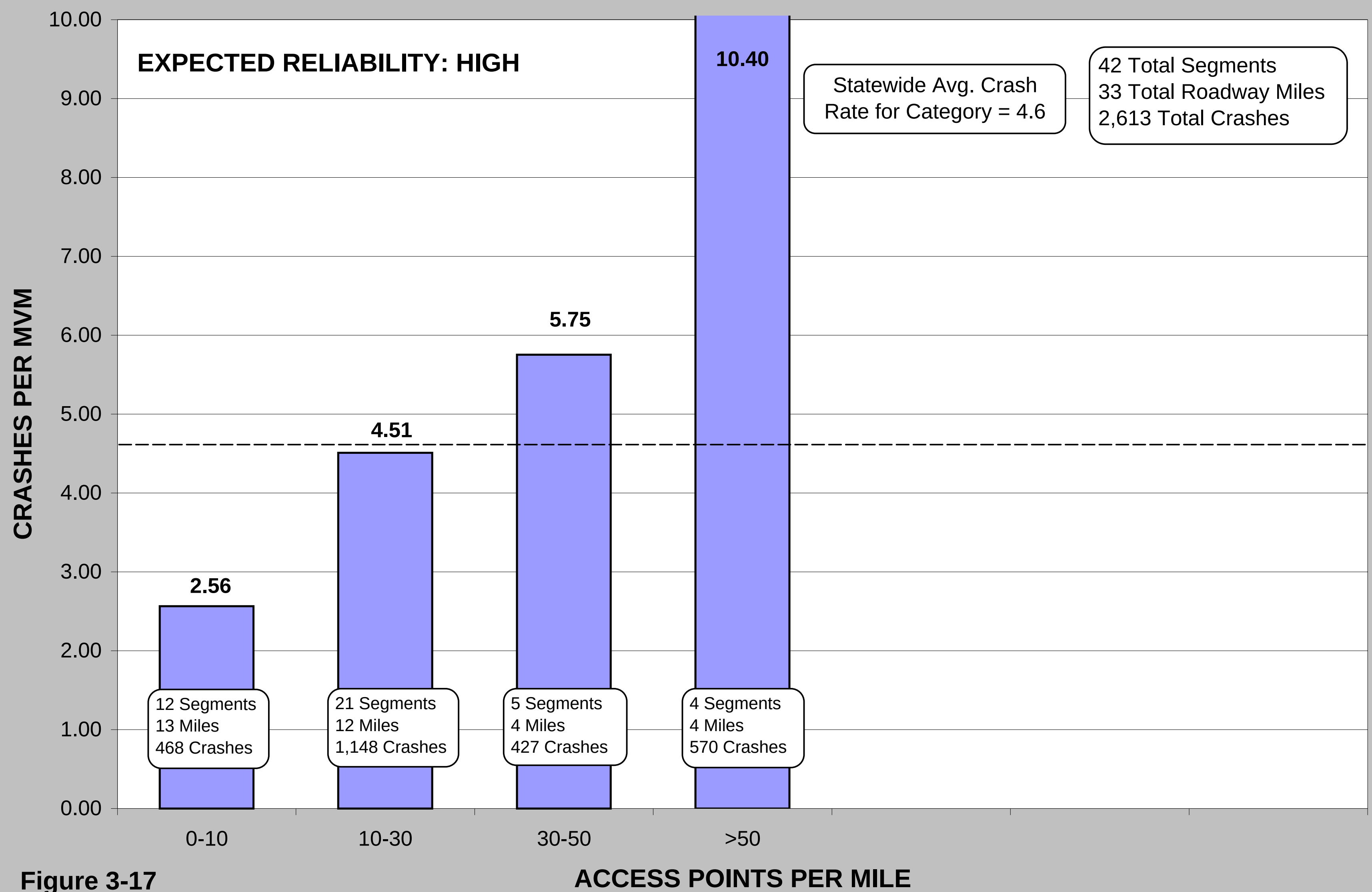


Figure 3-17

4 Lane Urban Conventional Roadways with Left Turn Lanes (UC4LT)

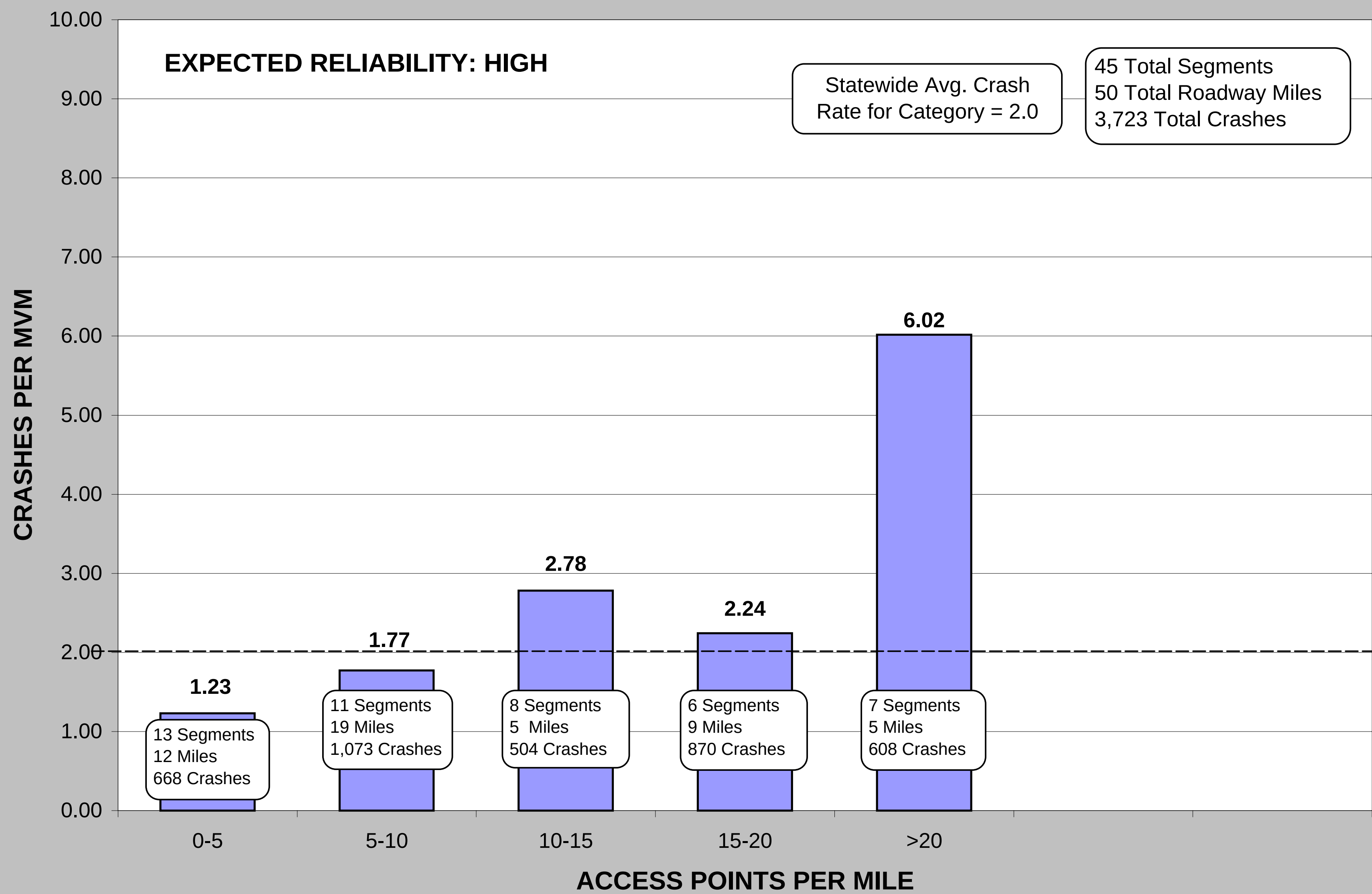


Figure 3-18

4 Lane Urban Expressway (UE4)

DATA FOR ACCESS SUMMARY CHARTS AND CRASH SUMMARY CHARTS												
DATA FROM SAMPLE												
CAT	**TOT Crash**	**TOT VMT**	**AVG Crash Rate (MVM)**	**Statewide Crash Rate**				**TOTAL ACCESS**	**TOTAL LENGTH**	**AVG ACC DEN**	**TOTAL STREET**	**TOTAL COMM**
R1	1,191	1,128,564,274	1.06	1.10	No LT Lanes	2-Lane	Rural	3,458	411.7	8.4	791	203
R2	156	83,056,317	1.88	1.90	w\ LT Lanes	2-Lane	Rural	256	20.7	12.4	71	14
R3	793	649,624,150	1.22	1.20		4-Lane	Rural	355	67.8	5.2	205	33
R4	130	38,662,887	3.36	3.40		6-Lane	Rural	66	6.8	9.7	33	3
R5	679	970,463,154	0.70	0.80		Expressway	Rural	452	79.6	5.7	204	57
RURAL	2,949	2,870,370,782	1.03	1.04		Total	Rural	4,587	586.7	7.8	1,304	310
U1	803	249,783,522	3.21	3.20	No LT Lanes	2-Lane	Urban	1,424	38.4	37.1	496	318
U2	2,116	374,996,762	5.64	5.30	No LT Lanes	4-Lane	Urban	1,295	28.7	45.1	449	639
U3	763	143,946,394	5.30	6.50		6-Lane	Urban	544	13.9	39.1	162	214
U4	733	173,768,250	4.22	4.30	w\ LT Lanes	2-Lane	Urban	433	13.6	31.7	169	96
U5	2,613	566,070,057	4.62	4.60	w\ LT Lanes	4-Lane	Urban	697	33.3	21.0	355	293
U7	3,723	1,818,912,787	2.05	2.00		Expressway	Urban	565	49.9	11.3	362	135
URBAN	10,751	3,327,477,772	3.23	3.10		Total	Urban	4,958	177.9	27.9	1,993	1,695

4.0 Additional Technical Analysis

In the previous chapter a strong relationship was observed between roadway access and crash rate. In order to further understand this relationship additional analysis was performed. The goal was to determine if the relationship between access density and crash rate is a result of other variables or dependent on other variables. The purpose of this chapter is to discuss each additional analysis and document its findings.

4.1 Volume

As noted above one of the important goals of the additional analysis was to determine if other segment variables account for the observed relationship of access density and crash rate. Traffic volume or ADT is a variable that has been previously suggested as possibly affecting crash rates.

The effect of traffic volume on crash rate is not well understood. Since the computation for crash rate corrects for volume it could be assumed that the crash rate would remain constant across all volume levels. However, different schools of thought produce different arguments for the effects of traffic volume on crash rate. One school of thought says that with increasing volumes there is greater opportunity for vehicular conflict and as a result crash rates will increase. An alternative school of thought argues that with increasing congestion speeds tend to decrease and possible crashes are therefore avoided. This would then lead to a decrease in the expected crash rate. These varying views of the effects of traffic volume make it an important variable to consider in this analysis.

In order to observe the effect of traffic volume on crash rate the crash rate for varying levels of volume for both rural and conventional roads was plotted. These charts are presented as Figures 4-1 and 4-2. The figure for rural conventional roads shows that there is very little change in crash rate across the different levels of traffic volume. The one exception to this is the second lowest category (1000 to 3000 ADT) where there appears to be a significant decrease in the crash rate. The figure of the urban conventional roads shows that the crash rate is fairly consistent across every level of traffic volume expect the lowest (0 to 3000 ADT). These figures suggest that traffic volume has little to no effect on the crash rate except at the lowest levels of traffic volume. This result of the traffic volume / crash rate analysis suggests that traffic volume does not effect the access density / crash rate relationship.

4.2 Speed Limit

Another variable that could account for the access density / crash rate relationship is segment speed limit. The effect of speed on the crash rate is also not well known. In an effort to better understand the vehicular speed / crash rate relationship and examine if it effects the access density / crash rate relationship several figures relating speed limit to access density and crash rate were created. Only figures for urban roadways were analyzed because there was little to no variance of speed limit on the rural segments (most rural segments had speed limits of 55 mph).

Figure 4-3 shows the crash rate for each speed limit. This figure shows a relationship that is not intuitively expected. In fact it shows a fairly strong negative observed relationship between speed limit and crash rate (crash rate decreased as the speed limit increased). Because this result was not expected further analysis was conducted, including documenting the speed limit / access density relationship shown in Figure 4-4. This figure shows a considerable negative observed relationship between speed limit and access density (access density decreased as the speed limit increased). It is also interesting to note that in both figures the highest speed limits (45, 50, and 55 mph) have corresponding values that are well below the averages for both average access density and average crash rate.

As noted previously, it is not intuitively obvious that higher speed limits result in lower crash rates. However, it is possible that this observed relationship between speed limit and crash rate is accounted for in other variables such as access density. A reasonable hypothesis for this would be that Mn/DOT is already applying some level of access management on roadways with higher speed limits.

4.3 Access Type

Up to this point, only the total number of access points and the overall effect they have on the crash rate have been analyzed. To further understand the access density / crash rate relationship it is also important to study the effects of individual types of access. As noted in the discussion on data collection the following types of access were inventoried:

- Public Streets
- Commercial Driveways

- Residential Driveways
- Field Access Driveways
- Other Access Points (access points that couldn't be qualified)

It was noted in the initial presentation of the access data that Public and Commercial access points were the most common in urban areas and that Residential and Public access points were the most common in rural areas.

Figure 4-5 shows the crash rate for different residential access density groups for the Rural 2-Lane with No Left Turn Lane category. The figure shows that there is only a slight change in the crash rate for the highest level of residential access density. This was the only access type plotted in this manner for this category because the other access types rarely had access densities of over five per mile.

Figure 4-6 shows the crash rate for different types of accesses across several levels of access density for the Urban 2-Lane with Left Turn Lane category. This figure shows that there are considerable positive differences in the crash rates between the highest and lowest levels of both public street and commercial accesses. However, there is very little difference in crash rate between the different levels of residential access.

Figure 4-7 shows the crash rate for different types of accesses across several levels of access density for the Urban 4-Lane with Left Turn Lane category. This figure also shows that there are considerable positive differences in the crash rates between the highest and lowest levels of both public and commercial accesses. The different levels of residential access were not plotted on this chart because almost all of the segments in this category had residential access densities of less than five accesses per mile.

These figures show that in rural areas the positive observed relationship between access density and crash rate doesn't appear to be a function of any particular type of access. However in urban areas it does appear that the observed relationship between access density and crash rate is mainly a function of public street and commercial driveway access.

4.4 Single Vehicle / Multiple Vehicle Crashes

All of the preceding analysis has dealt with the total number of crashes in each segment. As with studying the different types of access, an analysis of different types of crashes may lead to a better understanding of the access density / crash rate relationship.

It was mentioned earlier that the expectation is that most single vehicle crashes are not access related. This is due to the assumption that access related crashes involve vehicles entering or leaving a roadway and that this corresponding movement causes the vehicle to come into conflict with another vehicle, therefore causing a crash. This assumption regarding the access density / crash rate relationship could lead to an expectation that there would be no observed relationship between access density and single vehicle crash rate. It is also expected that the positive observed relationship between access density and multiple vehicle crash rate would be similar if not more significant than the access density / crash rate observed relationship.

Before any analysis of single vehicle and multiple vehicle crashes could occur it was necessary to determine which types of crashes constituted single vehicle crashes and which types of crashes constituted multiple vehicle crashes. The crash database includes 15 different types of crashes and it was determined that 3 of the types describe multiple vehicle crashes, 10 of types describe single vehicle crashes, and 2 of the types could not be qualified. Once the breakdown of crash type was determined it was then necessary to tabulate the crashes for each segment in order to get a single vehicle and a multiple vehicle crash rate for each segment.

Figures 4-8 through 4-14 present the single vehicle, multiple vehicle, and total vehicle crash rates for each access density group. Only the roadway categories that had high expected reliabilities (from Figures 3-8 through 3-18) are presented with these figures. In reviewing each of these figures it is clear that access density and multiple vehicle crash rate have a strong positive observed relationship. It is also shown in these figures that the single vehicle crash rate remains fairly consistent across each access density group. These figures support the prediction stated earlier that accesses have a significant effect on multiple vehicle crashes but little to no effect on single vehicle crashes.

4.5 Best and Worst Segments

The final analysis of this data compared the ten best and ten worst segments from each of the roadway categories based on crash rate. It is important to note that some categories did not include 20 total segments therefore the category was split by the top and bottom 50 percent. Figure 4-15 shows the median crash rate for each of the roadway categories by best and worst segment. This figure documents the large difference in crash rate between the best and worst segments. Table 4-1 presents a few summary statistics for the best and worst segments in each category. From this table it can be seen that the splitting of the best and worst segments resulted in similar total miles of roadway.

Comparisons were made between the best and worst segments for such roadway variables as:

- Total Access
- Public Access
- Commercial Access
- Residential Access
- Type of Vehicular Crash
- Severity of Vehicular Crash
- Speed Limit
- ADT (Volume)

Each of the variables was compared using the median of the best and worst segments. This was done in order to reduce the effect that any single segment would have on the entire group of segments.

Comparison of the speed limit variable showed that the best and worst segments in the rural categories all had median speed limits of 55 mph. It also showed a tendency in urban categories for the best segments to have higher median speed limits than the worst segments. This result is comparable to the relationship discovered earlier between crash rate and speed limit. This result also supports the hypothesis that some level of access management is already being practiced on roadways with higher speed limits.

Comparison of the ADT variable showed that there was really no trend between the best and worst segments. In some cases the best segments had higher ADT's and in some cases they had lower ADT's, but in general the ADT's between the best and worst segments were fairly similar. This result is also comparable to the relationship discovered earlier between ADT and volume and supports the argument that crash rate remains constant across varying volumes.

Figures 4-16 through 4-18 present the comparisons of the best and worst segments for total access density, public street access density, and commercial driveway access density. Figure 4-16 shows that in almost every category the worst segments have higher total access densities. The only two exceptions to this were in categories with few sample segments. Figure 4-17 shows an equally strong relationship between the best and worst segments for public street access density. Figure 4-18 shows the commercial driveway access density for the best and worst segments. This figure shows that there is practically no commercial access in the rural segments. However, in the urban segments the best segments generally had no commercial access and the worst segments had a significant amount of commercial access. Each of these figures supports and strengthens the observed relationship between access density and crash rate. Furthermore the data in Figure 4-18 supports the previous hypothesis that commercial access is a problem in the urban areas but not in the rural areas.

The comparison of percentage of multiple vehicle crashes is shown in Figure 4-19. This figure shows that in all rural categories and most of the urban categories that the percentage of multiple vehicle crashes is higher on the worst segments than on the best segments. The large difference in percentage of multiple vehicle crashes between the best and worst segments in the rural categories is especially striking because of the large percentage of single vehicle crashes on rural roadways.

4.6 Summary

Throughout the additional technical analysis various roadway characteristics were studied in order to further understand the access density / crash rate relationship. In each case the positive observed relationship between access density and crash rate has remained. Furthermore, a better understanding of the type of access that effect the crash rate in rural and urban areas was determined. In summary, it is clear from this data that a positive observed relationship (crash rate increases with increasing access density) between access density and crash rate exists. In order to determine if higher access densities are a true cause of higher crash rates, subsequent chapters detail the actual effect of access management projects and test the statistical reliability of the data.

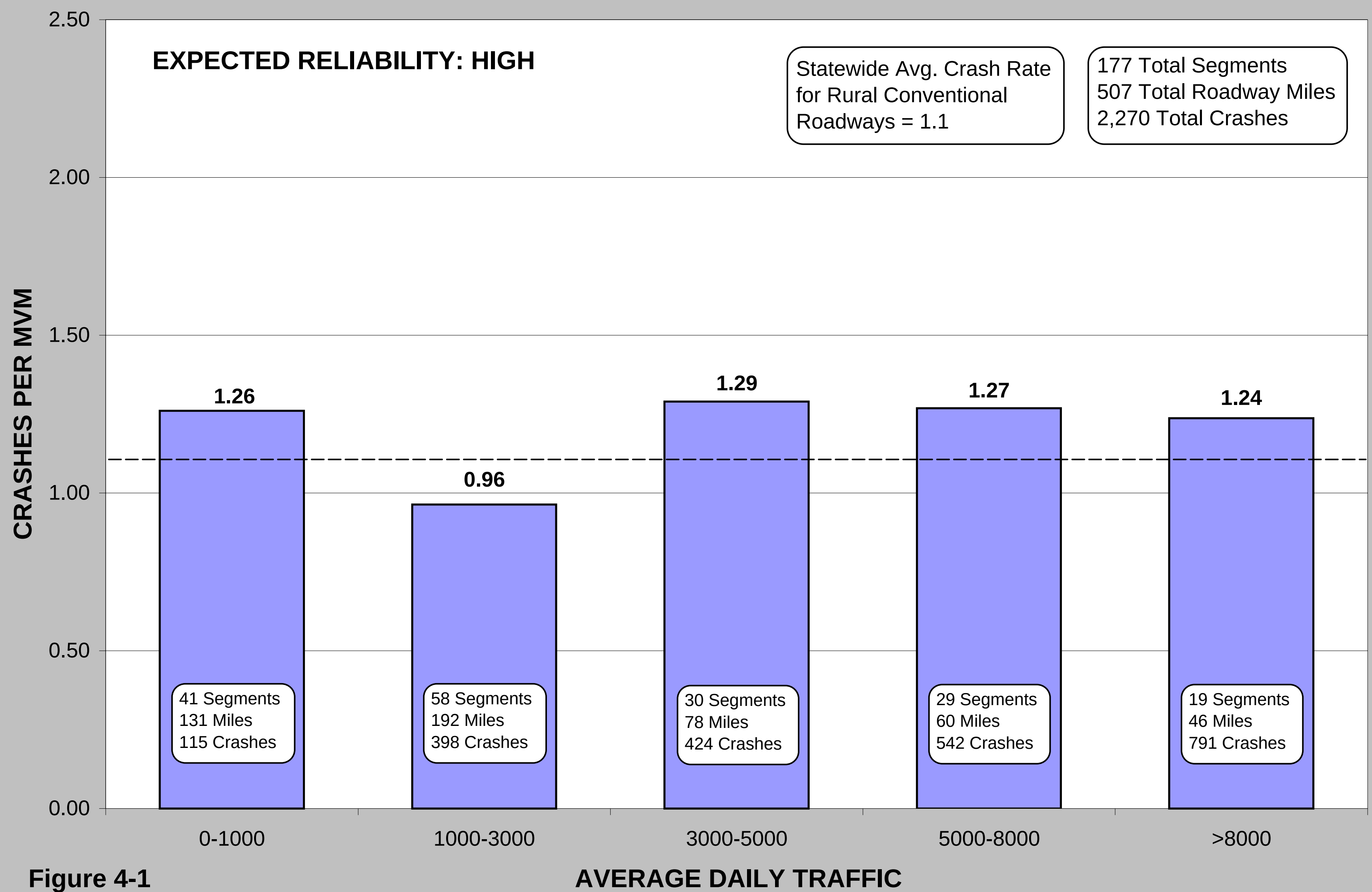


Figure 4-1

Rural Conventional Roadways (RC)
(Includes 2,4, and 6 Lane Roads)

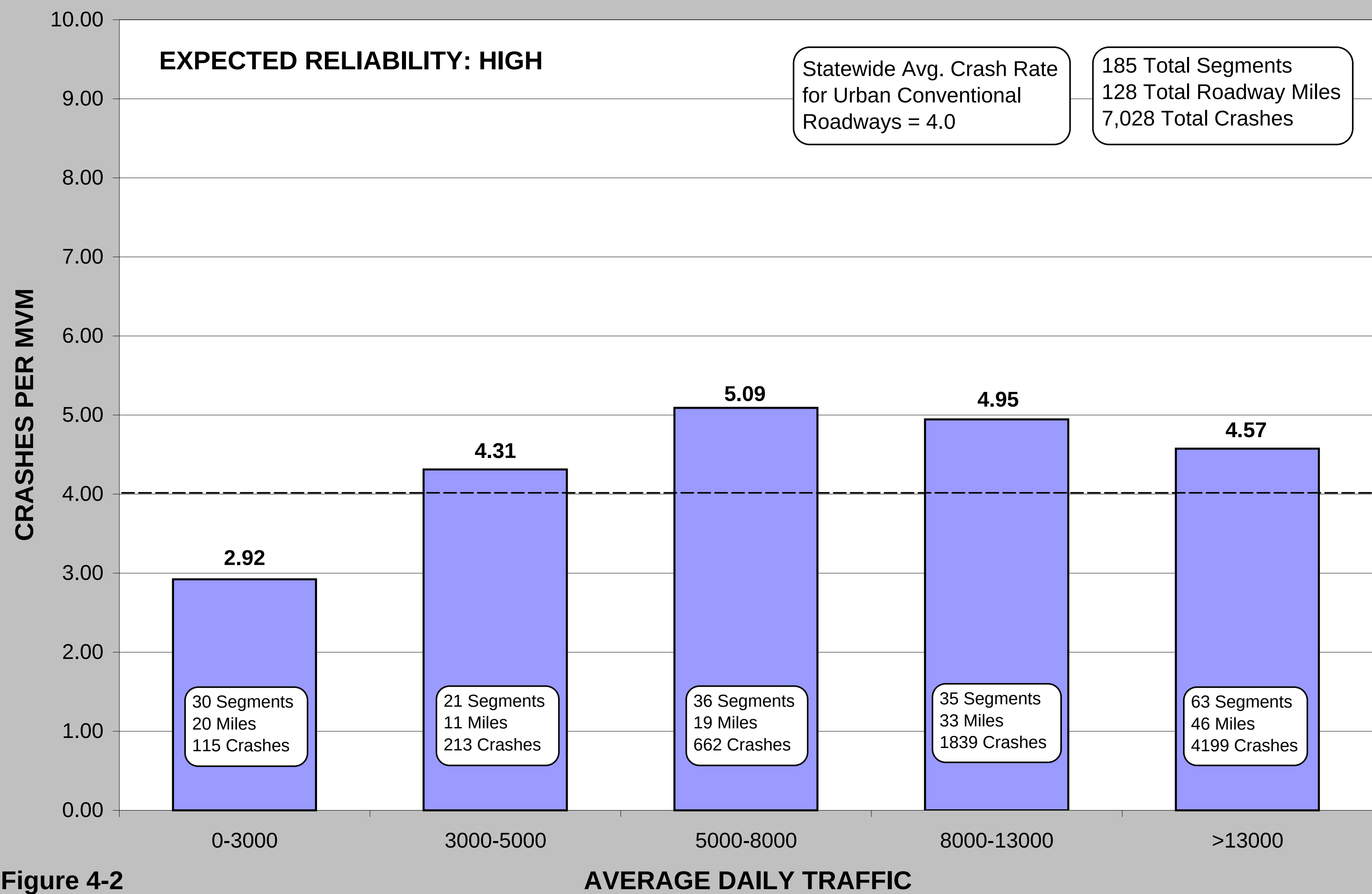
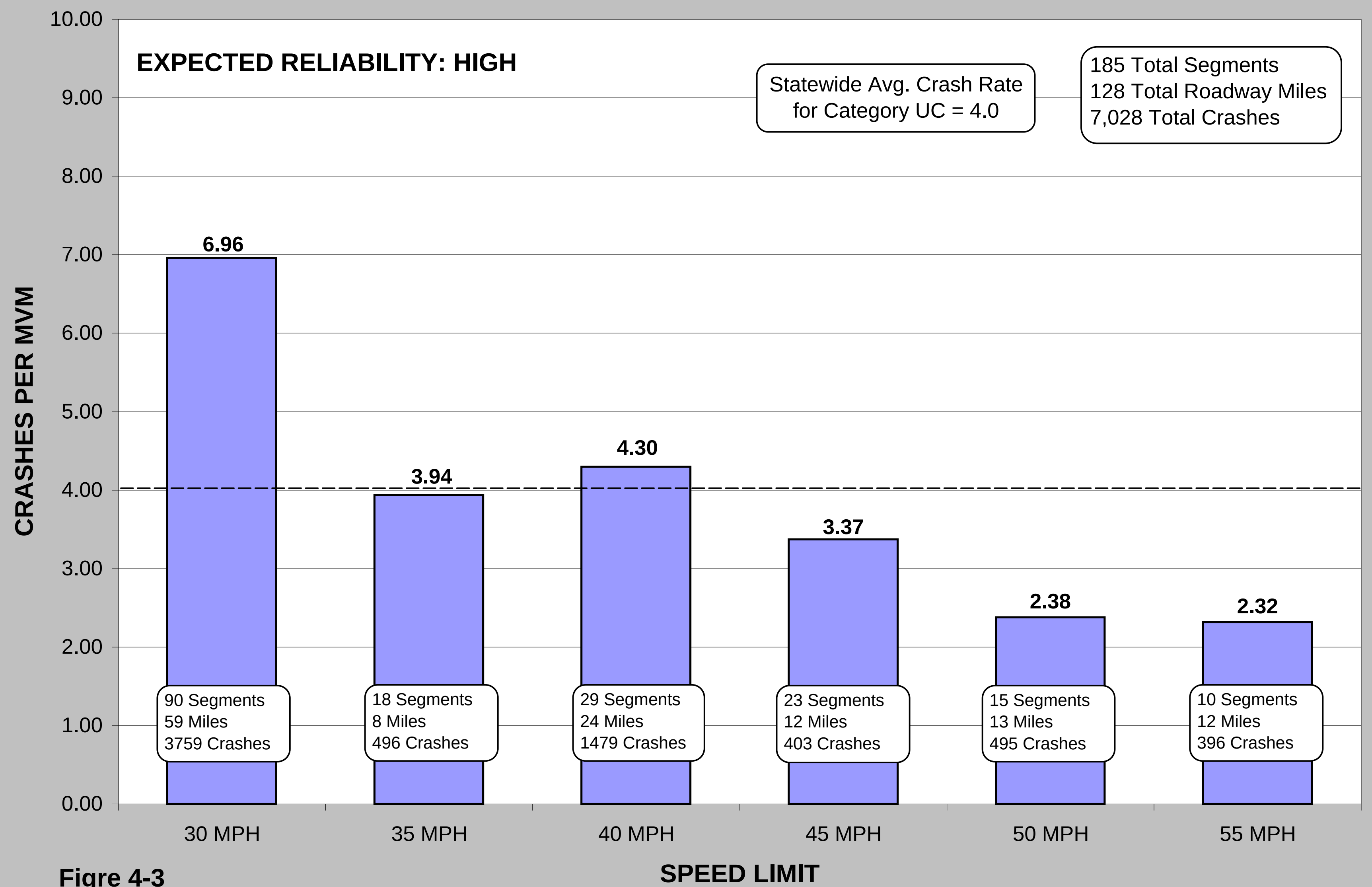


Figure 4-2

Urban Conventional Roadways (UC) (Includes 2,4, and 6 Lane Roads)



Figre 4-3

Urban Conventional Roadways (UC)
(Includes 2,4, and 6 Lane Roads)

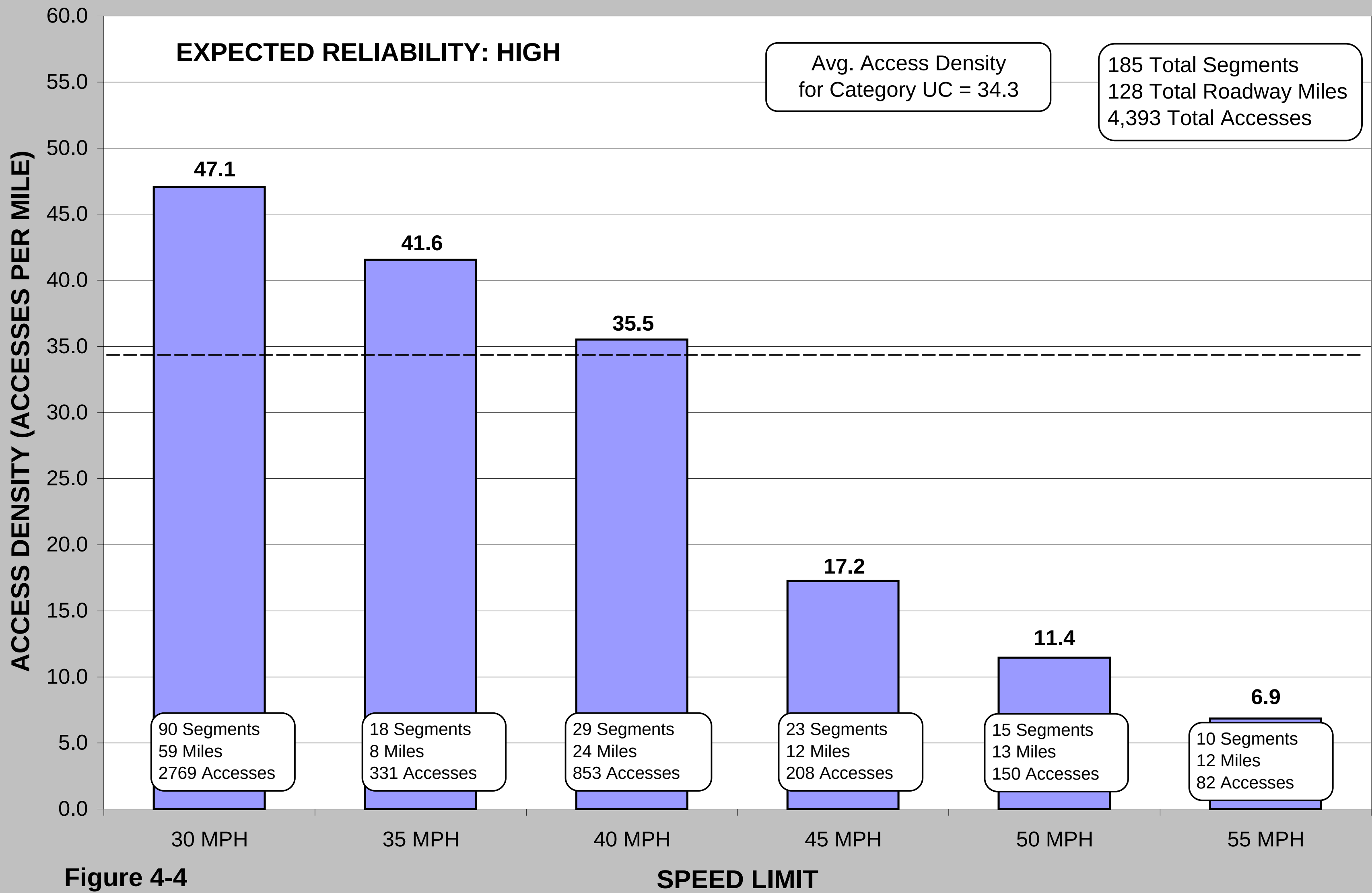


Figure 4-4

Urban Conventional Roadways (UC)
(Includes 2,4, and 6 Lane Roads)

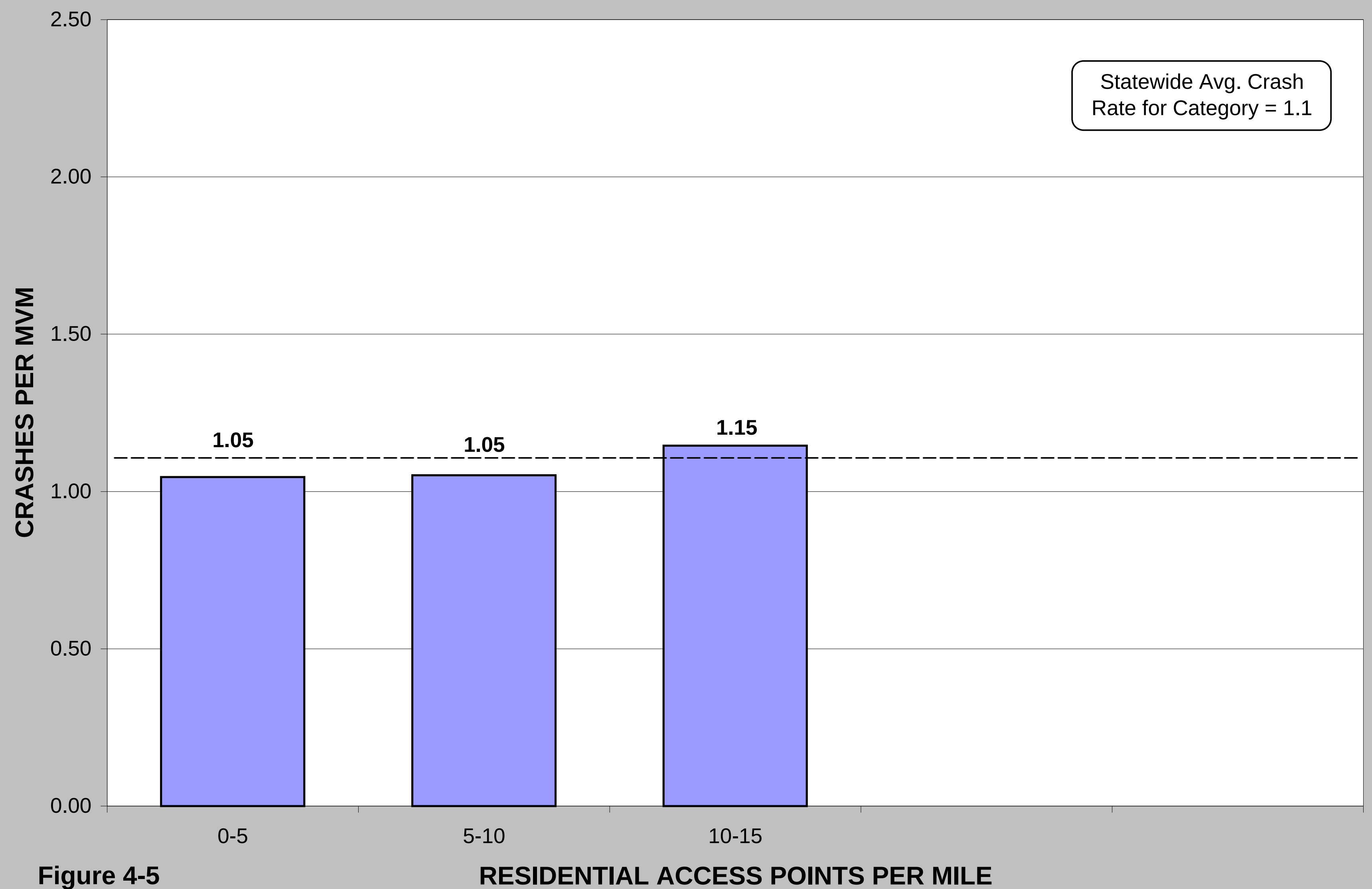


Figure 4-5

2 Lane Rural Conventional Roadways with No LT Lanes (RC2NLT)

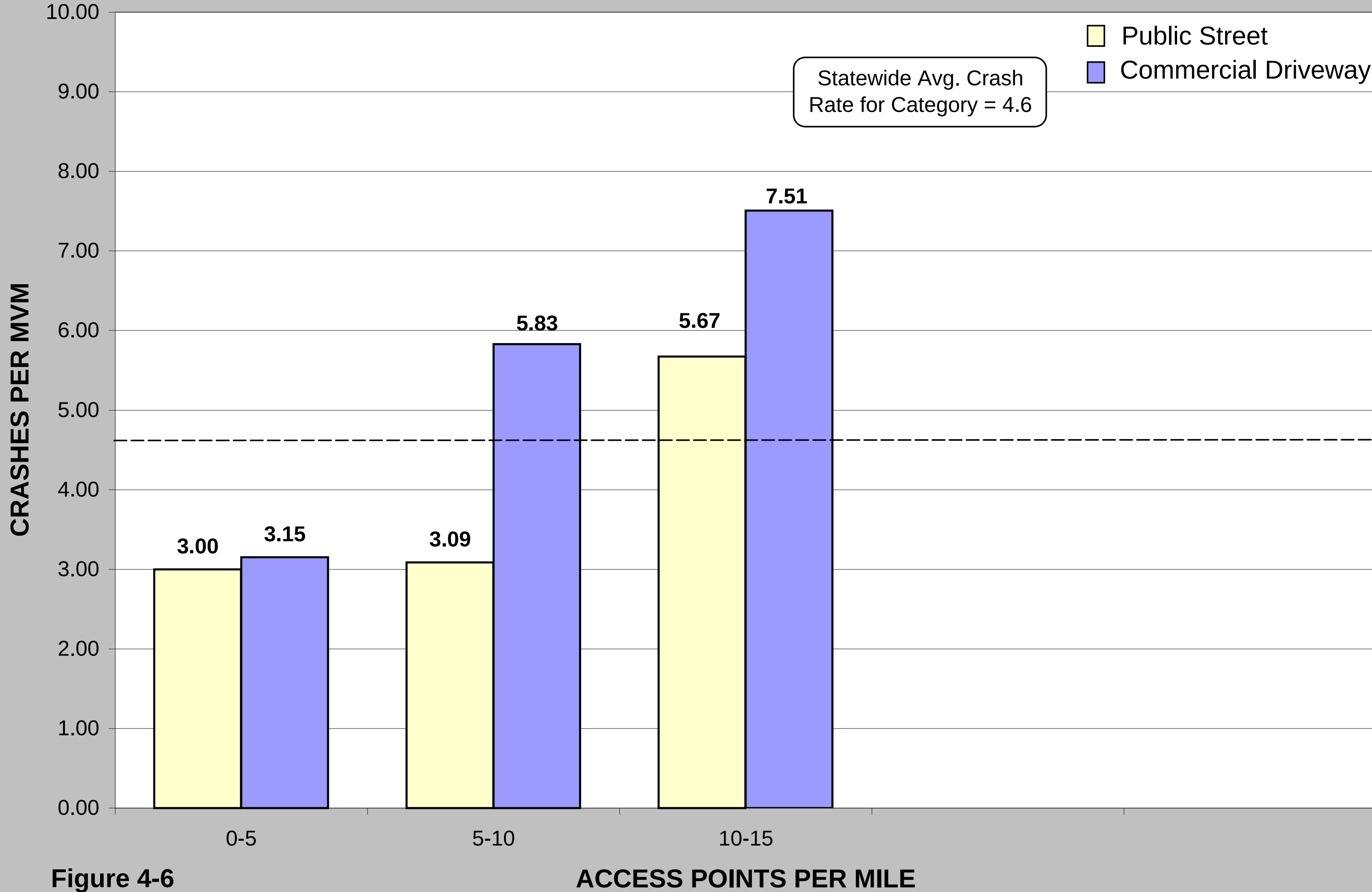


Figure 4-6

4 Lane Urban Conventional Roadways with Left Turn Lanes (UC4LT)

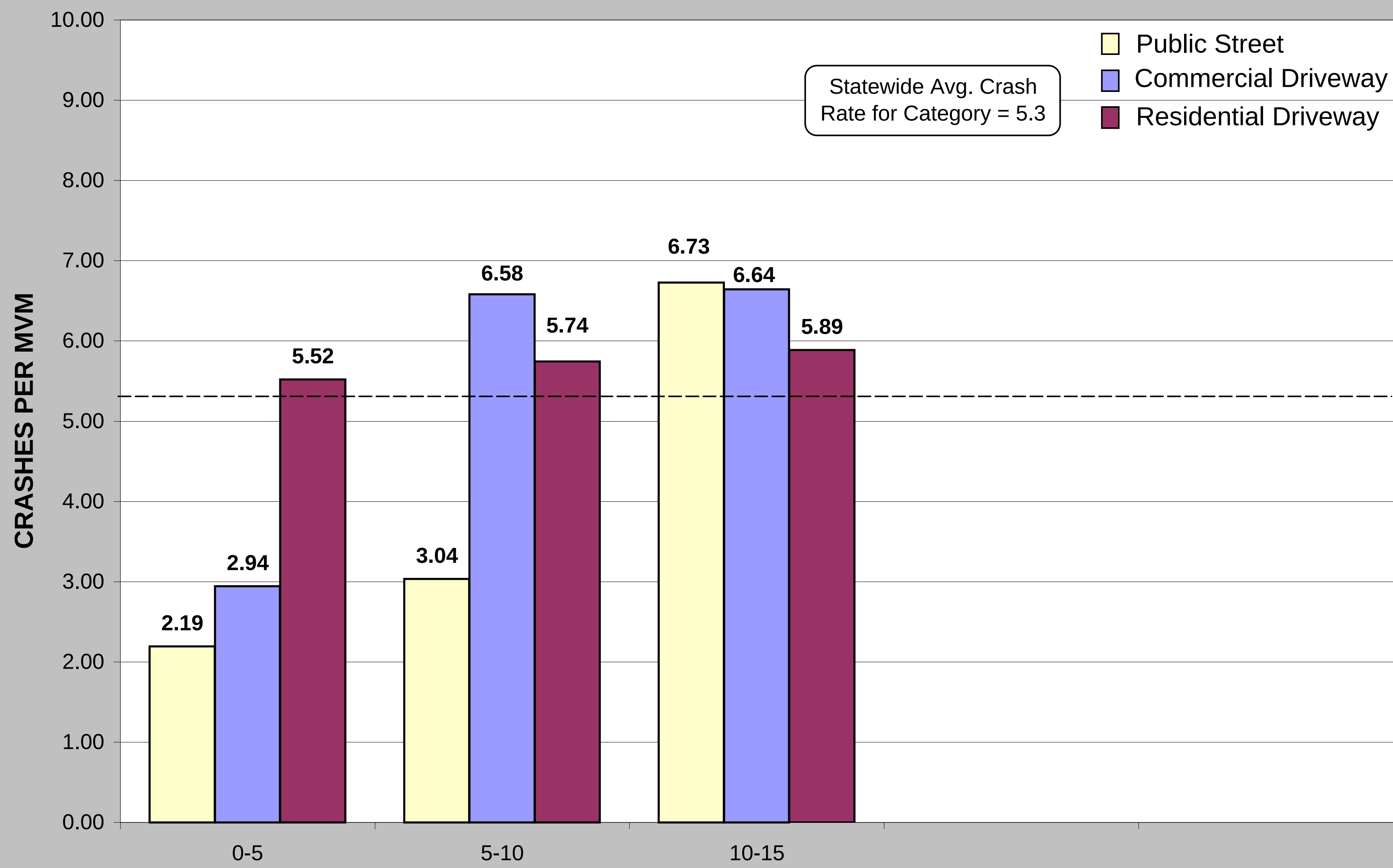


Figure 4-7

4 Lane Urban Conventional Roadways
with No Left Turn Lanes (UC4NLT)

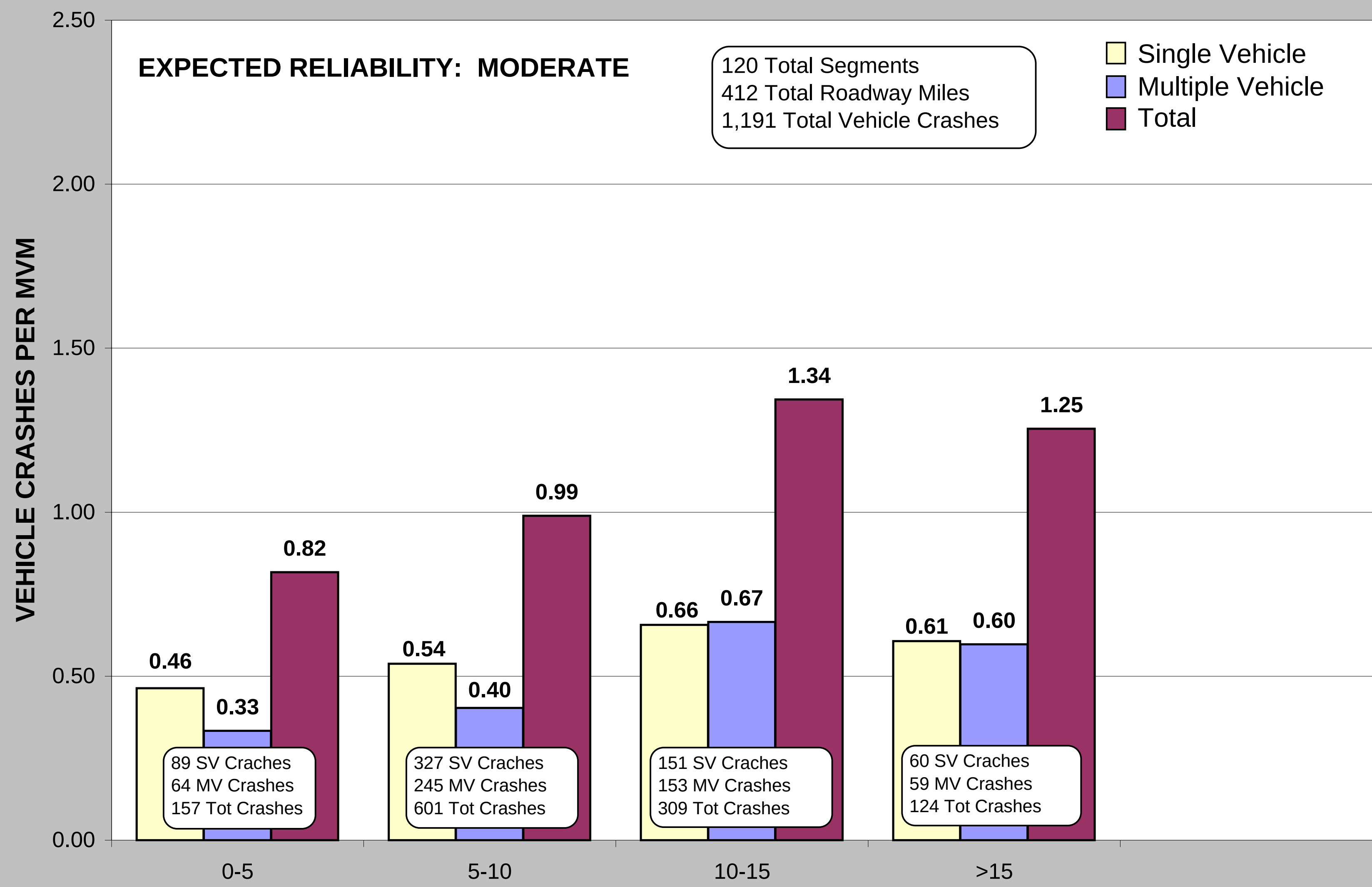


Figure 4-8

2 Lane Rural Conventional Roadways with No Left Turn Lanes (RC2NLT)

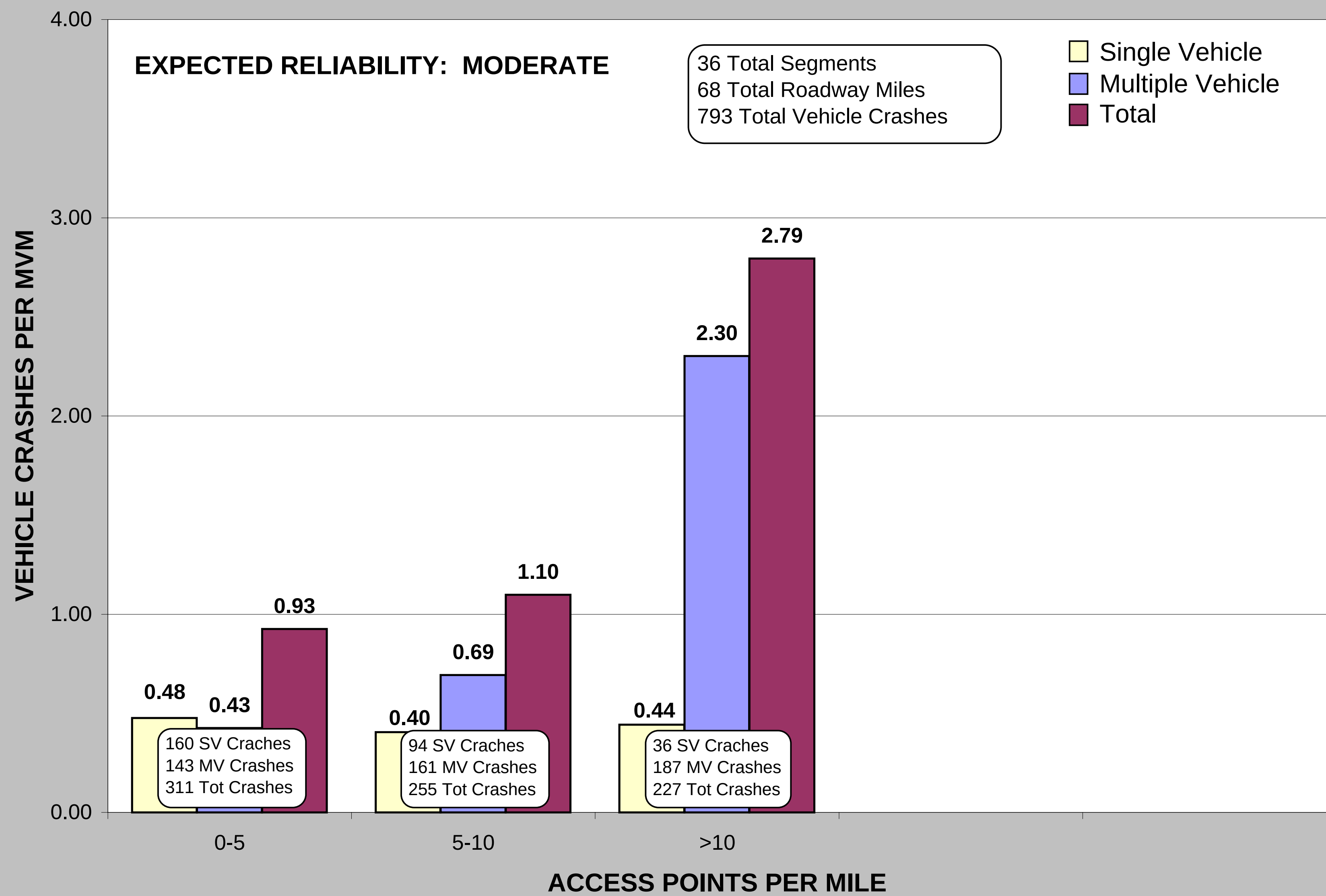


Figure 4-9

4 Lane Rural Conventional Roadways (RC4)

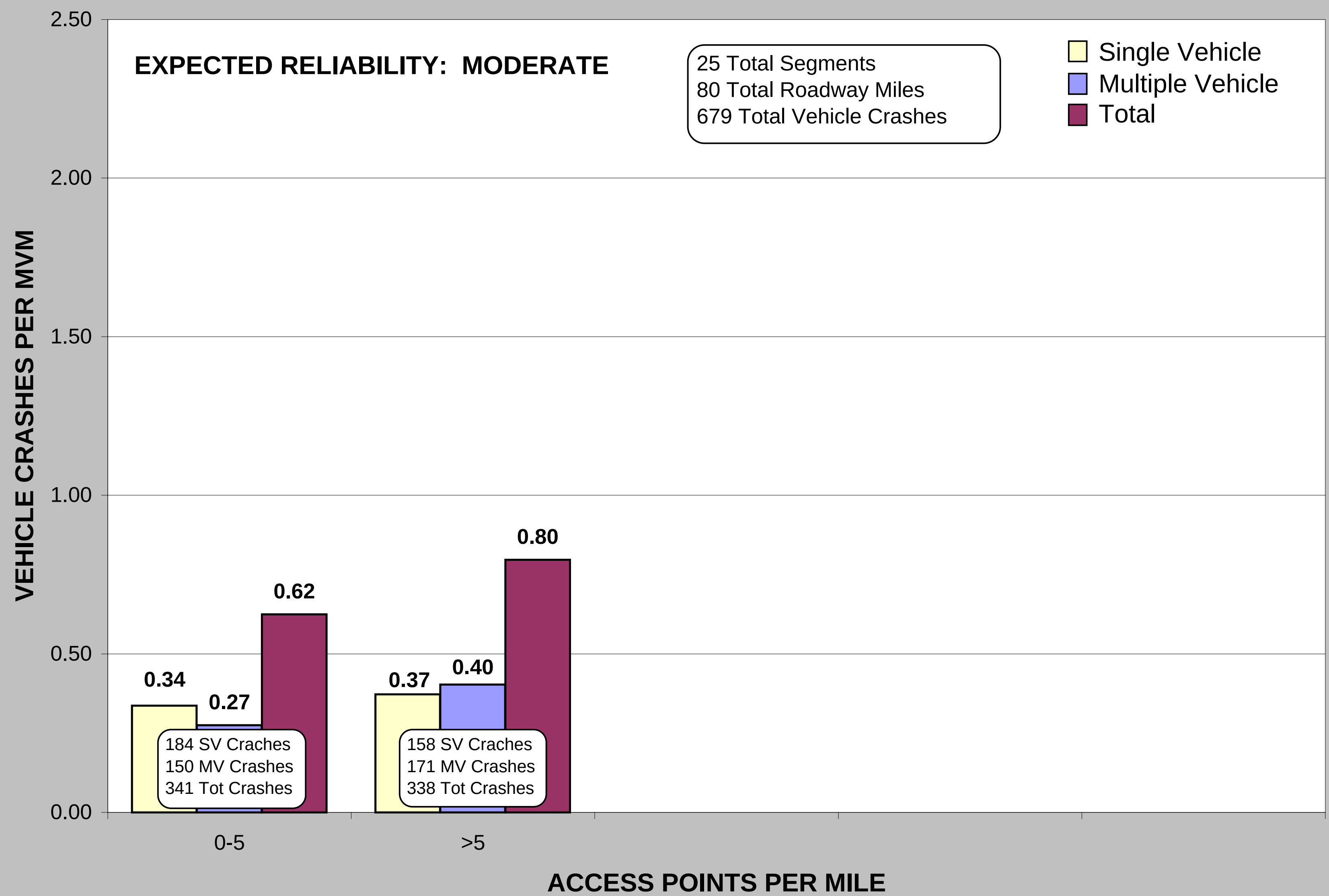


Figure 4-10

4 Lane Rural Expressway (RE4)

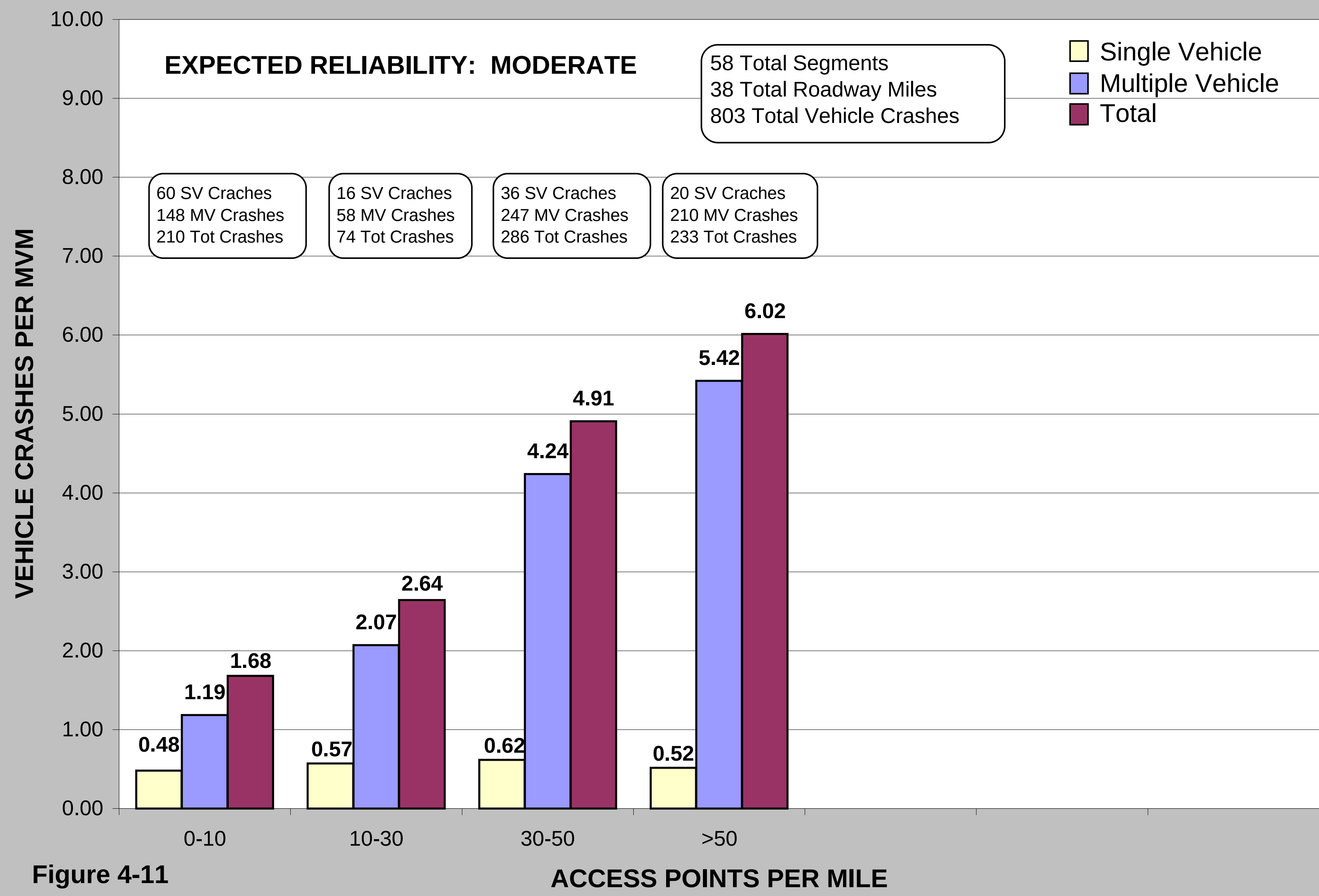


Figure 4-11

2 Lane Urban Conventional Roadways with No Left Turn Lanes (UC2NLT)

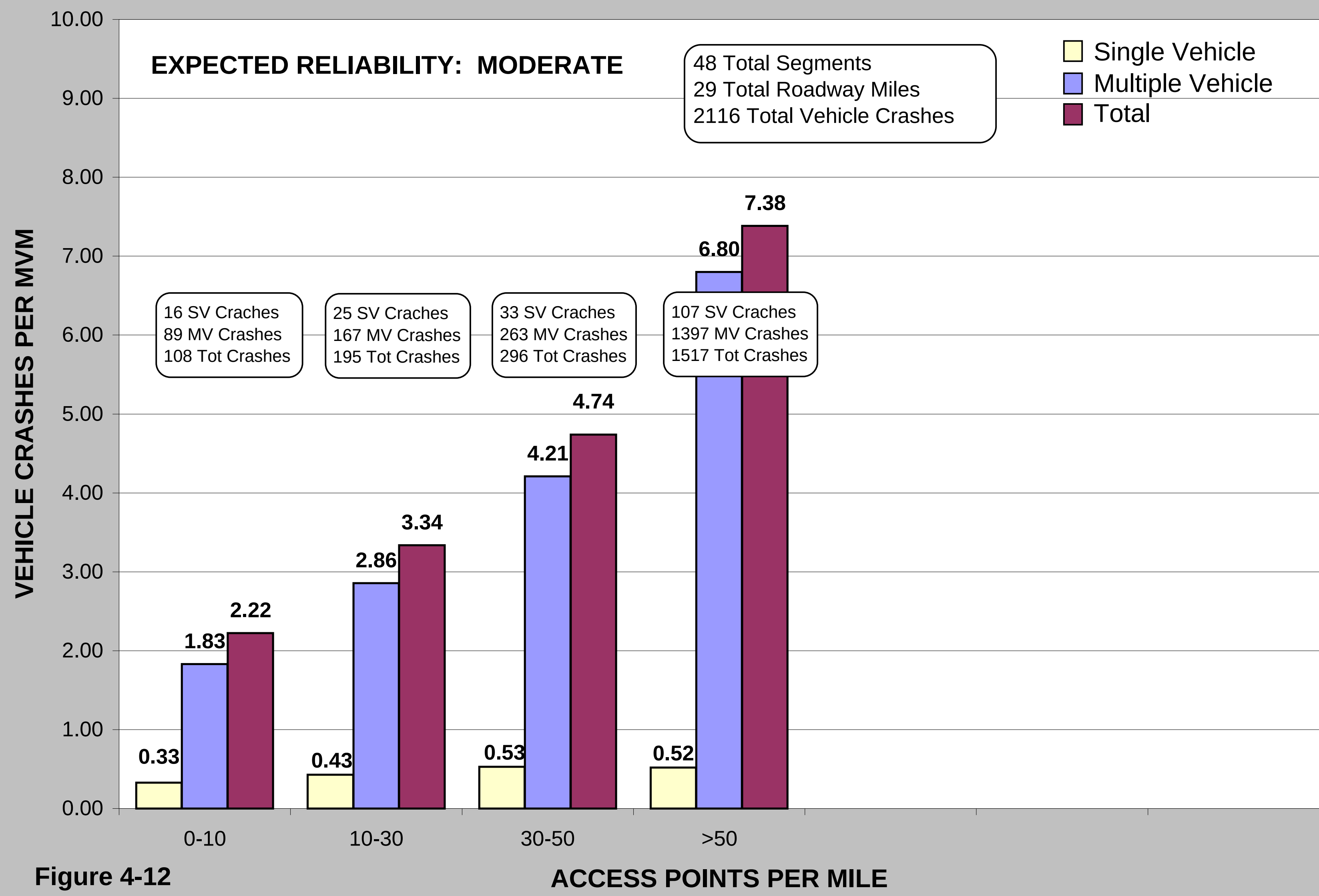


Figure 4-12

4 Lane Urban Conventional Roadways with No Left Turn Lanes (UC4NLT)

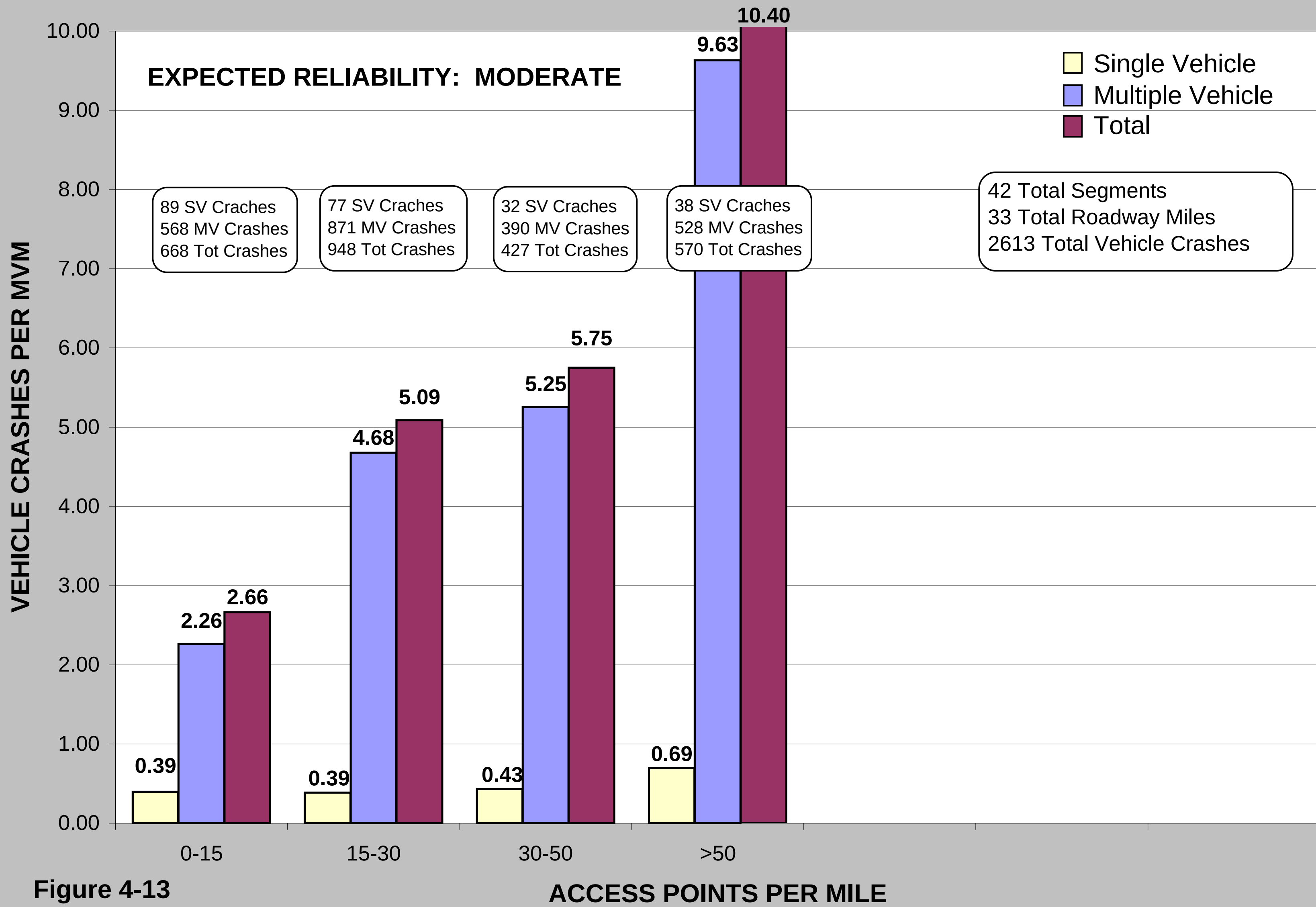


Figure 4-13

4 Lane Urban Conventional Roadways with Left Turn Lanes (UC4LT)

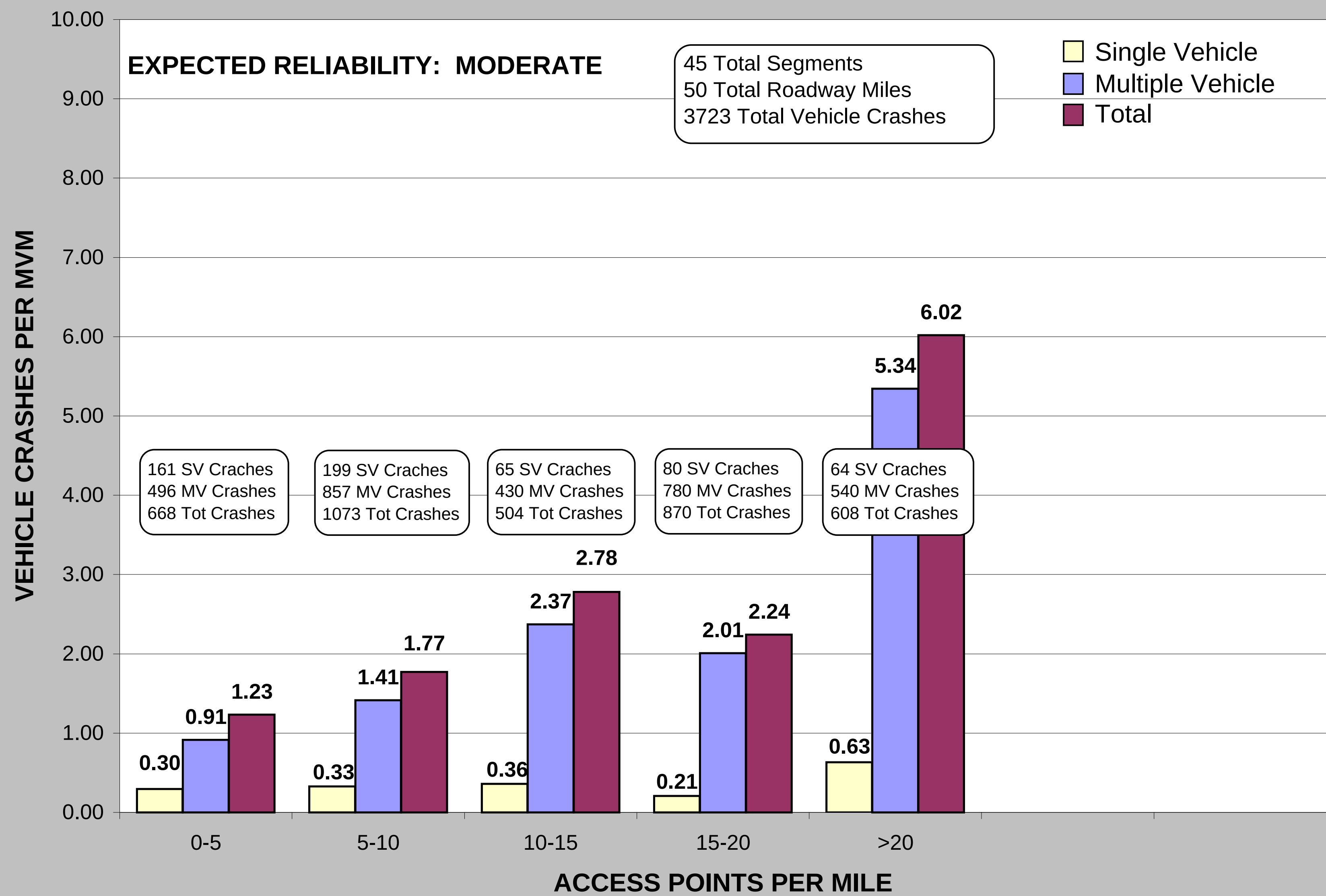


Figure 4-14

4 Lane Urban Expressway (UE4)

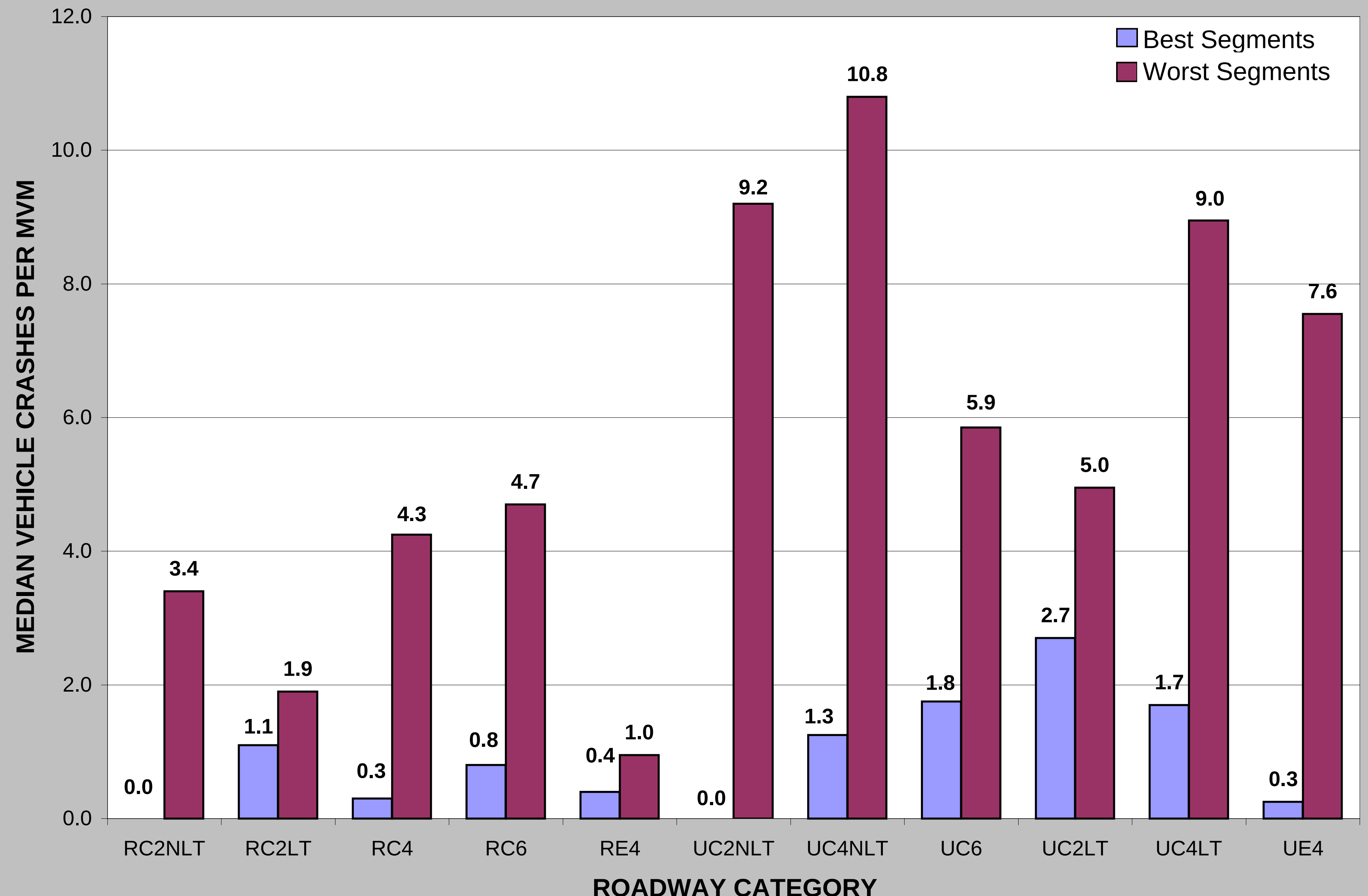


Figure 4-15

Median Crash Rate

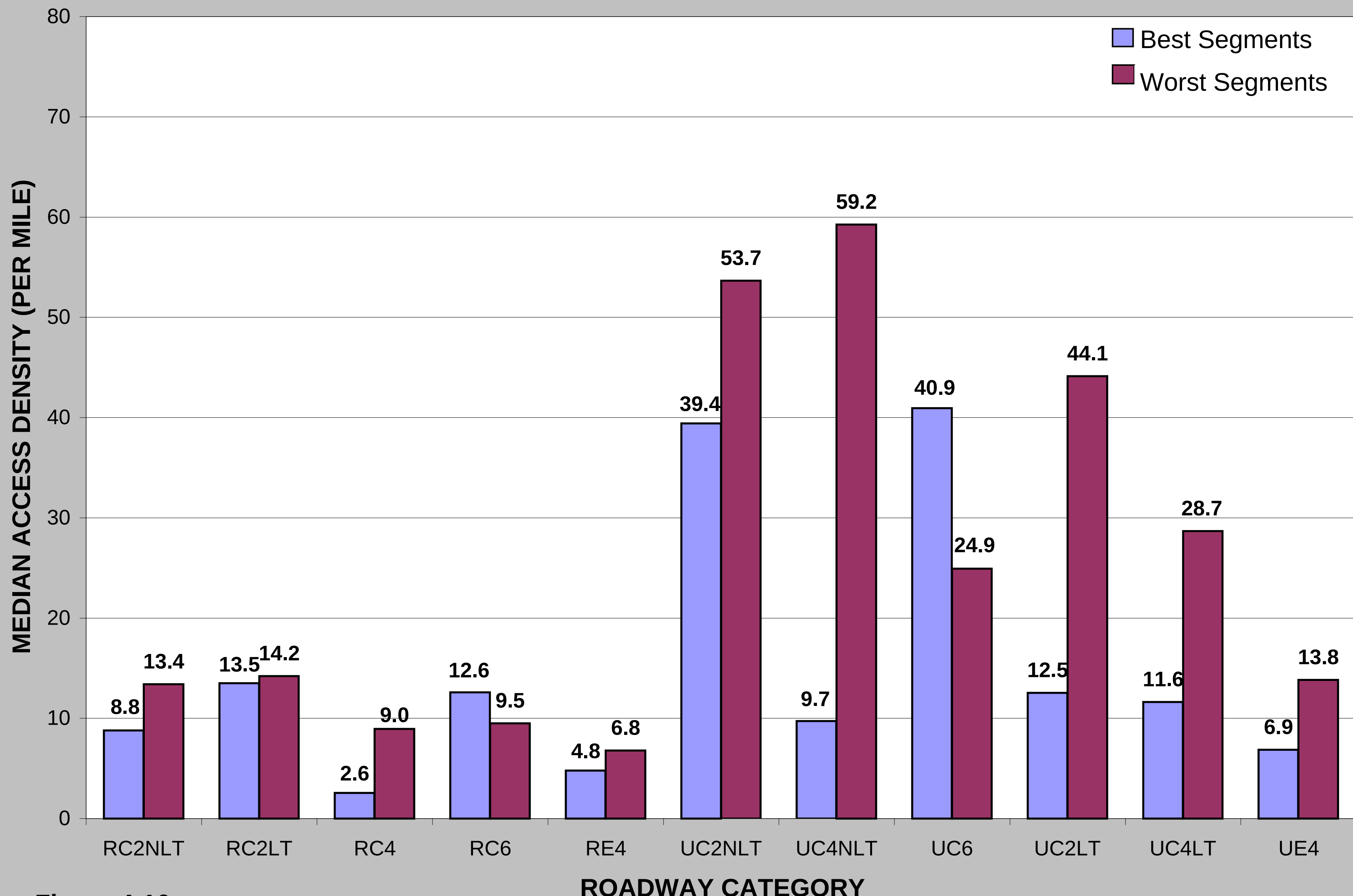


Figure 4-16

Median Access Density (per mile)

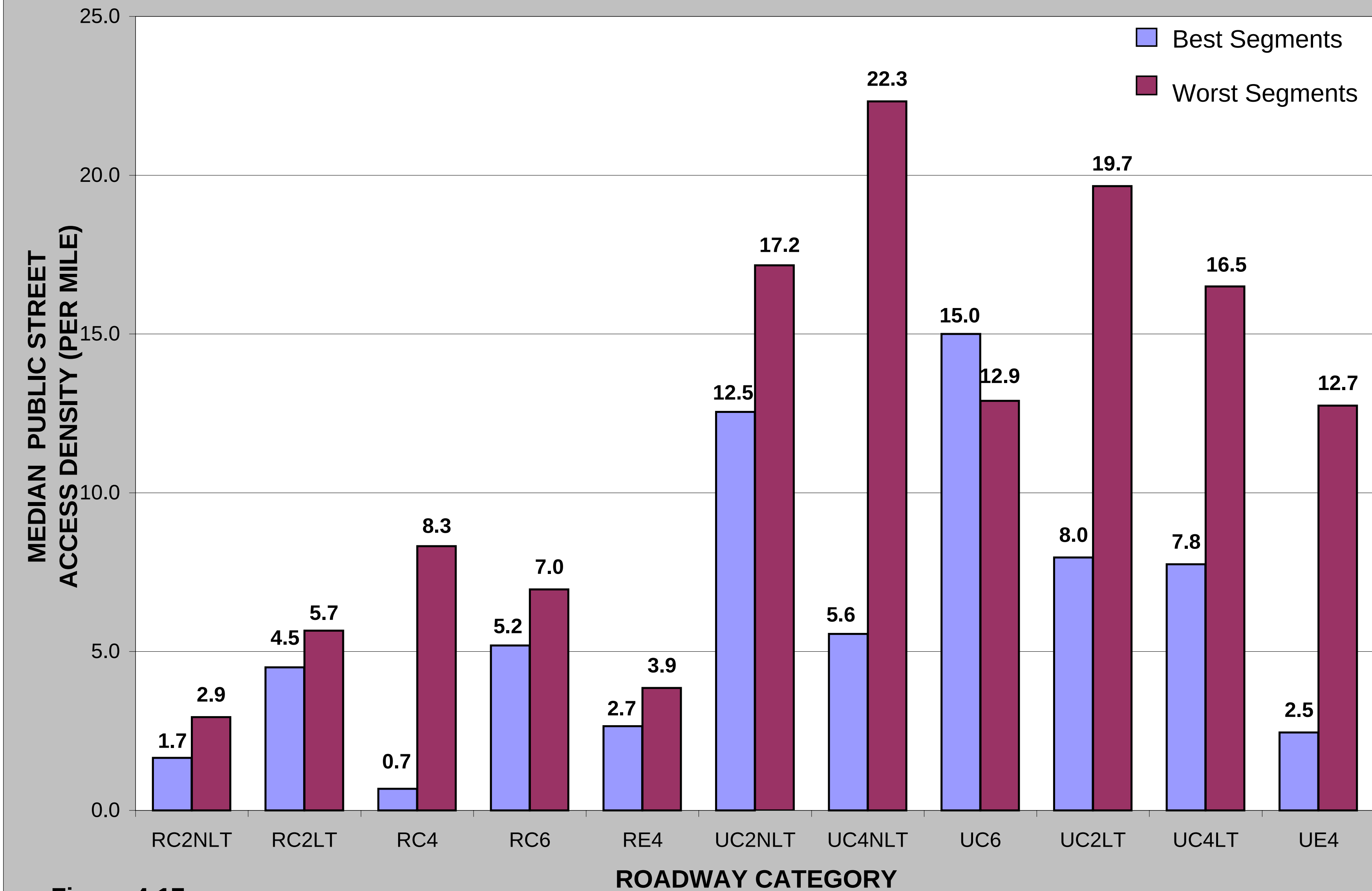


Figure 4-17

Median Public Street Access Density

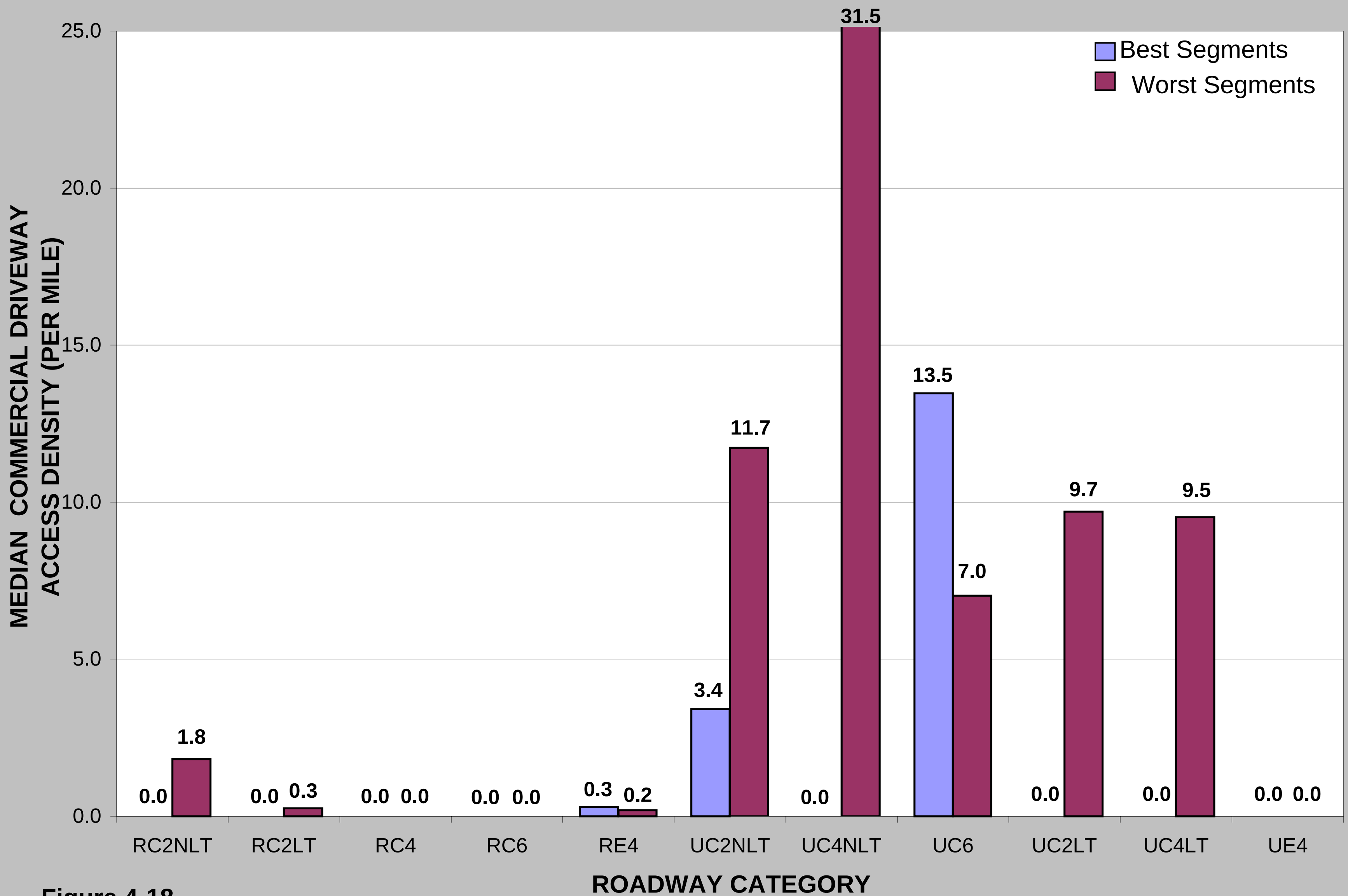


Figure 4-18

Median Commercial Driveway Access Density

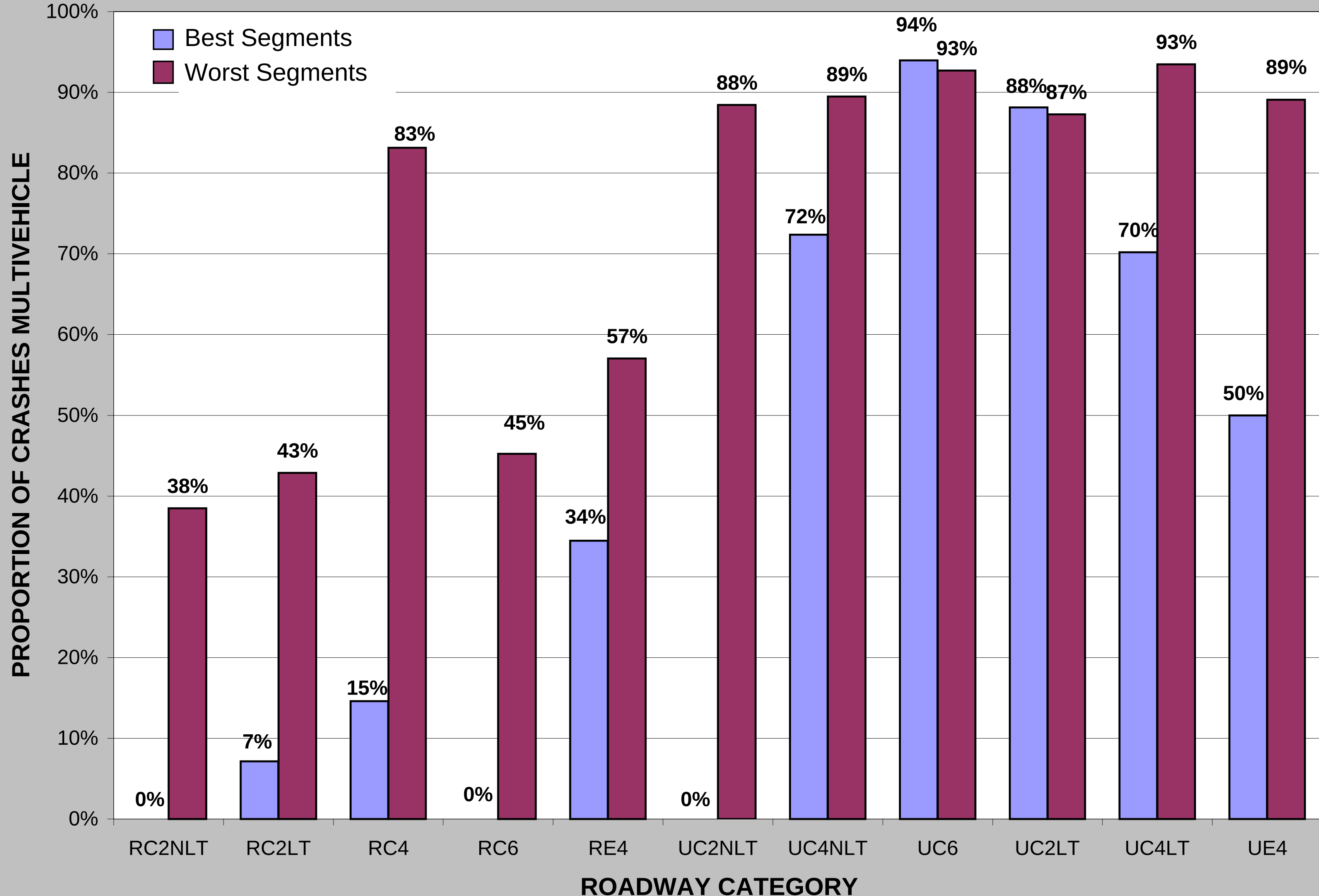


Figure 4-19

Median Percentage of Crashes that are Multi-Vehicle

Category	Number of Segments In Best/Worst Group	Percentage of Segments In Best/Worst Group	Total Crashes		Total Miles		Median Crash Rate	
			Best	Worst	Best	Worst	Best	Worst
RC2NLT	10	8%	3	120	25	24	0.0	3.4
RC2LT	7	50%	43	113	9	11	1.1	1.9
RC4	10	28%	59	303	18	9	0.3	4.3
RC6	3	43%	11	112	2	4	0.8	4.7
RE4	10	40%	188	316	36	22	0.4	1.0
UC2NLT	10	17%	3	193	5	4	0.0	9.2
UC4NLT	10	21%	92	1031	6	8	1.3	10.8
UC6	8	47%	183	505	6	7	1.8	5.9
UC2LT	10	50%	216	517	6	7	2.7	5.0
UC4LT	10	24%	158	960	8	5	1.7	9.0
UE4	10	22%	292	831	8	7	0.3	7.6

Table 4-1

Summary Comparison of Best and Worst Segments

5.0 Case Studies

The technical analyses in Sections 3 and 4 focused on the observed relationship between access density and crashes along a sample of Minnesota roadways. This chapter approaches the safety issues associated with access management form a second perspective, actual before/after case studies for three projects in Minnesota and eight projects in Iowa. The case studies selected are from various locations in Minnesota and Iowa and consisted of documenting the following project related information:

- General project description
- Before and after traffic volumes
- Before and after crash frequency
- Before and after crash rates
- Before and after access density (where data was available)
- Results

The Minnesota case studies discussed in the next section were all completed in the past 20 years by the Minnesota Department of Transportation. The Iowa case studies were conducted as part of a research project funded by the Iowa Department of Transportation, Iowa Highway Research Board, and the Federal Highway Administration. Research was conducted by a consortium involving the Center for Transportation Research and Education at Iowa State University, the University of Northern Iowa, and the University of Iowa. This project, the Iowa Access Management Awareness Project was intended to confirm results of previous access management research form around the nation, and to investigate Iowa-specific access management applications.

5.1 Minnesota Case Studies

All of the roadways included in the Minnesota Case Studies were experiencing significant safety problems. Prior to the implementation of the reconstruction projects, each of the roadways had significantly higher than expected crash frequencies and crash rates (see Figures 5-1 and 5-2.)

The Minnesota projects, overall, were designed to address the safety deficiencies by reducing conflicts along the three roadways studied. These projects include conversion of a two and four-lane undivided roadway to a three-lane road, conversion of a four-lane to a five-lane, and the addition of raised medians with protected turning bays to a four-lane roadway. As a result of these projects, crash frequency and crash rates were reduced by an average of more than 40 percent (Figure 5-3).

State Highway 49 (Rice Street) in Ramsey County, Minnesota

This case study is located along a 1.75-mile long section of Minnesota Trunk Highway 49 in the cities of Roseville, St. Paul, Maplewood, and Little Canada. In 1992, this study area was reconstructed from a four-lane undivided to a three-lane roadway section with a center two-way left-turn lane. The left-turn lane was intended to reduce rear-end conflicts created by left-turning traffic. The construction project also included some traffic signal revisions, including the addition of left-turn phasing.

Prior to this reconstruction project, the study area was experiencing significant safety problems. In the early 1990's, there was a high crash rate of about 13 crashes per million vehicle miles over the study area. Traffic volumes along this corridor varied from 15,500 to 24,000 vehicles per day.

After the project was completed, the crash rate along this section of Trunk Highway 49 was reduced to about 8.7 crashes per million vehicle miles, while traffic volumes varied from approximately 14,000 to 23,500 vehicles per day. This after crash rate is a reduction of approximately 33 percent.

State Highway 3 (Robert Street) in Ramsey County, Minnesota

This two-part case study is located along a three-mile long section of Trunk Highway 3 in St. Paul and West St. Paul. In 1987, the northern 1.0-mile section of the study area was reconstructed from a four-lane undivided to a three-lane roadway section with a center two-way left-turn lane. The southern 2.07-mile section was converted from a four-lane undivided road to a five-lane roadway with a center turning lane.

Prior to this reconstruction project, this study area was experiencing safety problems. Between 1985 and 1986, there were an average of 131 crashes per year in the entire study area. The corresponding crash rate for the area was between 6.2 and 6.3 crashes per million vehicle miles. During this period, daily traffic volumes were just under 19,000 vehicles per day.

After the project, the crash rate along Trunk Highway 3 was reduced to 3.2 crashes per million vehicle miles in the northern section and 3.4 crashes per million vehicle miles in the southern section. This is a crash rate reduction of approximately 49 percent in the northern section and about 45 percent in the southern section. Traffic volumes after this project rose to just above 19,000 vehicles per day.

US Highway 61 (Vermillion Street) in Hastings, Minnesota

This case study is located along a 2.8-mile long section of Trunk Highway 61 in Hastings. In the late 1970's and early 1980's, the northern 1.4-mile section of this study area was reconstructed from a four-lane divided roadway with a narrow raised median to a four-lane with protected left-turn bays at public street intersections only. This construction project also included the elimination of a few driveway access points along the study area. The southern section of the study corridor was converted in a similar way in the mid 1980's.

Prior to this reconstruction project, this study area was experiencing safety problems. Between 1976 and 1978, there were an average of 122 crashes per year in the northern section of the study area. The corresponding crash rate for this area was approximately 13.8 crashes per million vehicle miles. During this period, daily traffic volumes were approximately 17,000 vehicles per day. During the period from 1980 to 1982, the southern section of the roadway was experiencing an average of 19 crashes per year. This rate is approximately 4.57 crashes per million vehicle miles.

After the project was completed, the crash rate along the northern section of Highway 61 was reduced to approximately 7.47 crashes per million vehicle miles. The crash rate along the southern section was reduced to approximately 1.72 crashes per million vehicle miles. This was a reduction of around 46 percent for the northern section of the roadway, and about 62 percent for the southern section.

5.2 Iowa Case Studies

All of the roadways in the Iowa Case Studies were also experiencing high crash frequencies and crash rates (see Figures 5-4 and 5-5). The Iowa projects were designed to address these deficiencies by providing systems of left turn lanes, frontage roads and reducing the number of commercial driveways.

Research from the Iowa Access Management Awareness Project did show that the recent access projects in Iowa had a significant, positive impact in terms of traffic safety. The average reduction in the density of access was approximately 20 percent (Figure 5-6) and the reduction in annual crash rates was approximately 40 percent (Figure 5-7). Improvements in access also led to significantly improved roadway operations for most cases. The study also concluded that access management projects in Iowa, for the most part, do not have an adverse effect on the majority of businesses located along improved corridors.

US Highway 69 (South Duff Avenue) in Ames, Iowa

This case study is located along a 0.5-mile long section of US Highway 69 in Ames. During 1994, this study area was reconstructed from a four-lane undivided to a five-lane roadway section with a two-way left-turn lane. The fifth lane was intended to reduce rear-end conflicts from left-turning traffic. The construction project also included the elimination of 8 key commercial access points along the study area. This area is a major commercial strip for Ames.

Prior to this reconstruction project, the study area was experiencing safety problems. Between 1990 and 1992, daily traffic volumes were around 20,500 vehicles per day. During this period, there was an average of 53 crashes per year along the study area. The corresponding crash rate for this area was 7.12 crashes per million vehicle miles. The access density along this roadway was approximately 72 accesses per mile before the reconstruction.

After the project was completed, the Ames study area access density was reduced to around 56 accesses per mile. In addition, the crash rate along US 69 was reduced to 2.13 crashes per million vehicle miles during 1995. This was a reduction of approximately 70 percent. Traffic volumes in 1995 were around 22,000 vehicles per day.

US Highway 6 (2^{nd} Street) in Coralville, Iowa

This case study is located along a 0.7-mile long section of US Highway 6 in Coralville Iowa. During 1994 and 1995, this study area was reconstructed from a four-lane undivided to a five-lane roadway section with a center two-way left-turn lane. The fifth left-turn lane reduced rear-end conflicts from left-turning traffic. The construction project also included the elimination of 13 commercial access points along the study area. This study area is in close proximity to the University of Iowa athletic facilities, and often experiences heavy traffic during special events.

Prior to this reconstruction project, this mostly commercial study area was experiencing significant safety problems. Between 1991 and 1993, there was an average of 79 crashes per year in the study area. The corresponding crash rate for this area was 5.89 crashes per million vehicle miles. During this period, daily traffic volumes were around 29,000 vehicles per day. The access density along this roadway was about 54 accesses per mile before the reconstruction.

After the project was completed, the study area access density was lowered to approximately 33 accesses per mile. In addition, the crash rate along US Highway 6 was reduced to 3.75 accidents per million vehicle miles, while traffic rose to well over 30,000 vehicles per day. This was a crash rate reduction of over 36 percent.

US Highway 71 (South Grand Avenue) in Spencer, Iowa

This study is located along a 0.6-mile long section of US 71 in Spencer. In 1992, this study area was reconstructed from a four-lane undivided to a five-lane roadway section with a center two-way left-turn lane. The fifth lane reduced rear-end conflicts from left-turning traffic. The construction project also formalized the uncontrolled driveway accesses along the study area. This study area is located within a mostly commercial business district.

Prior to this reconstruction project, this study area was experiencing safety problems. Between 1988 and 1990, there were an average of 23 crashes per year within the study area. The corresponding rate was 4.30 crashes per million vehicle miles. During this period, daily traffic volumes were around 15,000 vehicles per day. The access density along this roadway was very high, well over 100 per mile, due to the lack of any set driveway structure.

After the project was completed, the study area access density was reduced to approximately 85 accesses per mile. This frequency is still quite high, but is an improvement on the previous situation. The crash rate along US 71 was reduced to 3.90 crashes per million vehicle miles, while traffic volumes along US 71 rose to almost 18,000 vehicles per day in 1995. The crash rate was reduced by approximately 9.3 percent. The relatively low crash reduction could be due to the high number of access points remaining along the roadway.

Northwest 86th Street in Clive, Iowa

This Iowa case study is located along a 0.6-mile long section of Northwest 86th Street in Clive. During 1991, this study area was reconstructed from a four-lane undivided to a five-lane roadway section with a combination of two-way left-turn lanes and center medians with protected turning bays. The project also eliminated one direct commercial access. The fifth left-turn lane and medians reduced conflicts due to left-turning traffic. This area is a major commercial center for Clive and the surrounding communities.

Prior to this reconstruction project, this study area was experiencing safety and congestion problems. Between 1988 and 1990, there were an average of 69 crashes per year in the study area. The corresponding crash rate for this area was 7.23 crashes per million vehicle miles. During this period, daily traffic volumes were around 26,000 vehicles per day. The access density along this roadway was about 55 accesses per mile before the reconstruction.

After the project was completed, the study area access density was changed very little, but left-turning conflict was reduced considerably. In addition, the crash rate along Northwest 86th was reduced to 4.17 crashes per million vehicle miles, while traffic rose to 28,000 vehicles per day. This change was a reduction in the crash rate of approximately 42 percent.

US Highway 69 (North Ankeny Boulevard) in Ankeny, Iowa

This case study is located along a 1.0-mile long section of US Highway 69 in Ankeny. In 1993, this study area was reconstructed from a two-lane undivided to a four-lane divided roadway with a center median. The added median provided storage and protection for left-turning traffic. The construction project was essentially a formalization of a previously unmanaged over-capacity two-lane roadway.

Prior to the reconstruction project, this rapidly growing commercial area was experiencing significant congestion and safety problems. Between 1989 and 1991, there were an average of 37 crashes per year in the study area. The corresponding crash rate for this area was 8.52 crashes per million vehicle miles. During this period, daily traffic volumes were around 12,000 vehicles per day. The access density along this roadway was about 27 accesses per mile before the reconstruction. Most of these access points were concentrated around one end of the study area that was much more developed with commercial activity.

After the completion of the project, the study area access density was about 24 accesses per mile, while traffic volumes rose to around 16,500 vehicles per day. In addition, the crash rate along the US Highway 69 study area was reduced to 5.37 crashes per million vehicle miles. This was a reduction in the crash rate of approximately 37 percent.

US Highway 69 (Southeast 14th Street) in Des Moines, Iowa

This Iowa-specific study is located along a 1.5-mile long section of US Highway 69 in Des Moines. In 1984 and 1985, this study area was converted from a four-lane undivided to a four-lane divided roadway with a center median with protected turning bays at major intersections. The median prevented most left-turning movements that were causing safety and congestion concerns. The project did not utilize any driveway consolidation measures.

Prior to the reconstruction project, this area of mixed land uses was experiencing congestion and safety problems. Between 1975 and 1977, there were 323 crashes per year along this study area. This was nearly one crash per day. The corresponding crash rate for this area was approximately 9.70 crashes per million vehicle miles. During this period, daily traffic volumes were around 26,000 vehicles per day. The access density along this roadway was high.

After the completion of the project, the study area access density remained about the same, but the elimination of most left-turns reduced potential conflict considerably. Traffic volumes rose to around 28,000 vehicles per day by 1986, but the crash rate along US 69 was reduced to 4.85 crashes per million vehicle miles between 1986 and 1988. This was a crash rate reduction of approximately 50 percent.

US Highway 18 (4^{th} Street Southwest) in Mason City, Iowa

This case study is located along a 0.17-mile long section of US 18 in Mason City. In 1991, this area was reconstructed from a four-lane undivided to a four-lane roadway with a center median at a major intersection. The median provided storage and protection for left-turning traffic at this high volume intersection.

Prior to the reconstruction project, this area was experiencing safety problems. Between 1988 and 1990, there were an average of 33 crashes per year in the study area. The corresponding rate for this area was 4.70 crashes per million vehicle miles. During this period, daily traffic volumes were around 19,000 vehicles per day. The access density along this roadway was around 88 accesses per mile before the reconstruction.

After the completion of the project, the study area access density was slightly lower, while traffic volumes rose to around 22,000 vehicles per day. In addition, the crash rate along US Highway 18 was reduced to 2.9 crashes per million vehicle miles. This change was a reduction in the crash rate of approximately 38 percent, or about 9 accidents per year.

US Highway 34 (West Burlington Avenue) in Fairfield, Iowa

This final Iowa case study is located along a 0.6-mile long section of US Highway 34 in Fairfield. In 1992, eight major commercial driveways along this study area were closed or consolidated. The project also involved improvements and upgrading to adjacent side streets to provide access to major traffic generators. This area is within a mostly commercial business district.

Prior to this project, this study area was experiencing safety problems. Between 1988 and 1990, there was an average of approximately 35 crashes per year within the study area. The corresponding accident rate was 5.70 crashes per million vehicle miles. During this period, daily traffic volumes were almost 17,000 vehicles per day. The access density along this roadway was around 65 accesses per mile.

After the project was completed, the study area access density was reduced to around 50 accesses per mile. More importantly, the accesses that were changed were some of the highest volume generators in the area. The resulting crash rate along US Highway 34 was reduced to 3.81 crash per million vehicle miles. This was a reduction of over 33 percent. Traffic volumes after the project actually dropped to less below 16,000 vehicles per day, due to the opening of parallel routes nearby.

5.3 Summary

From the information derived from these eleven case studies, it is clear that the principles behind access management are sound, and that access management projects do work. Whether simple driveway consolidation or closure, the addition of a turning lane, raised medians, or some combination, crash reductions can be expected.

When looking at the crash reductions resulting from the eleven projects, the crash reductions were quite significant. By following guidelines from Evaluation of Highway Safety Projects Student Manual, the crash reductions resulting from all but one of these access management projects are significant at a 95% confidence interval. The only case study where the resulting crash rate was not statistically significant is the Spencer case study in Iowa. The probable reason for this small decrease in crash rate is, as mentioned earlier, the high remaining frequency of access points along this study corridor.

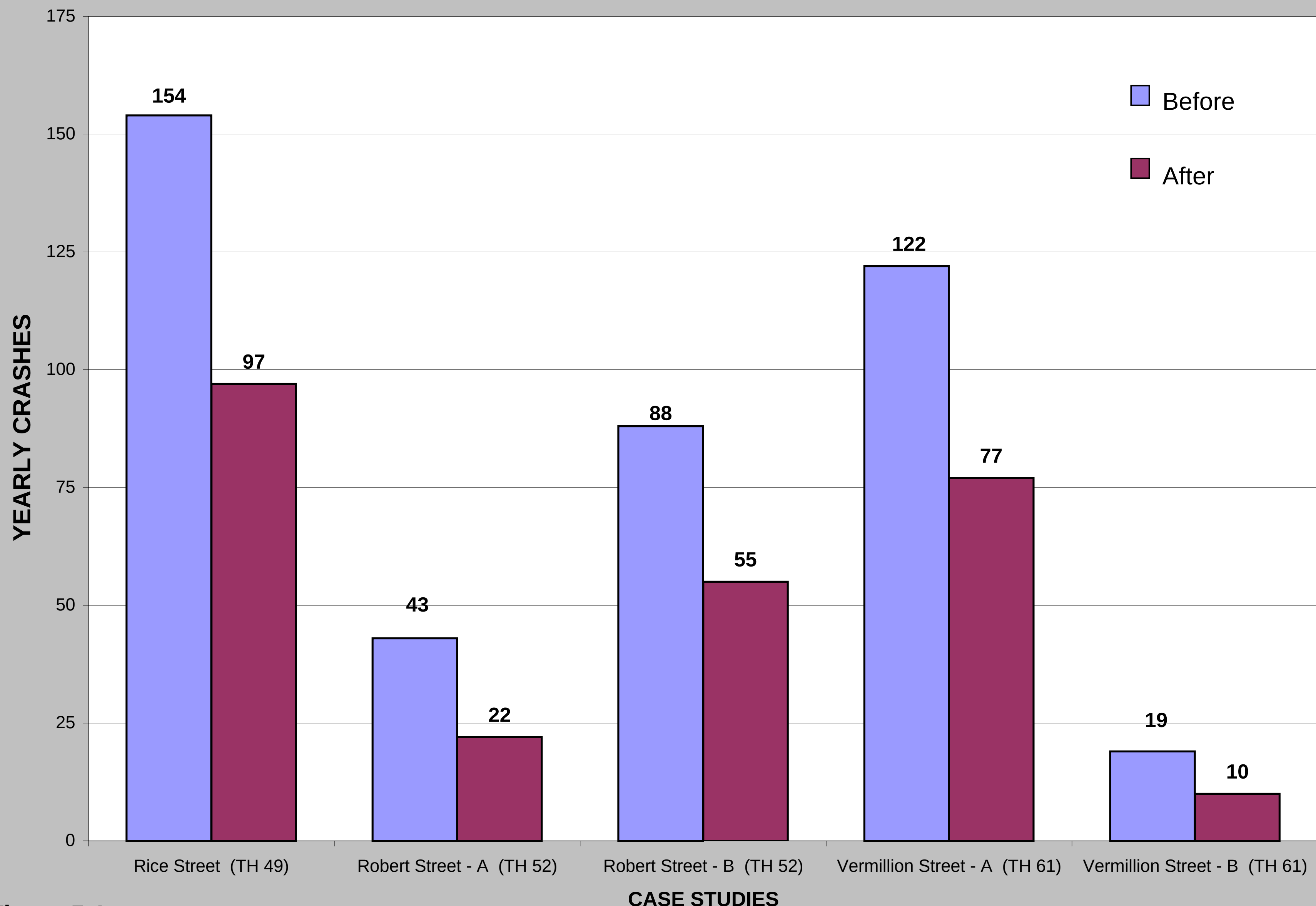


Figure 5-1

Minnesota Case Studies - Crash Frequency

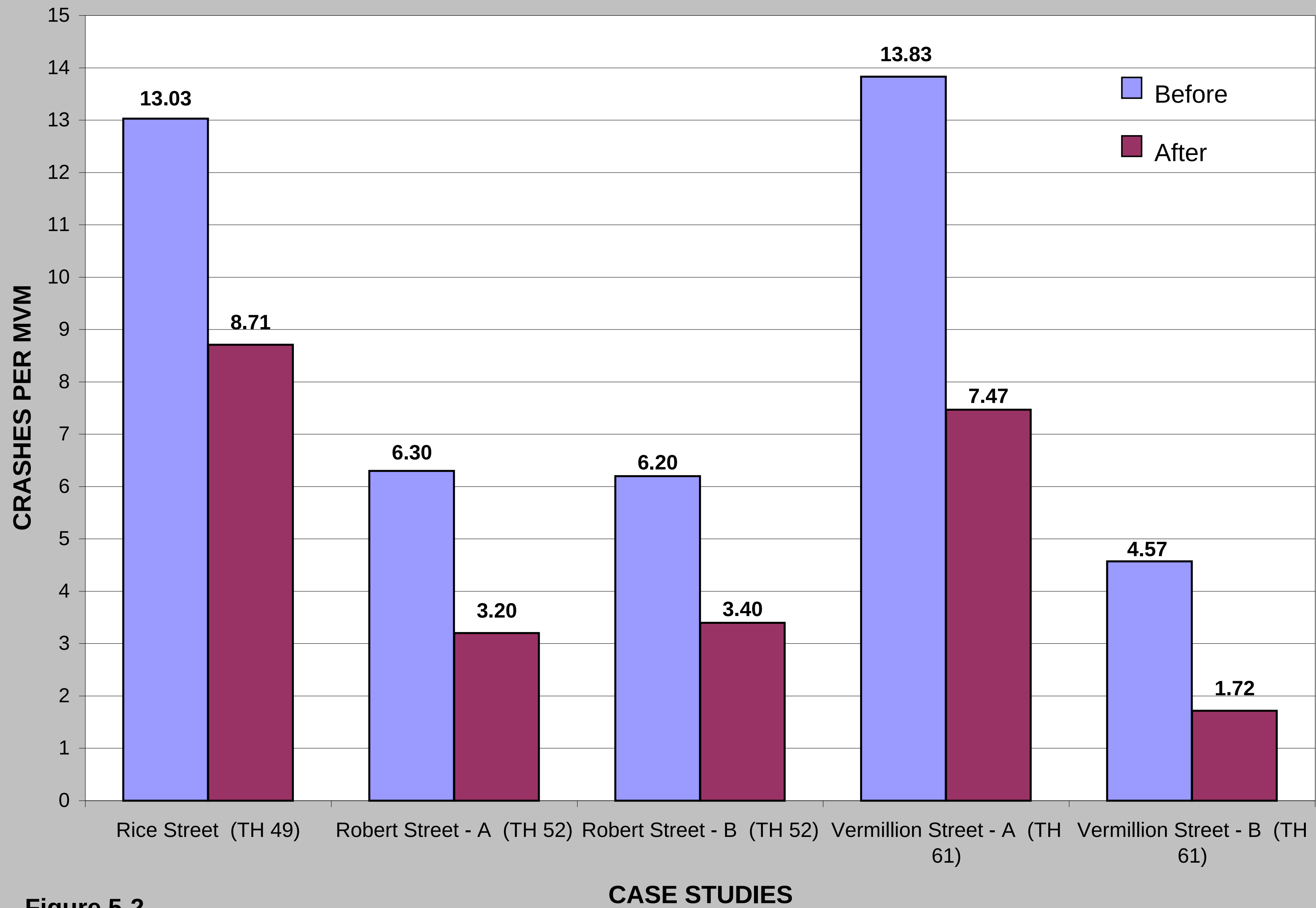


Figure 5-2

Minnesota Case Studies - Crash Rates

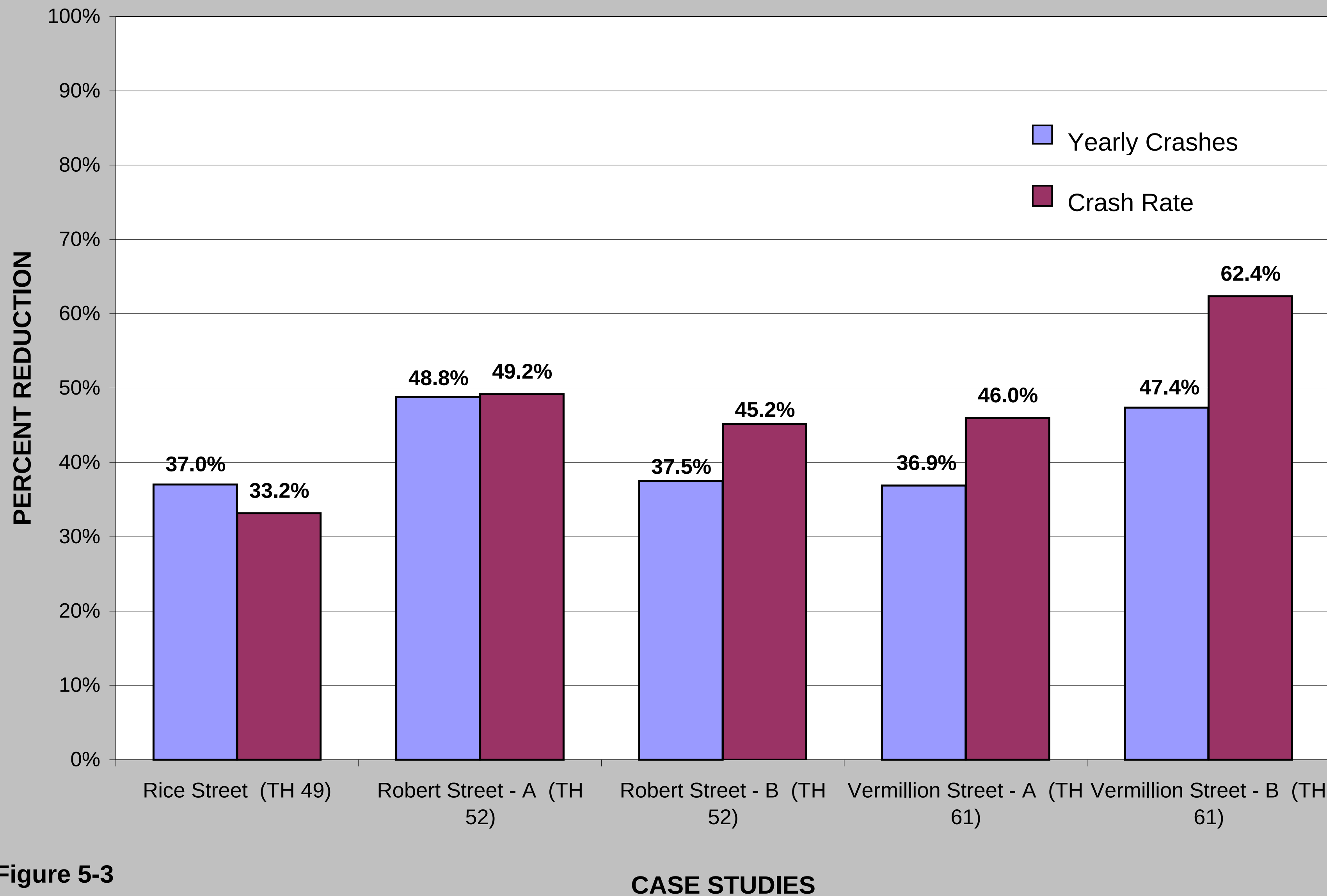


Figure 5-3

Minnesota Case Studies - Percent Reduction in Yearly Crashes and Crash Rates

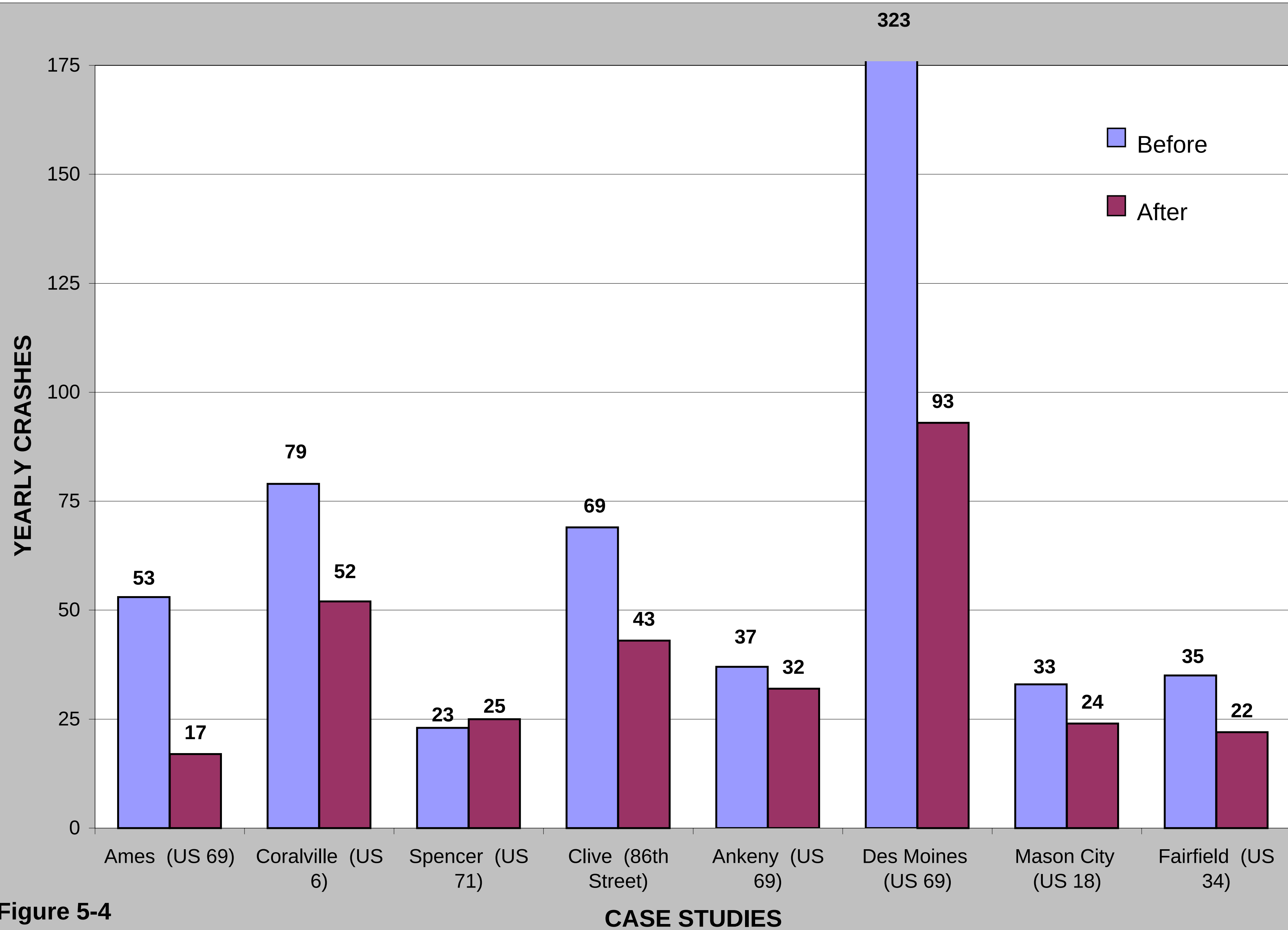


Figure 5-4

Iowa Case Studies - Crash Frequency

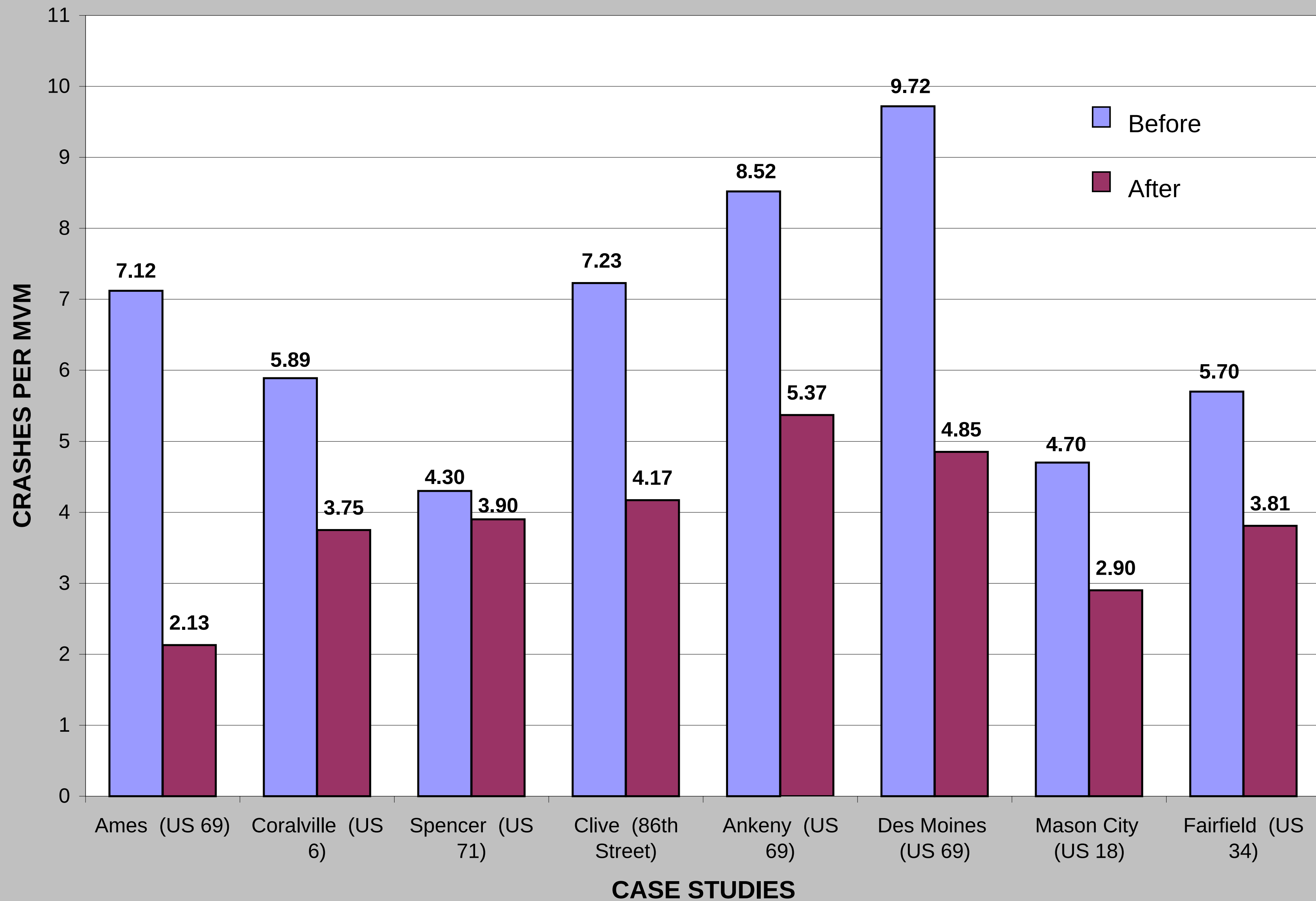


Figure 5-5

Iowa Case Studies - Crash Rates

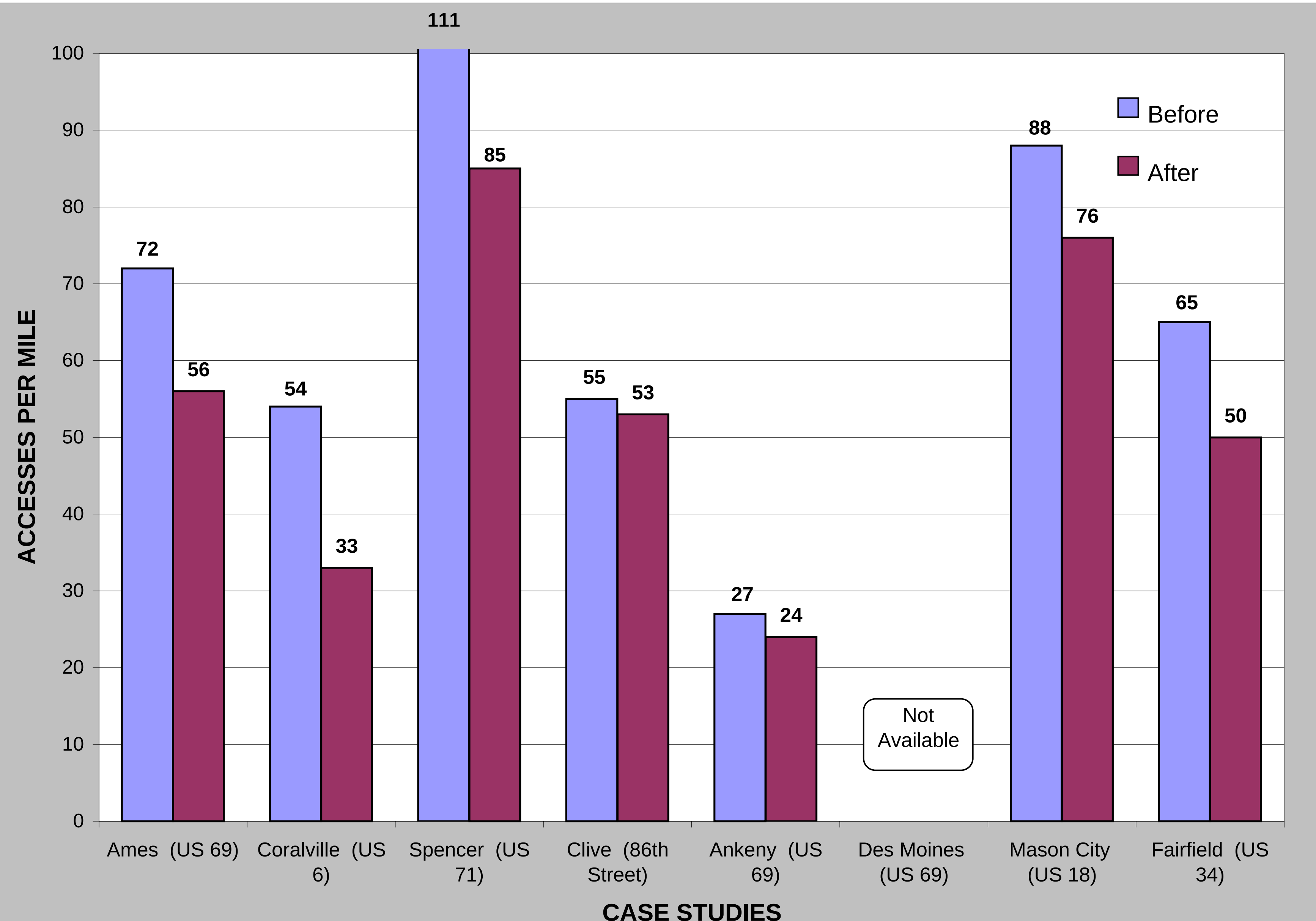


Figure 5-6

Iowa Case Studies - Access Density

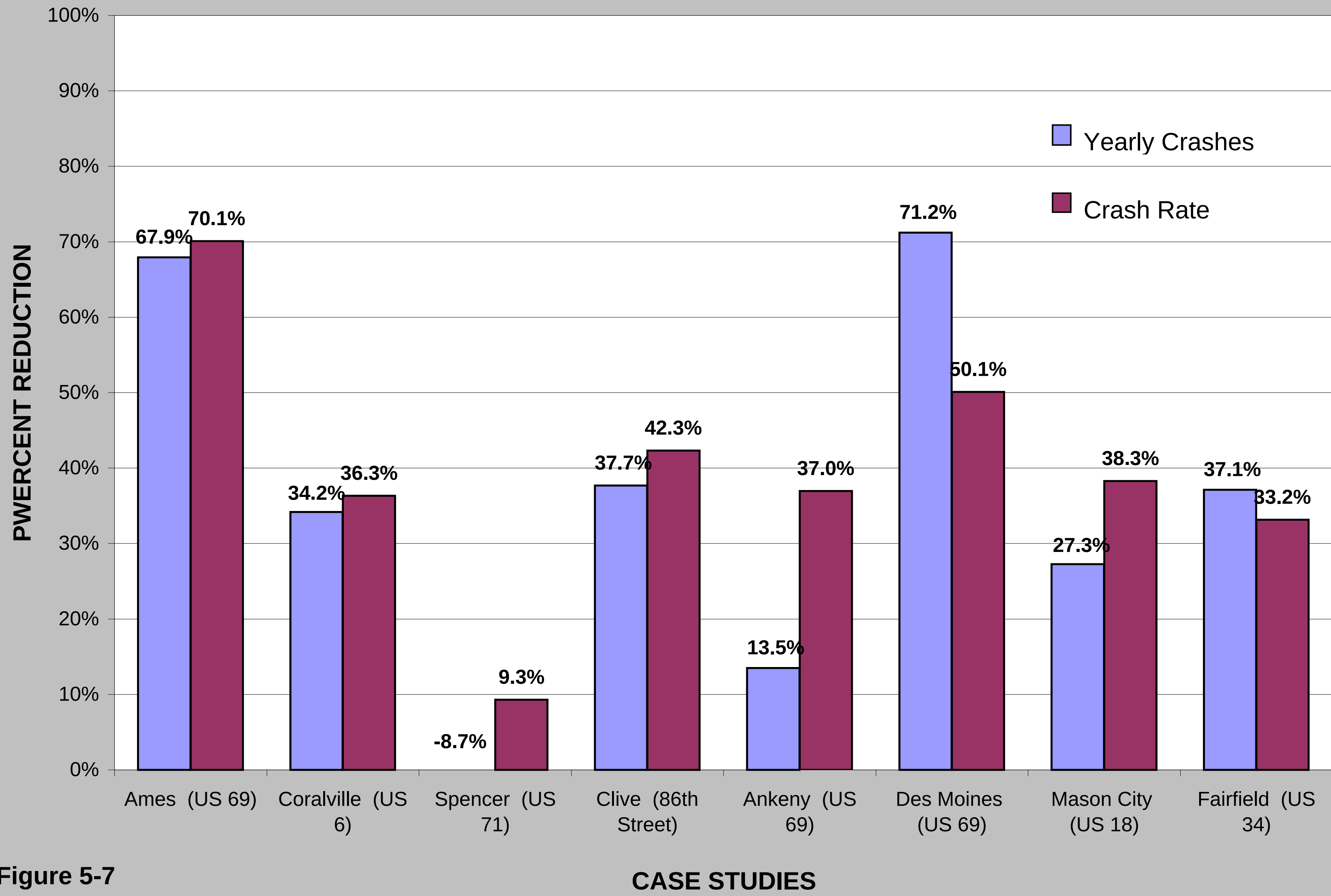


Figure 5-7

Iowa Case Studies - Percent Reduction in Yearly Crashes and Crash Rates

6.0 Statistical Analysis

Statistical analysis of the data was a key objective of this project to ensure the validity and reliability of the results about the relationship between access density and crashes. This chapter describes the statistical analysis that was performed for this project and provides a summary of the results. A more detailed discussion of the statistical methods that were utilized can be found in Appendix B.

6.1 Initial Statistical Analysis

As described in Chapter 2, the roadway sites utilized in this study were randomly selected. A randomly generated seed determined which segments would be sampled. This random selection process makes it likely that the samples are representative of the roadways in the state. This increases the probability of producing statistically reliable results.

6.1.1 Confidence Intervals

For the six combined roadway categories, 90% confidence intervals were constructed around the estimated crash rates for each category of access points per mile. These initial confidence intervals were constructed to see if the differences in crash rates for different numbers of access points were statistically significant. This confidence interval analysis was performed assuming that the crashes occurring on each segment are normally distributed. Subsequent analysis, described below, indicated that further refinement would be required.

6.1.2 Tests for Variability of Crash Rates within Categories

Within a roadway category, different sites may have different crash rates for a number of different reasons. Conclusions one may reach from a statistical analysis about the access density – crash rate relationship may be suspect unless other effects are found to be unimportant. Therefore, tests were performed to address these concerns.

One reason different sites may have different crash rates could be the dependency of the crash rate on traffic volume. Recent empirical work indicates that crash rates often decrease as a function of traffic volume. A simple test of the correlation between ADT and Access Density was performed to address this concern. The test was performed for both the combined and non-combined categories with the initial data. Low correlations were found for all of the combined categories and for nine out of the eleven categories. This indicated that the potential problem of dependency of the crash rate on traffic volume was not a concern for this analysis.

Another reason why sites within a category may have different crash rates could be because of unobserved differences among the sites. Therefore, a test was performed to check the variability of the observed crash rates within each of the six original roadway categories. The results indicated that the crash rates varied more than what would be expected (were overdispersed), thus posing problems for statistically reliable results. This was one reason the decision was made to abandon the use of the combined categories in favor of more homogeneous categories and obtain additional sample segments. In addition, further statistical analysis would be performed to address this concern.

6.2 Further Statistical Analysis

A specialized statistical analysis was under taken to address the concern of the variability of the crash rates. (Details of this analysis can be found in Appendix B.) This analysis would produce statistically reliable results for judging if crash rates tend to increase as access density increases, despite the variability found in the data. For the combined categories, the results showed that, the crash rate tends to increase as the access density increases (a significant access effect was found).

This analysis was later performed for the eleven roadway categories after obtaining additional sample segments. As described earlier, certain categories had a small statewide population (RC2LT, RC6, RE4, UC6, and UC2LT), and statistically reliable conclusions could not be reached relative to these categories. Out of the six roadway categories that had a large enough sample size (RC2NLT, RC4, UC2NLT, UC4NLT, UC4LT and UE4), five (all but UC2NLT) showed a significant access effect, that is the crash rate tends to increase as the access density increases.

Confidence intervals (90%) were also reconstructed for the six out of eleven roadway categories that had large sample sizes to produce statistically reliable results. Similar to the earlier confidence intervals, the sites were grouped by their level of access density. Here, five out of six categories (all but UC2NLT) showed a statistically significant difference in crash rates between the lowest access density range and the highest.

6.3 Summary

Numerous statistical tests were performed for this study with precautions taken to ensure the statistical validity of the results. Because of small statewide populations for five roadway categories, statistical conclusions about the access density – crash rate relationship may be drawn for six out of eleven roadway categories.

Table 6-1 presents a summary of the access density – crash rate relationship for each roadway category. A positive relationship was observed between access density and the crash rate (crash rate appears to increase as the access density increases) for ten of the eleven segments. Five out of six roadway types with a sufficient sample size to draw statistical conclusions were found to have a statistically significant access effect.

TABLE 6-1
Summary of Access Density – Crash Rate Relationship

Roadway Categories	Observed Positive Access/Crash Relationship	Adequate Sample Size for Statistical Analysis	Statistically Significant Access Effect
RC2NLT	✓	✓	✓
RC2LT	✓		
RC4	✓	✓	✓
RC6			
RE4	✓		
UC2NLT	✓	✓	
UC4NLT	✓	✓	✓
UC6	✓		
UC2LT	✓		
UC4LT	✓	✓	✓
UE4	✓	✓	✓

The statistical tests performed in this chapter show that on a majority of roadway types with a sufficient sample size, there is a statistically significant tendency for sites with higher access densities to have higher crash rates in both urban and rural areas. This evidence supports access management as a promising measure to reduce crash rates.

7.0 Benefit-Cost Analysis

This chapter presents an analysis of the benefits (based solely on crash reduction) that could be realized from the implementation of access management projects. Tables of benefit-cost ratios for each roadway category for different assumed levels of investment and crash reductions are provided.

7.1 Description

Benefit cost analysis looks at the benefits generated by a project and compares them to the cost incurred by the project over a certain analysis period. A project is considered economically feasible if the benefits are greater than the costs, producing a benefit-cost ratio greater than one. Typically, the benefits (cost savings) associated with transportation improvement projects may include delay savings, crash cost savings, operating cost savings, routine maintenance cost savings and environmental benefits. This study utilized only the benefits from crash reduction. Other benefits from transportation improvements are qualitative measures and cannot be associated with cost savings but certainly create a benefit.

7.2 Assumptions

As stated above, this analysis focused only on benefits due to crash reduction. An average crash cost for each category was calculated using the statewide distribution of crash severity and crash cost values currently used by Mn/DOT.

- Property Damage Only = $2,700
- Personal Injury = $30,500
- Fatality = $500,000

The number of crashes per mile was calculated for each category from statewide crash data for the three year period 1994, 1995 and 1996. The average crash cost per year per mile was then calculated for each category. Finally, values for crash reduction for each category were calculated for a range of crash reductions.

The costs presented for managing access represent initial capital investments annualized over 20 years with a discount rate of 5%. Operations and maintenance costs are not included.

7.3 Discussion/Potential Applications

Tables of benefit-cost ratios for each roadway category are provided (Tables 7-1 through 7-5 for rural roadways and 7-6 through 7-11 for urban roadways). A range of investment levels and crash reductions are used because it is not possible to determine at this time either the exact cost of an access management project or the exact reduction in crashes that would likely occur due to the level of investment in access management. However, the range of crash reductions and per mile costs presented in the tables should be sufficient to cover most rural and urban scenarios.

As illustrated on the tables, for many scenarios, the benefits of crash reduction outweigh the assumed cost of managing access. Crash reduction benefit-cost ratios over 1.0 exist in every roadway category. However, greater benefits for similar levels of investment accrue from crash reduction on urban roadways than or rural roadways:

- For a $500,000 investment that results in a 50% reduction in crashes, the crash reduction benefit-cost ratios range from 0.23 for a 2-lane rural conventional roadway with no left turn lanes to 4.06 for a 4-lane urban expressway.
- For a $250,000 investment that results in a 50% reduction in crashes, the crash reduction benefit-cost ratios range from 0.46 for a 2-lane rural conventional roadway with no left turn lanes to 8.12 for a 4-lane urban expressway.

The tables have the potential to be used as a guide for assessing the cost effectiveness of different access management projects.

TABLE 7-1
Crash Reduction Benefit-Cost Ratios
for
2 Lane Rural Conventional Roadway with No Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access				
	$100,000	$250,000	$500,000	$750,000	$1,000,000
10%	0.23	0.09	0.05	0.03	0.02
20%	0.46	0.18	0.09	0.06	0.05
30%	0.69	0.28	0.14	0.09	0.07
40%	0.92	0.37	0.18	0.12	0.09
50%	1.16	0.46	0.23	0.15	0.12
60%	1.39	0.55	0.28	0.18	0.14
70%	1.62	0.65	0.32	0.22	0.16
80%	1.85	0.74	0.37	0.25	0.18

TABLE 7-2
Crash Reduction Benefit-Cost Ratios
for
2 Lane Rural Conventional Roadway with Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access				
	$100,000	$250,000	$500,000	$750,000	$1,000,000
10%	0.40	0.16	0.08	0.05	0.04
20%	0.79	0.32	0.16	0.11	0.08
30%	1.19	0.48	0.24	0.16	0.12
40%	1.59	0.64	0.32	0.21	0.16
50%	1.99	0.79	0.40	0.26	0.20
60%	2.38	0.95	0.48	0.32	0.24
70%	2.78	1.11	0.56	0.37	0.28
80%	3.18	1.27	0.64	0.42	0.32

TABLE 7-3
Crash Reduction Benefit-Cost Ratios
for
4 Lane Rural Conventional Roadway

Crash Reduction	Cost Per Mile for Managing Access				
	$100,000	$250,000	$500,000	$750,000	$1,000,000
10%	0.67	0.27	0.13	0.09	0.07
20%	1.34	0.54	0.27	0.18	0.13
30%	2.01	0.81	0.40	0.27	0.20
40%	2.69	1.07	0.54	0.36	0.27
50%	3.36	1.34	0.67	0.45	0.34
60%	4.03	1.61	0.81	0.54	0.40
70%	4.70	1.88	0.94	0.63	0.47
80%	5.37	2.15	1.07	0.72	0.54

Note: Benefit-Cost ratios were calculated using the annualized cost of the investment over 20 years, using a discount rate of 5%

TABLE 7-4
Crash Reduction Benefit-Cost Ratios
for
6+ Lane Rural Conventional Roadway

Crash Reduction	Cost Per Mile for Managing Access				
	$100,000	$250,000	$500,000	$750,000	$1,000,000
10%	1.19	0.48	0.24	0.16	0.12
20%	2.38	0.95	0.48	0.32	0.24
30%	3.57	1.43	0.71	0.48	0.36
40%	4.77	1.91	0.95	0.64	0.48
50%	5.96	2.38	1.19	0.79	0.60
60%	7.15	2.86	1.43	0.95	0.71
70%	8.34	3.34	1.67	1.11	0.83
80%	9.53	3.81	1.91	1.27	0.95

TABLE 7-5
Crash Reduction Benefit-Cost Ratios
for
4 Lane Rural Expressway

Crash Reduction	Cost Per Mile for Managing Access				
	$100,000	$250,000	$500,000	$750,000	$1,000,000
10%	0.70	0.28	0.14	0.09	0.07
20%	1.40	0.56	0.28	0.19	0.14
30%	2.10	0.84	0.42	0.28	0.21
40%	2.80	1.12	0.56	0.37	0.28
50%	3.50	1.40	0.70	0.47	0.35
60%	4.20	1.68	0.84	0.56	0.42
70%	4.90	1.96	0.98	0.65	0.49
80%	5.60	2.24	1.12	0.75	0.56

Note: Benefit-Cost ratios were calculated using the annualized cost of the investment over 20 years, using a discount rate of 5%

TABLE 7-6
Crash Reduction Benefit-Cost Ratios
for
2 Lane Urban/Suburban Conventional Roadway with No Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	1.04	0.42	0.21	0.14	0.10	0.07	0.05
20%	2.08	0.83	0.42	0.28	0.21	0.14	0.10
30%	3.12	1.25	0.62	0.42	0.31	0.21	0.16
40%	4.17	1.67	0.83	0.56	0.42	0.28	0.21
50%	5.21	2.08	1.04	0.69	0.52	0.35	0.26
60%	6.25	2.50	1.25	0.83	0.62	0.42	0.31
70%	7.29	2.92	1.46	0.97	0.73	0.49	0.36
80%	8.33	3.33	1.67	1.11	0.83	0.56	0.42

TABLE 7-7
Crash Reduction Benefit-Cost Ratios
for
4 Lane Urban/Suburban Conventional Roadway with No Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	4.41	1.76	0.88	0.59	0.44	0.29	0.22
20%	8.82	3.53	1.76	1.18	0.88	0.59	0.44
30%	13.23	5.29	2.65	1.76	1.32	0.88	0.66
40%	17.64	7.06	3.53	2.35	1.76	1.18	0.88
50%	22.05	8.82	4.41	2.94	2.21	1.47	1.10
60%	26.46	10.58	5.29	3.53	2.65	1.76	1.32
70%	30.87	12.35	6.17	4.12	3.09	2.06	1.54
80%	35.28	14.11	7.06	4.70	3.53	2.35	1.76

TABLE 7-8
Crash Reduction Benefit-Cost Ratios
for
6+ Lane Urban/Suburban Conventional Roadway

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	4.05	1.62	0.81	0.54	0.41	0.27	0.20
20%	8.11	3.24	1.62	1.08	0.81	0.54	0.41
30%	12.16	4.86	2.43	1.62	1.22	0.81	0.61
40%	16.21	6.48	3.24	2.16	1.62	1.08	0.81
50%	20.27	8.11	4.05	2.70	2.03	1.35	1.01
60%	24.32	9.73	4.86	3.24	2.43	1.62	1.22
70%	28.37	11.35	5.67	3.78	2.84	1.89	1.42
80%	32.42	12.97	6.48	4.32	3.24	2.16	1.62

Note: Benefit-Cost ratios were calculated using the annualized cost of the investment over 20 years, using a discount rate of 5%

TABLE 7-9
Crash Reduction Benefit-Cost Ratios
for
2 Lane Urban/Suburban Conventional Roadway with Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	2.44	0.98	0.49	0.33	0.24	0.16	0.12
20%	4.88	1.95	0.98	0.65	0.49	0.33	0.24
30%	7.32	2.93	1.46	0.98	0.73	0.49	0.37
40%	9.76	3.91	1.95	1.30	0.98	0.65	0.49
50%	12.21	4.88	2.44	1.63	1.22	0.81	0.61
60%	14.65	5.86	2.93	1.95	1.46	0.98	0.73
70%	17.09	6.84	3.42	2.28	1.71	1.14	0.85
80%	19.53	7.81	3.91	2.60	1.95	1.30	0.98

TABLE 7-10
Crash Reduction Benefit-Cost Ratios
for
4 Lane Urban/Suburban Conventional Roadway with Left Turn Lanes

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	5.07	2.03	1.01	0.68	0.51	0.34	0.25
20%	10.14	4.06	2.03	1.35	1.01	0.68	0.51
30%	15.22	6.09	3.04	2.03	1.52	1.01	0.76
40%	20.29	8.11	4.06	2.70	2.03	1.35	1.01
50%	25.36	10.14	5.07	3.38	2.54	1.69	1.27
60%	30.43	12.17	6.09	4.06	3.04	2.03	1.52
70%	35.50	14.20	7.10	4.73	3.55	2.37	1.78
80%	40.57	16.23	8.11	5.41	4.06	2.70	2.03

TABLE 7-11
Crash Reduction Benefit-Cost Ratios
for
4 Lane Urban/Suburban Expressway

Crash Reduction	Cost Per Mile for Managing Access						
	$100,000	$250,000	$500,000	$750,000	$1,000,000	$1,500,000	$2,000,000
10%	4.06	1.62	0.81	0.54	0.41	0.27	0.20
20%	8.12	3.25	1.62	1.08	0.81	0.54	0.41
30%	12.18	4.87	2.44	1.62	1.22	0.81	0.61
40%	16.24	6.50	3.25	2.17	1.62	1.08	0.81
50%	20.30	8.12	4.06	2.71	2.03	1.35	1.02
60%	24.36	9.75	4.87	3.25	2.44	1.62	1.22
70%	28.42	11.37	5.68	3.79	2.84	1.89	1.42
80%	32.48	12.99	6.50	4.33	3.25	2.17	1.62

Note: Benefit-Cost ratios were calculated using the annualized cost of the investment over 20 years, using a discount rate of 5%

8.0 Conclusions

1. The previously published safety research has suggested a link between access and crash rates. However, this research did not actually document access density, did not account for differences between various roadway types or the data was based on very small sample. In addition, none of the research used either access or crash statistics from Minnesota.

2. This study is based on a representative random sample of segments from Minnesota's State Trunk Highway System. The samples were limited to the State System because of the availability of video log records, which greatly simplified the identification and counting of the access points.

3. Eleven roadway segment categories (five rural and six urban) were selected to isolate the potential relationship between crash rates and access density.

4. Characteristics of the study sample included:

   - 432 roadway segments
   - 765 miles
   - 9,545 access points
   - 13,700 crashes (over the three year period 1994-1996)

5. The average density of access was approximately 8 per mile along rural highways and 28 per mile along urban highways.

6. The most prevalent type of access along rural highways was residential driveways (38%), followed by public streets (28%). Commercial driveways accounted for only about 6% of the access in the rural sample.

7. The most prevalent type of access along urban highways was public streets (40%), followed by commercial driveways (34%).

8. The average crash rates for the sample segments was within 10 % of the statewide average crash rate for ten of the eleven categories (there was a 20 % difference in the urban 6-lane category).

9. There is an observed positive relationship between access density and crash rates in ten of the eleven highway categories (i.e., higher levels of access density resulted in higher crash rates). Only the 6-lane category does not show this correlation and this may be due to the small number of segments in this category.

10. Further analysis of the data suggests that there is no correlation between traffic volume and crash rates. The data also suggests that there is an inverse relationship between speed and crash rates. However, this may be due to Mn/DOT practicing some degree of access management on higher speed roadways, because the higher speed roadways in the sample also had lower levels of access density.

11. Additional analysis of the crash data in each of the categories revealed that in all cases, roadway segments with the highest crash rates have high levels of access density and segments with the lowest crash rates have low levels of access density.

12. The additional analysis also demonstrated an observed positive relationship between the density of commercial driveways and crash rates on urban roadways.

13. A review of case studies of eleven-access management related projects (three in Minnesota and eight in Iowa) documented an average crash reduction of approximately 40%. In addition, the crash reductions in ten of the eleven cases were statistically significant at the 95% confidence level.

14. A comprehensive package of statistical testing was preformed. The results of this testing indicate that there were sufficient sample sizes in six of the eleven roadway categories to reach statistically reliable conclusions (RC2NLT, RC4, UC2NLT, UC4NLT, UC4LT and UE4) and there was a statistically significant access effect in five of the six categories (all but UC2NLT).

15. A Benefit-Cost analysis was completed for each of the eleven roadway categories. The results are based on a range of estimated project costs and crash reductions and indicate that positive outcomes (a B/C ratio greater than 1) are possible in every category. However, the data also suggest that urban projects would likely result in greater crash reductions and therefore, greater benefits.

16. Crash data was analyzed from two different perspectives; a comparison of crash rates on a random sample of the State's Highway System and a Before/After comparison of crash rates from eleven case studies. The results from each approach suggest a strong and statistically sound relationship between levels of accessibility and crash rates.

17. The final conclusion addresses the key question identified in the Introduction. IS ACCESS MANAGEMENT A LEGITIMATE PUBLIC SAFETY ISSUE? All of the results of the various analyses suggest that yes; access management is a legitimate public safety issue.

APPENDIX A

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
TH	1	27+00.983	2	RC2LT
TH	1	39+00.991	2	RC2NLT
TH	1	119+00.050	2	RC2NLT
TH	1	191+00.843	1	RC2NLT
TH	1	286+00.450	1	RC2NLT
US	2	0+00.760	2	UE4
US	2	0+00.924	2	UC2NLT
US	2	1+00.260	2	UE4
US	2	20+00.474	2	RE4
US	2	25+00.299	2	UE4
US	2	26+00.900	2	UC4NLT
US	2	27+00.468	2	UE4
US	2	47+00.932	2	RE4
US	2	56+00.580	2	UE4
US	2	67+00.427	2	RE4
US	2	69+00.810	2	UE4
US	2	71+00.068	2	UC4NLT
US	2	86+00.890	2	RC4
US	2	88+00.349	2	UC4NLT
US	2	90+00.753	2	RE4
US	2	94+00.990	2	UE4
US	2	105+00.546	2	RE4
US	2	127+00.214	2	RC2NLT
US	2	179+00.030	1	RC4
US	2	182+00.373	1	UC4NLT
TH	3	19+00.440	9	RC2NLT
TH	3	32+00.600	9	UC6
TH	3	38+00.390	9	RC6
TH	4	41+00.090	7	RC2NLT
TH	4	63+00.134	7	UC2NLT
TH	4	128+00.641	8	RC2NLT
TH	5	32+00.293	5	UC4NLT
TH	5	42+00.080	5	RC4
TH	6	9+00.170	3	UC2NLT
TH	7	13+00.400	4	RC2NLT
TH	7	73+00.900	8	UC4NLT
TH	7	94+00.264	8	RC2NLT
TH	7	124+00.093	8	UC2NLT
TH	7	181+00.759	5	UC4LT
TH	7	182+00.528	5	UC4LT
TH	7	183+00.517	5	UE4
TH	7	190+00.286	5	UC4LT
TH	7	192+00.080	5	UC4LT
US	8	1+00.835	9	RC2NLT
US	8	11+00.413	9	UC2LT
TH	9	61+00.049	4	RC2NLT
TH	9	79+00.225	4	UC2NLT
TH	9	143+00.706	4	RC2NLT
TH	9	224+00.834	2	RC2NLT
US	10	1+00.110	4	UE4
US	10	2+00.020	4	UE4
US	10	2+00.924	4	UC4NLT
US	10	9+00.639	4	RE4
US	10	28+00.439	4	RE4
US	10	44+00.107	4	UE4
US	10	45+00.587	4	UE4
US	10	80+00.261	4	RE4
US	10	100+00.670	3	UC2NLT
US	10	113+00.000	3	RC4
US	10	114+00.670	3	UC4NLT
US	10	136+00.160	3	RC4
US	10	156+00.500	3	UC4NLT
US	10	167+00.886	3	RE4
US	10	196+00.330	3	RE4
US	10	203+00.250	3	UE4
US	10	212+00.470	3	UE4

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
US	10	212+00.930	3	UE4
US	10	213+00.207	3	UC4NLT
US	10	217+00.902	5	RE4
US	10	232+00.920	5	UE4
TH	11	20+00.866	2	RC2NLT
TH	11	81+00.080	2	RC2NLT
TH	11	127+00.980	2	RC2LT
TH	11	209+00.160	1	RC2NLT
US	12	42+00.297	4	UC2NLT
US	12	73+00.315	8	UC4LT
US	12	79+00.642	8	RC2NLT
US	12	100+00.059	8	UC2LT
US	12	134+00.198	3	RC2NLT
US	12	139+00.772	3	UC2NLT
US	12	147+00.254	5	UC2NLT
TH	13	0+00.246	6	UC2LT
TH	13	43+00.146	7	RC2NLT
TH	13	83+00.970	5	UC2LT
TH	13	84+00.298	5	UC2LT
TH	13	84+00.405	5	UC2LT
TH	13	85+00.001	5	UC2NLT
TH	13	90+00.782	5	UE4
TH	13	93+00.371	5	UE4
TH	13	101+00.230	9	UE4
TH	13	103+00.010	9	UC2LT
TH	13	105+00.700	9	UC4LT
TH	13	107+00.250	9	UC6
US	14	38+00.814	8	RC2NLT
US	14	100+00.420	7	RC6
US	14	101+00.473	7	UC6
US	14	102+00.044	7	UC4NLT
US	14	102+00.798	7	UC4NLT
US	14	133+00.250	7	RC4
US	14	134+00.334	7	RC2NLT
US	14	146+00.880	7	UC2NLT
US	14	173+00.671	6	RC4
US	14	211+00.179	6	UE4
US	14	212+00.698	6	UE4
US	14	225+00.603	6	RC2NLT
US	14	251+00.080	6	RC2LT
US	14	255+00.109	6	RC2LT
TH	15	9+00.392	7	UC6
TH	15	9+00.742	7	UC6
TH	15	10+00.258	7	UC6
TH	15	11+00.253	7	UC4LT
TH	15	11+00.587	7	UC4LT
TH	15	53+00.410	7	RC2LT
TH	15	57+00.512	7	UC4LT
TH	15	59+00.494	7	RC6
TH	15	101+00.131	8	UC4NLT
TH	15	115+00.265	8	UC2NLT
TH	15	145+00.550	3	RE4
TH	15	148+00.390	3	RC2NLT
TH	16	279+00.033	6	RC2NLT
TH	18	0+00.000	3	UC4NLT
TH	18	0+00.190	3	UC2NLT
TH	18	2+00.470	3	UC4LT
TH	19	10+00.395	8	RC2NLT
TH	19	34+00.786	8	UC2LT
TH	19	35+00.494	8	UC4NLT
TH	19	72+00.087	8	UC4LT
TH	19	89+00.279	8	RC2NLT
TH	19	133+00.840	7	UC2NLT
TH	19	154+00.670	5	RC2LT
TH	19	154+00.892	6	RC2LT
TH	19	166+00.174	6	RC2NLT

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
TH	19	174+00.330	6	UC2LT
TH	20	0+00.000	9	UC2LT
TH	22	7+00.230	7	RC2NLT
TH	22	46+00.790	7	RC6
TH	22	54+00.840	7	RC6
TH	22	94+00.329	7	RC2NLT
TH	23	19+00.142	8	RC2NLT
TH	23	22+00.870	8	UC2NLT
TH	23	66+00.730	8	RC4
TH	23	75+00.066	8	RC4
TH	23	103+00.113	8	UC4LT
TH	23	116+00.116	8	RC2NLT
TH	23	186+00.349	3	RC2NLT
TH	23	198+00.610	3	RC4
TH	23	203+00.120	3	UC4NLT
TH	23	203+00.930	3	UC4LT
TH	23	207+00.360	3	UC4LT
TH	23	208+00.180	3	UC4LT
TH	23	235+00.430	3	UC2NLT
TH	23	320+00.469	1	RC2NLT
TH	23	338+00.600	1	UC4NLT
TH	25	2+00.750	7	RC6
TH	25	2+00.909	7	RC6
TH	25	33+00.390	5	UC2NLT
TH	25	50+00.481	3	RC2NLT
TH	25	128+00.590	3	UC2NLT
TH	25	139+00.361	3	RC2NLT
TH	27	24+00.428	4	RC2NLT
TH	27	90+00.908	4	UC2NLT
TH	27	102+00.022	3	RC2NLT
TH	27	135+00.580	3	UC2NLT
TH	27	190+00.655	3	RC2NLT
TH	28	22+00.000	4	UC2NLT
TH	28	35+00.397	4	RC2NLT
TH	28	114+00.000	3	RC2NLT
TH	28	116+00.440	3	UC2NLT
TH	29	65+00.060	4	RC4
TH	29	65+00.320	4	RC2NLT
TH	29	76+00.710	4	UE4
TH	29	78+00.778	4	UE4
TH	29	79+00.203	4	UC4NLT
TH	29	79+00.731	4	UC4LT
TH	30	3+00.918	8	RC2NLT
TH	30	25+00.474	8	UC2NLT
TH	30	92+00.677	7	RC2NLT
TH	32	19+00.941	4	RC2NLT
TH	32	41+00.656	2	UC2NLT
TH	32	87+00.300	2	RC2NLT
TH	33	5+00.630	1	RC2NLT
TH	34	65+00.881	4	UC2NLT
TH	36	7+00.002	9	UE4
TH	36	10+00.596	9	UE4
TH	37	0+00.846	1	UC4NLT
TH	38	26+00.539	1	RC2NLT
TH	40	56+00.706	8	RC2NLT
TH	41	1+00.750	5	UC4NLT
TH	41	3+00.315	5	UC2NLT
TH	43	35+00.560	6	RC2NLT
TH	44	52+00.456	6	RC2LT
TH	46	26+00.008	2	RC2NLT
TH	47	2+00.064	5	UC4NLT
TH	47	4+00.889	5	UC4NLT
TH	47	5+00.029	5	UC4NLT
TH	47	9+00.091	5	UE4
TH	47	43+00.920	3	UC2NLT
TH	47	68+00.998	3	RC2NLT

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
TH	48	14+00.219	1	RC2NLT
TH	49	14+00.267	9	UC6
TH	49	16+00.997	9	UC6
TH	51	7+00.580	9	UE4
TH	51	8+00.180	9	UE4
US	52	72+00.260	6	RE4
US	52	91+00.472	6	RC4
US	52	104+00.000	9	RE4
US	53	20+00.959	1	RE4
US	53	49+00.254	1	RE4
US	53	75+00.789	1	RC2NLT
US	53	92+00.150	1	UC2NLT
US	53	146+00.410	1	RC2NLT
TH	55	41+00.860	4	RC2NLT
TH	55	105+00.000	3	RC2NLT
TH	55	155+00.200	3	UC4LT
TH	55	177+00.578	5	UE4
TH	55	186+00.622	5	UE4
TH	55	196+00.760	5	UC4NLT
TH	55	197+00.180	5	UE4
TH	55	210+00.836	9	RE4
TH	55	211+00.270	9	RC2NLT
TH	55	219+00.528	9	UC4LT
TH	56	35+00.451	6	UC2NLT
US	59	12+00.330	7	RC2NLT
US	59	74+00.185	8	UC2NLT
US	59	89+00.701	8	RC2NLT
US	59	183+00.617	4	RC2NLT
US	59	280+00.501	4	RC2NLT
US	59	356+00.419	2	UC6
US	59	357+00.379	2	UC6
US	59	359+00.819	2	RC2NLT
US	59	376+00.950	2	UC2NLT
TH	60	0+00.000	7	RC2NLT
TH	60	40+00.542	7	UC4NLT
TH	60	41+00.300	7	UC4NLT
TH	60	94+00.370	7	RE4
TH	60	134+00.324	6	RC2NLT
TH	60	146+00.427	6	RC4
TH	60	147+00.888	6	UC4LT
TH	60	163+00.362	6	UC2NLT
US	61	1+00.476	6	UC4LT
US	61	10+00.120	6	RC4
US	61	11+00.800	6	RC4
US	61	17+00.930	6	RC4
US	61	22+00.615	6	RC4
TH	61	26+00.432	1	RC2NLT
US	61	27+00.305	6	UC4LT
US	61	29+00.525	6	UC4LT
TH	61	31+00.740	1	RC4
TH	61	37+00.390	1	RC4
US	61	40+00.000	6	RC4
US	61	45+00.014	6	RC4
US	61	53+00.460	6	RC4
US	61	58+00.820	6	RC4
US	61	80+00.797	6	RC2NLT
US	61	89+00.424	6	UC4NLT
US	61	90+00.858	6	UC4LT
US	61	115+00.142	9	UC2LT
US	61	115+00.611	9	UC4LT
US	61	118+00.920	9	RE4
TH	61	120+00.261	1	RC2NLT
US	61	140+00.091	9	UC4LT
US	61	141+00.380	9	UC4NLT
TH	61	150+00.280	1	RC4
US	61	158+00.890	9	UC4LT

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
US	61	160+00.660	9	UC6
US	61	161+00.297	9	UC4LT
US	63	9+00.440	6	RC2NLT
US	63	12+00.450	6	UC2NLT
US	63	32+00.888	6	RC4
US	63	39+00.549	6	UC4LT
US	63	41+00.961	6	UC4LT
US	63	60+00.664	6	RC4
TH	65	4+00.137	5	UE4
TH	65	9+00.837	5	UE4
TH	65	15+00.442	5	UE4
TH	65	35+00.183	3	RC4
TH	65	51+00.010	3	RC4
TH	65	80+00.000	3	RC2NLT
TH	65	158+00.513	1	RC2NLT
TH	65	250+00.308	1	RC2NLT
US	65	304+00.960	6	UC2NLT
US	65	308+00.890	6	RC4
US	65	310+00.960	6	UC4LT
US	65	312+00.512	6	UC4NLT
US	65	313+00.430	6	UC4NLT
TH	67	33+00.195	8	RC2NLT
TH	67	70+00.216	8	UC2NLT
TH	68	38+00.653	8	UC2LT
TH	68	58+00.978	8	RC2NLT
TH	68	86+00.924	7	UC2NLT
US	69	12+00.052	6	UC4LT
US	71	56+00.274	8	RC2NLT
US	71	126+00.132	8	RC4
US	71	134+00.268	8	RC2NLT
US	71	186+00.540	3	UC2NLT
US	71	199+00.320	3	UC2LT
US	71	219+00.635	3	RC2NLT
US	71	238+00.960	3	UC2NLT
US	71	358+00.379	2	RC2NLT
TH	73	9+00.830	1	RC2NLT
TH	73	98+00.861	1	RC2NLT
TH	74	42+00.700	6	UC2NLT
US	75	10+00.356	7	UC4NLT
US	75	36+00.880	8	RC2NLT
US	75	119+00.628	8	RC2NLT
US	75	195+00.791	4	RC2NLT
US	75	204+00.962	4	UC2NLT
US	75	206+00.924	4	RC4
US	75	248+00.645	4	UC4LT
US	75	249+00.737	4	UC4NLT
US	75	251+00.382	4	UC4LT
US	75	265+00.903	4	RC2NLT
US	75	302+00.451	2	UC2NLT
US	75	319+00.207	2	UC6
US	75	337+00.260	2	RC2NLT
US	75	377+00.115	2	UC2NLT
US	75	410+00.059	2	RC2NLT
TH	78	26+00.620	4	RC2NLT
TH	83	21+00.409	7	RC2NLT
TH	84	0+00.000	3	UC4NLT
TH	87	30+00.052	3	UC2NLT
TH	87	40+00.851	2	RC2NLT
TH	88	2+00.853	9	UE4
TH	89	66+00.010	2	RC2NLT
TH	89	132+00.712	2	RC2NLT
TH	92	6+00.081	2	RC2NLT
TH	92	60+00.589	2	RC2NLT
TH	95	41+00.694	3	UC2NLT
TH	95	55+00.610	9	RC2NLT
TH	95	92+00.910	9	RC2LT

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
TH	95	96+00.810	9	RC2LT
TH	95	100+00.710	9	RC2LT
TH	95	102+00.676	9	UC2LT
TH	95	110+00.696	9	RC4
TH	99	4+00.845	7	RC2NLT
TH	99	25+00.590	7	UC2NLT
TH	100	9+00.060	5	UE4
TH	100	12+00.556	5	UE4
TH	101	39+00.640	5	UE4
TH	104	14+00.446	4	RC2NLT
TH	105	12+00.069	6	UC4NLT
TH	105	12+00.915	6	UC2LT
TH	106	0+00.000	4	UC2NLT
TH	108	4+00.825	4	RC2NLT
TH	109	0+00.000	7	UC2NLT
TH	111	0+00.000	7	UC2NLT
TH	111	0+00.460	7	RC2NLT
TH	113	38+00.543	4	RC2NLT
TH	119	5+00.387	4	RC2NLT
TH	120	0+00.000	9	UC4LT
TH	120	2+00.530	9	UC2LT
TH	120	5+00.050	9	UC2LT
TH	120	6+00.060	9	UC2LT
TH	120	8+00.560	9	UC2LT
TH	149	0+00.000	9	RC2NLT
TH	149	1+00.150	9	RC2LT
TH	149	3+00.381	9	UC4LT
TH	149	7+00.180	9	UC2NLT
TH	156	0+00.250	9	UC4LT
US	169	10+00.176	7	RE4
US	169	65+00.390	7	UC4NLT
US	169	66+00.540	7	UC4NLT
US	169	98+00.850	5	UE4
US	169	99+00.592	5	RE4
US	169	137+00.177	5	UE4
US	169	139+00.552	5	UC4LT
US	169	140+00.004	5	UE4
US	169	145+00.817	5	UC4NLT
US	169	146+00.431	5	UE4
US	169	179+00.530	3	RC2NLT
US	169	186+00.000	3	RE4
US	169	270+00.000	3	RC2NLT
US	169	304+00.023	1	UC4NLT
US	169	305+00.671	1	UC4NLT
US	169	341+00.837	1	RE4
TH	169	412+00.946	1	RC2NLT
TH	197	0+00.000	2	RC2LT
TH	197	1+00.958	2	UC4LT
TH	197	2+00.208	2	UC4NLT
TH	197	3+00.922	2	UC4NLT
TH	197	4+00.304	2	UC4NLT
TH	197	5+00.314	2	UC4LT
TH	197	5+00.374	2	UC4LT
TH	197	5+00.794	2	UC4LT
TH	200	18+00.410	2	UC2NLT
TH	200	19+00.620	2	RC2NLT
TH	200	74+00.368	2	RC2NLT
TH	200	163+00.000	3	RC2LT
TH	200	167+00.027	3	RC2NLT
TH	210	23+00.870	4	RE4
TH	210	45+00.583	4	RC2NLT
TH	210	120+00.270	3	UC4LT
TH	210	121+00.100	3	UC4NLT
TH	210	121+00.763	3	UC4NLT
TH	210	122+00.040	3	UC4NLT
TH	210	125+00.450	3	RC2NLT

SYSTEM	ROUTE	BEGIN REF POINT	Mn/DOT DISTRICT	ROADWAY CATEGORY
TH	210	141+00.750	3	UC2NLT
TH	210	196+00.480	1	RC2NLT
TH	210	215+00.710	1	RC4
US	212	37+00.146	8	RC2NLT
US	212	71+00.112	8	UC2NLT
US	212	75+00.654	8	UC2LT
US	212	76+00.006	8	UC6
US	212	76+00.250	8	UC6
US	212	76+00.547	8	UC6
US	212	76+00.713	8	UC6
US	212	76+00.790	8	UC4NLT
US	212	121+00.173	8	RC4
US	212	127+00.319	8	RC4
US	212	131+00.197	5	UE4
US	212	132+00.260	5	RC2NLT
US	218	28+00.822	6	UC2NLT
TH	219	0+00.000	2	RC2NLT
TH	220	57+00.080	2	RC2NLT
TH	235	3+00.045	4	RC2NLT
TH	238	0+00.000	3	UC2NLT
TH	244	0+00.000	9	UC6
TH	247	0+00.000	6	RC2NLT
TH	247	11+00.800	6	UC2NLT
TH	258	4+00.015	7	RC2NLT
TH	270	3+00.677	7	RC2NLT
TH	275	0+00.000	8	UC2NLT
TH	280	2+00.529	9	UE4
TH	288	0+00.021	5	UC4NLT
TH	297	0+00.000	4	UC2NLT
TH	308	0+00.000	2	RC2NLT
TH	361	0+00.690	9	UC2NLT
TH	371	6+00.753	3	RC4
TH	371	18+00.172	3	RC2NLT
TH	371	29+00.040	3	UC4NLT
TH	371	37+00.420	3	RE4
TH	610	0+00.642	5	UE4

APPENDIX B

Statistical Tests and the Negative Binomial Model

The first methodology considered for statistical analysis of these data was the Poisson regression model. The Poisson model was first considered because of the discrete nature of crash counts and their relatively low frequency on any given segment. A closer examination of the data showed that overdispersion may have interfered with the Poisson distribution of the sample. Consequently, the negative binomial model (which tests and accounts for overdispersion) was chosen for estimation.

The Negative Binomial Model

For each of the eleven categories, a negative binomial regression model was estimated. The negative binomial has the functional form:

$$\lambda = \lambda_0 d^{\beta}$$

Where λ is the predicted crash rate, λ_0 is the base crash rate, d is the access density and β is the marginal effect of access as predicted by the model.

Note that if the coefficient $\beta=0$, then the sites have an accident rate that is independent of access density, while if $\beta>0$, the accident rate tends to increase as access density increases. To allow for overdispersion, we assumed that the accident counts were distributed as negative binomial random variables, rather than as Poisson random variables.

This necessitated estimating a third parameter ***a***, which governed the degree of overdispersion shown by the data. Without going into detail, ***a***=0 corresponds to the data being generated as Poisson counts, while as ***a*** increases above 0, the data show increasing variability over that provided by the Poisson model.

For each class of sites, the parameters λ, ***a*** and β were estimated using maximum likelihood, and the computations were implemented using Mathcad 6+. It was then possible to test whether or not the negative binomial provided a reasonable fit to the data, whether or not the data showed significant overdispersion, and whether or not the parameter β was significantly different from zero (using the standard z test with a 90% confidence level). The results are summarized in Table B-1.

The findings of the negative binomial model are most meaningful when a category has a sample size near or above 50 observations. Consequently the findings for categories RC2NLT, RC4, UC2NLT, UC4NLT, UC4LT and UE4 are more statistically valid than other categories.

Findings of the Negative Binomial

Negative binomial models estimated on each of the eleven categories found a statistically significant access density-crash rate correlation in seven. A significant correlation was found in 5 of the 6 categories which had robust sample sizes. Categories RC2NLT, RC4, UC4NLT, UC4LT and UE4 were found to have a statistically significant access density-crash rate correlation.

While there was adequate sample size in category UC2NLT (2 lane urban roadways without left turn lanes), the access-crash rate relationship was not found to be statistically significant. Because at this time the actual turning volumes and other potential conflicts on these segments have not been quantified, we cannot draw any conclusions regarding 2 lane urban roadways without left turn lanes.

Confidence Intervals

For the six categories in which the sample size was large enough for the negative binomial estimation to be meaningful, further modeling was done on the access-crash rate relationship. In each of these categories, the sites were grouped by their level of access density (similar to the analysis in section 3.3). For each of these levels of access density, a crash rate was estimated by the negative binomial model along with the upper and lower bounds of the 90% confidence interval for this estimation.

The upper and lower bounds of the confidence interval demonstrate the degree to which 90% of samples taken from the population may vary above or below the crash rate estimated by the model (at each given level of access). For each of these six categories, estimated crash rates with upper and lower bounds at the 90% confidence interval for different levels of access density are provided in Table B-2.

This table shows that even in categories where crash rates do not always significantly vary between levels of access, the crash rate at the highest level of access is always significantly greater than the crash rate at the lowest level of access.

TABLE B-1

Site Class	Sample Size	Overdispersed	Significant Access Effect?	λ (Constant)	A (Dispersion)	B (Access Effect)
RC2NLT	120	Yes	Yes	-.59	.24	.33
RC2LT	14	Yes	Yes	-.72	.3	.57
RC4	36	Yes	Yes	-.91	.37	.81
RC6	25	Yes	No	1.28	.32	-.1
RE4	25	Yes	No	-.76	.13	.24
UC2NLT	58	Yes	No	.99	.47	.12
UC4NLT	48	Yes	Yes	.42	.4	.36
UC6	17	Yes	No	1.4	.27	.021
UC2LT	20	Yes	Yes	-.33	.09	.57
UC4LT	42	Yes	Yes	.12	.19	.49
UE4	45	Yes	Yes	.15	.61	.43

TABLE B-2

Category	Access Range	Predicted Rate	Lower Bound	Upper Bound
RC2NLT	0-5	0.87	0.69	1.1
	5-10	1.04	0.91	1.19
	10-15	1.31	1.06	1.62
	15+	1.75	1.27	2.4
RC4	0-5	0.95	0.72	1.27
	5-10	1.73	1.2	2.49
	10+	3.42	2.31	5.08
UC2NLT	0-10	3.52	2.1	5.9
	10-30	2.75	1.86	4.08
	30-50	4.11	3.2	5.31
	50+	5.59	4.05	7.73
UC4NLT	0-10	2.56	1.56	4.21
	10-30	4.32	3.06	6.11
	30-50	5.61	3.96	7.96
	50+	7	5.5	8.92
UC4LT	0-10	3.14	2.44	4.05
	10-30	4.45	3.67	5.36
	30-50	7.04	4.84	10.23
	50+	9.37	6.26	14
UE4	0-5	1.99	1.33	2.97
	5-10	1.82	1.26	2.64
	10-15	6.58	4.27	10.13
	15-20	3.41	2.02	5.75
	20+	4.11	2.57	6.58

FAX

Date: Friday, May 08, 1998 **Time:** 13:31:01 4 **Pages**

To: Howard Preston

Fax: 370-1378
Voice:

From: Gary A. Davis
University of Minnesota

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Comments:

Howard,
Here is the formula for confidence intervals, plus some other considerations.

Howard,

Here are some written comments on your access/accident statistics, including the formula for commputing confidence intervals. I've also identified some criticisms which one should be able to defend against if the analysis is used to formulate public policy. In the interest of being reasonbly complete I've no doubt belabored points with which you are familiar. My only defense is that at least the important points are now summarized on one document.

I. The standard approach to analyzing accident data is based on a Poisson statistical model of accident counts.

Notation:

y_k = accident count for site #k, k=1,...,N
v_k = traffic count for site k,
l_k = length of site k,
λ = accident rate.

Assumptions:

(1) All sites in sample have a common accident rate λ,
(2) Given λ, v_k and l_k, the accident count y_k are independent Poisson random outcomes with mean value

$$m_k = E[y_k] = \lambda v_k l_k .$$

II. Statistical Theory:

The maximum likelihood estimator (MLE) of the common accident rate λ is

$$\hat{\lambda} = \frac{\sum_{k=1}^{N} y_k}{\sum_{k=1}^{N} v_k l_k}$$

The expected value and variance of the MLE are:

$$E[\hat{\lambda}] = \lambda \quad (i.e.\ \hat{\lambda}\ is\ unbiased)$$

$$\sigma^2 = Var[\hat{\lambda}] = \frac{\lambda}{\sum_{k=1}^{N} v_k l_k}$$

When the expeced number of accidents $\lambda \sum v_k l_k \geq 70$, the MLE is approximately normally distributed.

III. Using the above results an approximate 1-α confidence interval for the estimated rate would be:

$$\lambda \pm z_{\alpha/2}\sqrt{\frac{\hat{\lambda}}{\sum_{k=1}^{N} v_k l_k}}$$

For example, suppose we had the following data, where the accident counts were made over one year:

Site #	accident count	ADT	length
1	10	1900	1.5
2	14	2000	1.35
3	18	5500	4.5
4	11	3000	0.53
5	30	4000	2.48

The estimated accident rate would be:

$$\hat{\lambda} = \frac{10+14+18+11+30}{365((1900)(1.5)+(2000)(1.35)+(5500)(4.5)+(3000)(.53)+(4000)(2.487))}\times 1{,}000{,}000$$

$$= \frac{83\ \textit{accidents}}{15.291\ \textit{MVMT}} = 5.43\ \textit{accidents/MVMT}$$

and the estimate of the standard error would be:

$$\hat{\sigma} = \sqrt{\frac{\hat{\lambda}}{\sum_{k=1}^{N} v_k l_k}} = \sqrt{\frac{5.43}{15.291}} = 0.6\ \textit{accidents/MVMT}$$

For a 90% confidence interval, α=0.10, so

$$z_{\alpha/2} = 1.645$$

$$\hat{\lambda} - z_{\alpha/2}\hat{\sigma} = 5.43-(1.645)(0.6) = 4.44\ \textit{accidents/MVMT}$$

$$\hat{\lambda} + z_{\alpha/2}\hat{\sigma} = 5.43+(1.645)(0.6) = 6.42\ \textit{accidents/MVMT}$$

IV. The statistical issues concerning the validity of the analysis stem from the model's assumptions. Criticisms which could be leveled at the analysis are:

(1) The accident counts at different sites are not independent.

(2) Even within a roadway category, the different sites have different accident rates. This could stem from

(a) unobserved differences (latent factors) among the sites which affect accident occurrance,

(b) a dependency of accident rate on traffic volume.

(3) The accidents counts are not distributed as Poisson random outcomes.

(4) Even if there is an association between access and accidents, there may not be a causal connection.

Criticism (1) can be dealt with by noting that the sites were selected randomly, and by checking the spatial separation of the selected sites. If the sites are well-separated, it would be difficult to imagine how the occurance of an accident at one site could effect the likelihood of an accident occurring at some other sites.

Criticism (2) is much more difficult to deal with, since recent empirical work indicates that

(a) even within relatively homogeneous sites, accident rates tend to vary, and

(b) accident rate often decreases as a function of traffic volume,

so that any conclusions one reached would be suspect unless one could show that these effects were unimportant. Assessing the importance of these effects would require an additional analysis, in which a model allowing for variability in the accident rates and traffic volume effects is fitted to the data. This would allow one to test whether or not rate variability and volume effects were present in the data, and to see if different conclusions might be reached when these effects were accounted for. The statistical methods for doing this sort of analysis are somewhat specialized, although research versions of software are available. Time permitting, I would be willing to undertake such an analysis (say during the second and third weeks of June) or provide guidance if you or one of your associates wanted to take it on.

Criticism (3) is actually related to criticism (2), and its importance would come out as a by-product of the above analysis.

Criticism (4) is simply the old "correlation does not imply causation" caveat, and stems from the fact that since we did not experimentally manipulate the access at the sites, there remains the possibility that some unobserved variable jointly causes both access and accidents, rather than there being a causal connection between access and accidents. This criticism cannot be answered by statistical analysis, but only be drawing on background knowledge concerning the causal mechanisms by which accidents are produced.

FAX

Date: Tuesday, June 30, 1998 **Time:** 15:23:01 3 **Pages**

To: Howard Preston

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From: Gary A. Davis
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Comments:

Results from overdispersion analyses of access/crash data

Date: June 30, 1998
To: Howard Preston
From: Gary A. Davis

Subject: Additional analyses of accident/access data sets

Howard,

At our last meeting, results were presented which indicated that:

(1) there was a statistically significant tendency for sites with higher access densities to have higher accident rates,

(2) the low correlations between exposure and access density indicate that the relation observed in (1) is probably not due to exposure being a common cause of accident rate and access density,

(3) however, in computing standardized residuals it appeared that the accident count data were overdispersed compared to the Poisson accident model. That is, the accident counts tended to have greater variability than allowed for in the Poisson model.

To determine if overdispersion compromised the finding of a significant access density effect, I fit a simple generalized linear regression model of the form

$$\lambda_i = \lambda d_i^{\,b}$$

to each of the six categories of sites used in your rersults. In the above equation

λ_i = accidents per MVMT at site #i,
λ = base accident rate for all sites in category,
d_i = access density for site #1,
b = coefficient which governs the access effect.

Note thate if the coefficient b=0, then sites have an accident rate that is independent of access density, while if b>0, accident rate tends to increase as access density increases. To allow for overdispersion, I assumed that the accident counts were distributed as negative binomial random variables, rather than as Poisson random variables. This necessitated estimating a third parameter, a, which governed the degree of overdispersion shown by the data. Without going into detail, a=0 corresponds to the data being generated as Poisson counts, while as a increases above 0, the data show increasing variability over that provided by the Poisson model.

For each class of sites, the parameters λ, a, and b were estimated using maximum likelihood, and the computations were implemented using Mathcad 6+. It was then possible to test whether or not the negative binomial model provided a reasonable fit to the data, whether or not the data showed significant overdispersion, and whether or not the parameter b was significant different from zero. The results are summarized in the following table

Site Class	Overdispersed?	Significant Access Effect?	λ	*a*	*b*
RC2	yes	yes	0.50	0.265	0.39
RCM	yes	yes	0.385	0.378	0.82
RE4	yes	yes	0.33	0.137	0.47
UC2	yes	yes	1.34	0.421	0.32
UCM	yes	yes	1.29	0.306	0.35
UE4	yes	yes	0.64	0.215	0.61

For all six categories, the accident data appeared to be overdispersed when compared to the Poisson model, but the effect of access denisty on accident rate still appears, in the sense that the estimated *b* parameters were significantly different from zero. To interepret the parameter estimates in the above table, suppose one had a section of rural two-lane highway with an access density of 7.5 accesses/mile. The predicted accident rate would then be

$$\lambda = \lambda d^{b} = (0.5)(7.5)^{0.39} = 1.1 \ accidents/MVMT$$

If you play around with the above equation, you'll see that the generalized linear regression model gives accident rates in the same neighborhood as the estimates presented in your tables.

In summary, it appears that the accident rate/access density relationship is robust with respect to overdispersion, and at this time I can think of no additional statistical quibbles which might compromise this finding. I'll send you copies of all my computations, along with a copy of a paper describing maximum likelihood estimation for negative binomial models, on which I based by analyses. If you have any further questions, please feel free to give me a call.