Case Study Operational and Safety Evaluation of an Interstate Highway

Alejandra Medina[1], Suzie Lee[1], and Hesham Rakha[2]

Abstract

The significant truck volume that traverses the I-81 corridor in addition to a number of highly publicized vehicle crashes that have occurred on I-81 over the past few years has raised public concern about the safety of the facility. Consequently, the operation and safety of a 120-mile section of I-81 from milepost 80 to 200 (termed the Study Area) in the state of Virginia was studied. The study demonstrated that apart from five sections along the entire I-81 corridor in the state of Virginia, the operational characteristics are within the design level-of-service C. In terms of safety, the data suggest that the fatal crash rate along the Study Area does not appear to be higher than the national rate for similar interstate facilities. In addition, the data do not suggest any non-fatal crash safety hazard along the Study Area or for any of the Study Area segments. Furthermore, the data suggest that Study Area experiences an injury and property damage crash rate that is lower than the national average rate.

1. Introduction

The significant truck volume that traverses the I-81 corridor in addition to a number of highly publicized vehicle crashes that have occurred on I-81 over the past two years has raised public concern about the safety of the facility. This concern warrants a systematic analysis of the safety and operation of I-81. Specifically, a 120-mile section of I-81 from milepost 80 to 200 (termed the Study Area) has been identified as a potentially hazardous section by a number of citizens in the Roanoke Area. A first step in addressing this highly publicized citizen concern is to quantify the operational and safety level of the Study Area.

1.1 Study Objectives

The objectives of this report are two-fold. The first objective is to quantify the operational level of the Study Area in terms of a number of Measures of Effectiveness (MOEs) that include the operating level of service, the operating speed, and the operating traffic density. The operating conditions are compared to the design MOEs in order to establish the operational level.

The second objective of the report is to quantify the safety level of the Study Area using a number of measures of effectiveness that include the crash rates of fatal crashes, fatalities, non-fatal crashes, injury crashes, property damage crashes, and passenger injuries.

1.2 Overview of Study Approach

This section provides a brief overview of the approach that was utilized to establish the operational and safety level of the Study Area.

---

[1] Virginia Tech Transportation Institute, Blacksburg, VA 24061.

[2] Charles Via Department of Civil and Environmental Engineering, Blacksburg, VA 24061. E-mail: hrakha@vt.edu. Tel: (540) 231-1505.

1.2.1 Operational Evaluation

The operational evaluation involved three steps. The first step established the criteria that were utilized for the design of I-81 in general and the Study Area in specific. The second step involved characterizing the current operating conditions along I-81 and the Study Area utilizing traffic data that were provided by the Virginia Department of Transportation (VDOT). The third and final step involved comparing the existing conditions along the Study Area, which were established in step 2, to the design criteria that were established in step 1. Finally, conclusions were made based on this comparison as will be presented in this report.

1.2.2 Safety Evaluation

Numerous researchers have attempted to develop measures that can be utilized to evaluate the level of safety of a roadway system. These research efforts have resulted in a fairly common measure of traffic safety, which is the crash rate. The crash rate is computed as the frequency of crashes per million Vehicle Miles Traveled (VMT). The use of vehicle miles traveled as the denominator ensures that the safety measure is not skewed by the facility length or by the traffic volume traversing the facility.

The safety level of the Study Area was established by comparing its crash rate to national crash rates for each of the five years that were analyzed, to state crash rates, to I-81 average crash rates, and to crash rates on a number of similar freeways in the state of Virginia including I-64 and I-77.

The crash frequency (numerator of the crash rate) was estimated using three crash databases that include the VDOT Highway and Traffic Records Information System (HTRIS) (VDOT, 2000), the General Estimates System (GES) (USDOT, 1998a) database, and the Fatal Accident Reporting System (FARS) (USDOT, 1998b) database. The VMT (denominator of the crash rate) was computed as the product of the Average Annual Daily Traffic (AADT) and the facility length. The HTRIS database served as a local database that provided crash frequencies along the Study Area of I-81, as illustrated in Figure 1. The FARS and GES databases provided national average crash frequencies for typical interstate facilities. Specifically, the GES database was utilized to estimate national crash frequencies and non-fatal crash frequencies on similar interstate facilities. Alternatively, the FARS database, which is a more comprehensive national database, was utilized to compute national fatal crash frequencies in addition to localized crash frequencies.

As indicated earlier, the VMT was computed as the product of the AADT and the section length. The AADT is typically computed as the average daily flow rate based on four days of counts that are conducted in each of the four seasons of the year. The computation of national interstate VMT is more complex. The Office of Highway Management provides a VMT for different facility types that include interstate, arterial, collector, and local roadways. These facilities are further categorized into rural and urban roadways. Using the national crash frequencies (total, fatal and non-fatal) together with the national VMT estimates, a national crash rate was computed for rural and urban interstate facilities. These crash rates were computed for five years in order to ensure that the comparison was not biased by an outlier year (1995 through 1999).

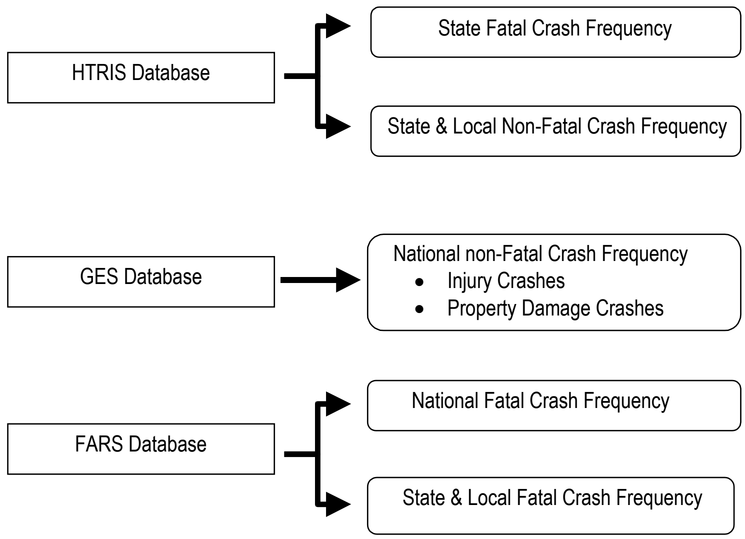

Figure 1: Study Approach for Estimating Crash Frequencies

1.3 Report Layout

The report first provides a brief background of I-81 prior to describing the study approach. Subsequently, the results of the operational evaluation are presented followed by the results for the safety evaluation of the Study Area. Finally, the conclusions of the study are presented together with recommendations for further analyses.

2. BACKGROUND

This section provides a brief description of I-81 in terms of its topography and basic characteristics. The objective of this description is to provide the reader with a background of the Study Area prior to describing the specifics of the analysis.

2.1 Overview of Interstate 81

According to Kozel (WWW, 2000), "*Interstate 81 in Virginia traverses 325.51 miles (including the 8.01 mile overlap with I-77, and the 29.91 mile overlap with I-64) from the Tennessee border in the City of Bristol to the West Virginia border in Frederick County. I-81 serves the towns and cities of Bristol, Abingdon, Marion, Wytheville, Pulaski, Radford, Christiansburg, Salem, Roanoke, Lexington, Buena Vista, Staunton, Harrisonburg, New Market, Strasburg, and Winchester. I-81 was built near to and parallel to an existing major interregional highway, US-11 from Tennessee to West Virginia.*

The terrain I-81 crosses is varied, with rolling to mountainous terrain in the southern half, and rolling to gently rolling Shenandoah Valley terrain on the northern half. I-81 in effect crosses many small transportation barriers, and crosses one major one, Christiansburg Mountain, where the highway has a long grade several miles long, bypassing US-11/US-460, a 4-lane highway that was the scene of numerous serious accidents before the Interstate opened there in 1971. I-81 provides 70 mph design speeds along the entire highway in Virginia.

I-81 crosses a wide variety of mostly rural areas and some major urban areas. It runs through Bristol, a city of 20,000 people, and there is an Interstate spur connector to the downtown, I-381. I-81 serves the Roanoke/Salem area, a metropolitan area of 200 thousand people, and there is an Interstate spur connector to downtown Roanoke, I-581. In Virginia, I-81 serves as the *"main street" of western Virginia, and in conjunction with I-64 also provides Interstate service from the western part of the state to the Richmond area and the Norfolk/Hampton Roads area. I-81 in conjunction with I-66 provides Interstate service between western Virginia and the Washington, D.C. area. I-81 passes through 12 counties in Virginia, with a total of about 20% of the state's population.*"

2.2 Virginia Department of Transportation I-81 Segments

As mentioned earlier, there have been well-publicized safety concerns about I-81, particularly concerning a 120-mile section extending 60 miles south of Roanoke and 60 miles north of Roanoke. This Study Area is divided into a number of segments. The segments are used by VDOT for maintenance and analysis purposes. The I-81 Study Area encompasses VDOT Segments 4 through 9, as summarized in Table 1. The segments vary in length from 6.5 miles (Segment 8) to 38.4 miles (Segment 4). As part of the analysis that is presented in this report, the operational and safety levels are estimated for the Study Area in addition to each segment within the Study Area.

Given that the segments are fairly short and that crashes, especially fatal crashes, are rare events, it is important to be vigilant in drawing conclusions regarding the safety level of each highway segment.

Table 1: I-81 Study Area Segment Classification

I-81 Segment	From Milepost	To Milepost	Length
4	80.7	119.1	38.4
5	119.2	136.4	17.2
6	136.5	152.4	15.9
7	152.5	162.7	10.2
8	162.8	169.3	6.5
9	169.4	201.4	32.0

3. EVALUATION APPROACH

This section describes the approach that was utilized to quantify the operational and safety level of the Study Area. The operational evaluation attempts to establish whether the current operation of I-81 is consistent with its design criteria. The safety evaluation compares the crash rate along the Study Area to national, state, and similar interstate crash rates. The objective of the comparison is to establish whether the Study Area poses a safety hazard to drivers when compared to similar interstate facilities in the US and in the state of Virginia.

3.1 Operational Evaluation

A first step in evaluating the operational level of a highway section is to define its design criterion. The design criterion represents the reference to which operating conditions are compared. If the operating conditions are consistent or better than the design criteria then the highway is considered adequate in terms of its operation.

According to the Highway Capacity Manual (HCM) (TRB, 1998), *capacity* is defined as the maximum number of vehicles that can use a specific section of roadway during a specific period of time that is at least a 15-minute duration. A principal objective of capacity analysis is the estimation of the maximum number of people or vehicles that can be accommodated by a given facility within a specified time period. Capacity analysis is therefore a set of procedures for estimating the traffic-carrying ability of facilities over a range of defined operational conditions.

The definition of operational criteria is accomplished by introducing the concept of levels of service. Level of Service (LOS) is used as a qualitative measure that characterizes the operational conditions within a traffic stream. Levels of service are characterized in terms of two factors that include average travel speeds and service volumes. The HCM defines six levels of service that range from A to F, with the level of service A representing the best operating conditions and level of service F representing the worst operating conditions, as summarized in Table 2.

Table 2: HCM Level of Service Description

LOS	Description
LOS A	Represents free-flow where vehicles can maneuver within the traffic stream and easily maintain the posted speed limit.
LOS B	Represents stable flow where drivers are somewhat restricted in maneuverability, but usually maintain the posted speed limit.
LOS C	Still in the zone of stable slow, but the maneuverability and speed are more restricted with high traffic volumes.
LOS D	Approaches unstable flow where temporary restrictions to the traffic flow may cause substantial drops in the operating speed. Drivers have little freedom to maneuver to pass, and the comfort and convenience of the driver are lowered.
LOS E	Represents the capacity of the facility. The traffic flow is unstable, vehicles are unable to pass, there may be momentary stoppages in the traffic flow, and the vehicles' operating speeds are very low.
LOS F	A forced traffic flow condition usually with low operating speeds and traffic volumes that are below capacity. This is often described as stop-and-go conditions.

The computation of traffic volume for use in estimating the level of service requires converting trucks, buses, and recreational vehicles into equivalent passenger cars. These factors range from a minimum of 1.2 for recreational vehicles traveling on level terrain to 6.0 for trucks traveling along mountainous sections, as summarized in Table 3 Given the rolling and mountainous terrain of I-81, the vehicle equivalency factor for trucks would range from 3.0 to 6.0. The accepted unit of time for expressing flow rate is a 1-hour period. It is customary to design highways with a sufficient number of lanes and with other features that will enable them to accommodate the forecast Design Hourly Volume (DHV) for the design year, which is frequently 20 years from the date of construction.

Table 3: HCM Vehicle Equivalency Factors for Estimating Levels of Service (AASHTO, 1994)

	Terrain		
	Level	Rolling	Mountainous
Trucks and Buses	1.5	3.0	6.0
Recreational Vehicles	1.2	2.0	4.0

Because traffic conditions vary during an hour, the HCM considers the most congested 15-minute period of the hour to establish the level of service for the hour as a whole.

The states use as a standard to design the different types of roads the "Policy on Geometric Design of Highways and Streets" (AASHTO, 1994) published by the American Association of State Highway and Transportation Officials, generally known as the "Green Book." The Guide specifies (Page 556 of Chapter VIII) that "*although choice of the design level is left to the user of the HCM, designers should strive to provide the highest level of service feasible and consistent with anticipated conditions…. For acceptable degrees of congestion, freeways and their auxiliary facilities, i.e. ramps, main lane weaving sections and C-D roads in urban and developing areas should generally be designed for level of service C*." The AASHTO Guide also indicates that "*in heavily developed sections of metropolitan areas, conditions may necessitate the use of level-of-service D for freeways and arterials, but such use should be rare and at least* *level-of-service C should be strived for*." Consequently, given the rural nature of I-81 it was assumed that the Study Area was designed for a level of service C.

The existing level of service along the Study Area and within each of the five segments of the Study Area were estimated based on traffic flow counts and speed measurements that were conducted by a number of consulting firms, as will be described later. The existing conditions were compared against the design level of service C in order to establish the adequacy of the current operational conditions along the Study Area.

It should also be noted that VDOT has indicated that the design speed for the I-81 freeway was 70 mph for most of the 325-mile section in the state of Virginia. While the operational evaluation presented in this report does not compare the design speed to existing speeds on the highway, driving experience clearly indicates that traffic typically travels at speeds that are higher than the 70 mph design speed.

3.2 Safety Evaluation

As mentioned earlier, the safety evaluation involved estimating crash rates for the Study Area as a whole and crash rates for each segment within the Study Area. These crash rates, which included total, fatal, and non-fatal crash rates, were compared against national average and state-wide average crash rates in order to provide a benchmark of the safety level along the Study Area. In addition, the crash rates along the Study Area were compared to crash rates on similar interstate highways in the state of Virginia. These interstates included portions of I-64 and I-77.

The analysis approach was structured in nature and included a number of validation checks at several points within the analysis in order to ensure that the data being generated and analyzed were accurate. To fulfill the objective of this report, a comparative analysis was done between the specified I-81 section and the National Interstate System, the Virginia Interstate System, I-81 Virginia, and similar interstates in the State of Virginia.

This section describes the safety evaluation approach in terms of the spatial and temporal scope of the evaluation and how crash rates were computed from the crash frequency data provided within the crash databases.

3.2.1 Spatial Scope of Safety Evaluation

a. National Interstate System and Virginia Interstate System

The Federal-Aid Highway Act of 1944 originally established the Eisenhower National System of Interstate and Defense Highways. The Federal-Aid Highway Act of 1956 and the companion Highway Revenue Act of 1956 further defined the purpose and extent of the system and, as subsequently amended, dedicated a group of Federal excise taxes on motor fuel and automotive products to support Federal-aid highway activities. By law, the Interstate System is limited to 42,500 miles (68,397 kilometers) under Section 103 of Title 23 and other routes incorporated under Section 139(a) of Title 12 that are logical additions or connections and meet Interstate System design standards. The Interstate System under Section 139(c) is limited only to Alaska and Puerto Rico. Highways may also be designated as part of the Interstate System under provisions of Section 1105(e) of ISTEA as amended under Section 332 of the National Highway System Designation Act of 1995. The total length of the Interstate System for 1999 is 46,413 miles, 33,076 of which are rural and 13,343 are urban. In 1999, the Virginia Interstate System had a total length of 1,113.62 miles, with 730.38 miles classified as rural and 383.24 miles classified as urban (VDOT). These figures remain fairly constant over the five-year analysis period (1995-1999).

b. Interstate I-81 and Study Area

Interstate I-81 Virginia, as described in the background section, traverses 325.51 miles from the Tennessee border in the City of Bristol to the West Virginia border in Frederick County. For maintenance purposes, VDOT divides the entire I-81 Virginia section into a total of 15 segments.

The specific Study Area of this report covers a section of I-81 between exit 80 (milepost 80.60) and exit 200 (milepost 201.43) for a total of 120.83 miles. This section covers segments 4 through 9 of the VDOT Inventory. For purposes of this report this section will be referred as Study Area.

c. Comparable Interstate Highways within the State of Virginia

In order to have a baseline of comparison to other, possibly similar interstates, two candidate interstate highways were included in this study. Comparison interstates were limited to those within Virginia, since it would be difficult to obtain non-fatal crash data from other states within the timeframe of this report. Features for comparison included road geometry (terrain), traffic volume, and percentage truck volume. The two interstates that were used for comparison were I-77 and I-64.

From its departure from I-81 to the North Carolina border, the I-77 terrain is similar to the I-81 Study Area, with traffic volume and truck traffic approaching I-81 Study Area levels. This portion of I-77 is classified as Segment 1, and includes mileposts 40.0-67.0. Segment 2 of I-77 from the West Virginia border to its intersection with I-81 near Wytheville is also considered to be very similar to the Study Area of I-81 in terrain (mileposts 0-27.2); however, it carries a significantly lower volume of truck traffic compared to the Study Area. Consequently, a comparison of the Study Area to Segment 2 of I-77 provides an opportunity to isolate the impact of higher truck volumes on the safety level of a highway system.

VDOT also suggested that sections of I-64 would be similar to the Study Area in terms of terrain, traffic volume, and truck traffic. From the West Virginia border until it intersects with I-81, I-64 is similar to the I-81 Study Area in terrain, but not in terms of traffic volume or truck traffic (Segment 1, mileposts 0-57.2). From its departure from I-81 to Charlottesville, the terrain is similar, and the traffic volume and truck traffic approach I-81 levels (Segment 2, mileposts 87.0-124.0). From Charlottesville until the boundaries of the Richmond area, the terrain is not as similar, but the traffic volumes and truck traffic are very similar to the I-81 Study Area (Segment 3, mileposts 124.1-177.0). Other areas of I-64 as it passes through Richmond and terminates in the Virginia Beach area were not analyzed because these highway sections are more urban in nature.

Consequently, the analysis attempted to include a number of highway segments that were similar in some aspects and different in others in order to isolate potential causes for differences in safety measures.

3.2.2 Temporal Scope of Safety Evaluation

This report covers a 5-year period that extends from 1995 to 1999. The data availability, accuracy, and access were major factors for the selection of the time period. Specifically, prior to 1995 the crash databases are limited in terms of information provided and consequently were not considered in the analysis. The use of a 5-year period is not uncommon. For example, traffic signal warrant analyses utilize crash statistics over a 5-year period for warranting the installation of a traffic signal. Consequently, it was concluded that this five-year period was long enough to take into account the latest changes in traffic volume, traffic patterns, and geometric design while providing sufficient data to conduct the analysis.

3.2.3 Computation of Crash Rates

In evaluating the safety level of any roadway, care must be taken to determine a suitable measure so that any two roadways can be meaningfully compared in terms of their safety. Raw numbers of vehicle crashes, usually in the form of the number of crashes occurring on a certain stretch of roadway over a certain period of time, tells part of the story, but it does not go far enough.

According to the Highway Design and Traffic Safety Engineering Handbook (Ruidiger L. *et al*., 1999), "*in accident analysis it does not make much sense to compare absolute numbers of accidents because of differing comparative conditions. Under comparative conditions, however, it is understood that section length and traffic volumes exhibit an influence on the accident situations. For instance, the longer the road section is the higher the accident possibilities are. Similarly, the higher the traffic volume is, the higher the accident possibilities are. Therefore the length of an investigated section and the traffic volume on that section (in this case vehicle miles traveled or VMT) must be considered in comparative accident reports. For this reason, relative accident numbers, such as accident rate, consider the length of the roadway section and the traffic volume to allow direct comparisons of different road sections with respect to traffic sections*."

For example, a roadway with very little traffic, which has 10 accidents per year, may have a higher accident rate than a more heavily traveled roadway with 30 accidents per year. In other words, there would be more accidents on the less traveled road for every mile driven on that road as compared to every mile driven on the more traveled road. Another important consideration is the type of accident being considered: fatal versus non-fatal, and for non-fatal, injury versus property damage only. The number of fatalities and injuries resulting from these accidents is also important. Rural versus urban accident rates can also be compared when adequate data are available.

Crash rates are obtained by taking the crash category of interest (e.g., number of fatal crashes) and dividing this by the number of vehicle-miles of travel (VMT) for each specific section or type of facility. Because crashes are such rare events, the resulting crash rates are easier to comprehend when presented in terms of 100 million vehicle-miles of travel (crashes per 100 million VMT). This is the standard reporting convention for crash rates, and it is used in this report.

Based on the different basic type of crashes and the total rural or urban categories, different crash rates can be computed. In many cases, analysis of rural versus urban crash rates is possible. For FARS, there is an urban/rural interstate variable. For GES, the urban/rural variable was dropped in 1999, so a population density variable was used instead. Both FARS and GES classify crashes as urban/rural according to ANSI standards, based on census information. VDOT does not use an urban/rural variable for non-fatal crash data; however, information on the boundaries of the different urban and rural classifications were utilized to identify whether a crash occurred in a rural of urban section.

4. OPERATIONAL EVALUATION

This section summarizes the findings of the operational evaluation of the Study Area along Interstate 81. These findings utilize data provided by the Virginia Department of Transportation based on the "Interstate 81 Improvement Study" that was contracted by VDOT to a number of consulting firms in 1998 (Anderson and Associates, 1998; Anderson and Associates, 1999; HDR Engineering, 1998; Whitman Requardt and Associates, 1998; and Wiley & Wilson, 1998). As part of this study, several Roadway Reports were conducted on I-81 by a number of consulting firms. The reports recommended methods to provide additional roadway capacity on I-81 and its connecting roadways and ramps, and to accommodate heavy truck traffic in an efficient and safe way. Traffic counts were obtained both manually and through machine counts and as a result an analysis of the level of service for the base year was performed (1996-1997). This base year represents a horizon of 25 years from the initial construction of the highway (1971). Consequently, the base year would be consistent with the design year of the highway, which is typically 20 years.

An analysis of the level of service of the corridor indicates that this facility currently provides a level of service C or better during peak hours with the exception to five sections, as summarized in Table 4. It is important to note that the AASHTO Guide does mention that "*in heavily developed sections of metropolitan areas, conditions may necessitate the use of level of service D*." Only five sections fell outside the design LOS. These sections included the southbound section of I-81 from milepost 143 to 141 (LOS F-D), the northbound section of I-81 from mileposts 141 to 143, 143 to 146, 195 to 200, and 200 to 205. Consequently, these five sections would require some measures of improvement in order to attain the design LOS of C. The section between Exit 141 and 143 Southbound that has a Level of service D-F for the base year covers the entrances to the City of Salem and Roanoke, and specifically the Junction of I-581 and I-81. A LOS of F is clearly not acceptable; however, VDOT is currently implementing a number of geometric improvement strategies that include increasing the length of the I-581 on-ramp acceleration lane. Further analyses and traffic simulation studies would be required to investigate whether these proposed geometric improvement alternatives are sufficient to reduce the LOS to C.

Table 4: Level of Service of the Study Area Mainline

Exit Number		Peak Hour LOS	
From Exit	**To Exit**	**Northbound**	**Southbound**
80	81	B	B
81	North of 81	B	B
84	86	B	B
86	89	B	B
89	92	B	B
92	94	B	B
94	98	B	B
98	101	B	B
101	105	B	B
105	108	B	A-B
108	109	B	B
109	114	B	B
114	118	B	A-B
118	128	B	A-B
128	132	B	B
132	137	B	B
137	140	C	B-C
140	141	B	C-D
141	143	D-C	F-D
143	146	C-D	B-C
146	150	C-B	B
150	156	B	A
156	162	B	B
163	167	B	C
167	168	B	B
168	175	B	B-C
175	180	B	B
South of180	180	B	B
180	188	C	B
188	191	B	B
191	195	C	B
195	200	D	C
200	205	D	C

5. SAFETY EVALUATION

Accident statistics are most often used to quantify and describe three principal informational elements (McShane R. *et al*., 1990). These elements include accident occurrence, accident severity, and accident involvement. Accident occurrence is generally described as the number or types of accidents that occur. Accident severity is generally expressed as the number of deaths (known as fatalities) and/or person injuries that are incurred. Accident involvement identifies which categories of vehicles and drivers are involved in these accidents. This report focuses on the two first elements, namely accident occurrence and severity. Accidents are commonly classified into two main classifications, fatal and non-fatal crashes. Non-fatal crashes include injury and property damage crashes, as summarized in Table 5. Accident severity is characterized by two parameters. The first is the number of fatalities, which is the number of persons killed in a fatal crash. The second severity measure is theof the number of injuries, which is the number of persons that are injured in the crash.

Table 5: Accident Classifications

Crash Type	Description
Fatal Crashes	Crashes in which one or more persons were killed as a result of the accident.
Non-Fatal Injury Crashes	Crashes in which no one died but at least one person sustained injuries because of the crash.
Non-Fatal Property Damage Crashes	Crashes in which no one died or was injured but damage to vehicles or other property was incurred.

5.1 Estimation of Crash Frequencies

The number of accidents (commonly known as crashes in the traffic safety community) can be obtained through local, state, and federal databases depending upon the type and location of the crash. The national sources for crash data are the Fatal Accident Reporting System (FARS) and General Estimates System (GES), both maintained by the National Highway Traffic Safety Administration (NHTSA). In addition, VDOT collects crash data including statewide fatal and non-fatal crashes in its HTRIS database.

The estimation of national and statewide VMT is provided in the Highway Statistics (USDOT, 1996; USDOT, 1997; USDOT, 1998c; USDOT, 1999 and USDOT, 2000), published each year by the USDOT Federal Highway Administration (FHWA). The estimation of localized VMT is provided within VDOT's HTRIS database. The HTRIS database is similar to other state crash databases that are typically used by transportation safety researchers nationwide in conducting more specific safety analyses.

This section first describes the various state-of-practice crash databases before describing the procedures for estimating VMT. Subsequently, the various analyses that were conducted as part of this study are presented.

5.1.1 State-of-Practice Crash Databases

For purposes of conducting this study, two national databases were explored over a five-year analysis period (1995 through 1999). The number of fatal crashes for each year was obtained using the Fatal Accident Reporting System (FARS), a national database maintained by the U.S. DOT and NHTSA. In addition, the National Accident Sampling System's (NASS) General Estimates System (GES) was utilized in this study to estimate non-fatal crashes. The GES database is also maintained by NHTSA and provides estimates of the number of crashes and injuries that relate to accident, vehicle, driver, and person variables. Although the GES database can provide *estimates* of fatalities, extremely accurate fatality data can be obtained using FARS. Thus GES was only used for the non-fatal crash analysis, while FARS was used for the fatal crash analysis. Each of these databases are described in more detail in the following sub-sections.

a. The FARS Crash Database

FARS was created in 1975 to assist the traffic safety community in identifying traffic safety problems and evaluating both motor vehicle safety standards and highway safety initiatives. The mission of FARS is to make vehicle crash information accessible and useful so that traffic safety can be improved. FARS includes all crashes that result in a fatality (to a vehicle occupant or non-motorist) that occur within 30 days of the crash due to injuries resulting from the crash. FARS contains data on all fatal traffic crashes within the 50 states, the District of Columbia, and Puerto Rico.

For the FARS analyses, a top-down approach was used. National data were obtained first, followed by Virginia, Virginia I-81, I-81 Study Area, I-81 Study Area segments, I-64 comparison area, and I-77 comparison area. Urban and rural figures were obtained for each analysis. The databases were analyzed using SAS statistical analysis software. Since states, roadways, and mileposts are identified for each fatal crash, it was possible to have a very accurate count for all fatal crashes occurring on Virginia interstates, down to the nearest milepost.

b. The GES Crash Database

In the GES system, accidents are sampled and the results weighted so that national estimates can be obtained. The database includes all crashes including both fatal and non-fatal crashes. Since the GES database uses a sampling technique, there is a margin of error in the estimates derived from the database. Through formulas provided for each year of the database, the 95% confidence interval for these estimates can be calculated.

For purposes of this study, given that the FARS database in more accurate in terms of fatal crashes, the GES database was only utilized for non-fatal crash analysis. In extracting the crashes from the database, only interstate crashes were analyzed over the five-year analysis period. For 1995 through 1998, it was possible to obtain good estimates of urban versus rural interstate crashes, but in 1999, the relevant variable was dropped, and a population density variable was thus used to estimate the urban versus rural numbers for 1999. As a check, the urban and rural crash estimates for 1999 using the population density variable were compared to 1995 through 1998 estimates and found to be consistent.

Unlike FARS, because of the GES sampling approach, it was not possible to obtain crash estimates by state, roadway, or milepost. Thus, non-fatal crash data for the state of Virginia were obtained from VDOT's HTRIS database that will be described next.

c. The State HTRIS Database

VDOT maintains the Highway and Traffic Records Information System (HTRIS) state database. HTRIS contains data for crashes involving death, personal injury, or property damage (report not required for property damage crashes less than $1,000) reported by investigating officers. As mentioned above, there were limits on the non-fatal crash data available from the GES system, and thus the HTRIS database was utilized to augment the GES database. The HTRIS database provides information on the number of fatal and non-fatal interstate crashes in Virginia, including the type and location of the crash.

The HTRIS data were provided to the Virginia Tech Transportation Institute (VTTI) by VDOT (VDOT, 2000a). In order to ensure the accuracy of the database, two checks were made. The first check involved comparing the HTRIS fatal crash frequency against FARS data as will be described later. The second check involved comparing the VMT estimated by the Manual of Highway Statistics against HTRIS estimates.

5.2 Estimation of Vehicle Miles Traveled

The Manual of Highway Statistics is published annually by the Office of Highway Information of the US DOT Federal Highway Administration (FHWA). The FHWA collects from the states and publishes in the Manual of Highway Statistics information necessary to support its responsibilities to Congress and the public. The information comes from several sources, including various administrative agencies within 50 states, over 30,000 units of local government, the FHWA, and other Federal agencies. This information is used in the development of highway legislation at both the Federal and State level.

Section 5, Highway Usage and Performance, contains data on the physical, operational, usage, extent, and performance characteristics of public roads existing in the United States. Table VM-2 contains a summary of the states' estimated highway travel based on traffic counts taken along selected highway sections that are grouped into functional systems, according to the character of service they provide.

The FHWA currently uses Daily Vehicle-Miles of Travel (DVMT) as the primary measure of travel activity for the U.S. highway system. The daily travel times 365 days (366 days for leap years) equals the annual travel. Each state reports the amount of travel to the nearest thousand DVMT by functional system for rural areas, small urban areas, and individual urbanized areas. In concept, travel is calculated as the product of the annual average daily traffic (AADT) and the centerline length of the section for which the AADT is reported. AADT is required to be reported for each section of Interstate, National Highway System (NHS), and other principal arterials; as a result, travel can be computed for these functional systems on a 100% basis. The current data are based on the Highway Performance Monitoring System (HPMS). The HPMS comprises a combination of sample data on the condition, use, performance, and physical characteristics of facilities functionally classified as arterials and collectors (except rural minor collectors); certain conditions and use data for all rural arterials and urban principal arterials; and system-type data for all public road facilities within each state. In most cases, the calculated universe travel by functional system agrees with the state reported area-wide value.

5.3 Estimation of Crash Rates

In estimating the crash rates for the purposes of the study, a number of data sources were utilized. Specifically, the crash data were obtained from three crash databases, namely the FARS, GES, and HTRIS database. The VMT were obtained from two sources, namely the Manual of Highway Statistics and the HTRIS database. The fatal crash analysis only utilized the FARS database for estimating crash rates, as summarized in Table 6. Alternatively, the non-fatal crash analysis utilized a combination of the GES and HTRIS databases, as summarized in Table 7.

Table 6: Fatal Accident Analysis Data Sources

Facility	Accident Data Source	VMT Data Source
National Interstates	FARS	Highway Statistics
Virginia Interstates	FARS	Highway Statistics
I-81	FARS	HTRIS
I-64	FARS	HTRIS
I-77	FARS	HTRIS

Table 7: Non-Fatal Accident Analysis Data Sources

Facility	Accident Data Source	VMT Data Source
National Interstate	GES	Highway Statistics
Virginia Interstate	HTRIS	Highway Statistics
I-81	HTRIS	HTRIS
I-64	HTRIS	HTRIS
I-77	HTRIS	HTRIS

Two checks were made in order to ensure consistency across the various data sources. The first check compared the VMT estimates that were provided from the Manual of Highway Statistics against the HTRIS estimates, as illustrated in Figure 2. The figure clearly indicates a close match between the two sources of VMT data that were utilized in the study. Consequently, the comparison clearly demonstrates the validity of the HTRIS VMT data.

The second check involved comparing the number of fatal crashes for the State of Virginia provided by FARS (federal database) to those provided by the HTRIS (VDOT database), as illustrated in Figure 3. Again, the figure clearly demonstrates consistency between the two crash databases. While the FARS database was only utilized in conducting the fatal crash analysis, it did provide confidence in the HTRIS database for conducting the non-fatal crash analysis.

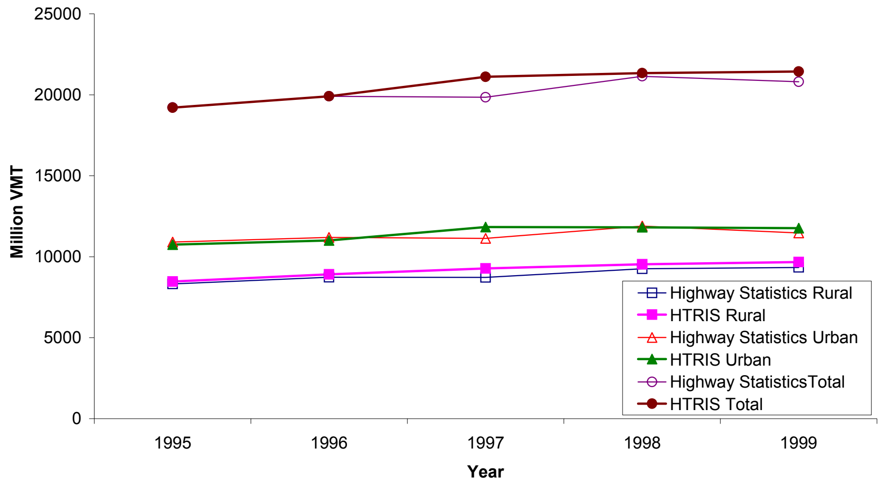

Figure 2: Comparison of VDOT and Highway Statistics VMT Estimates

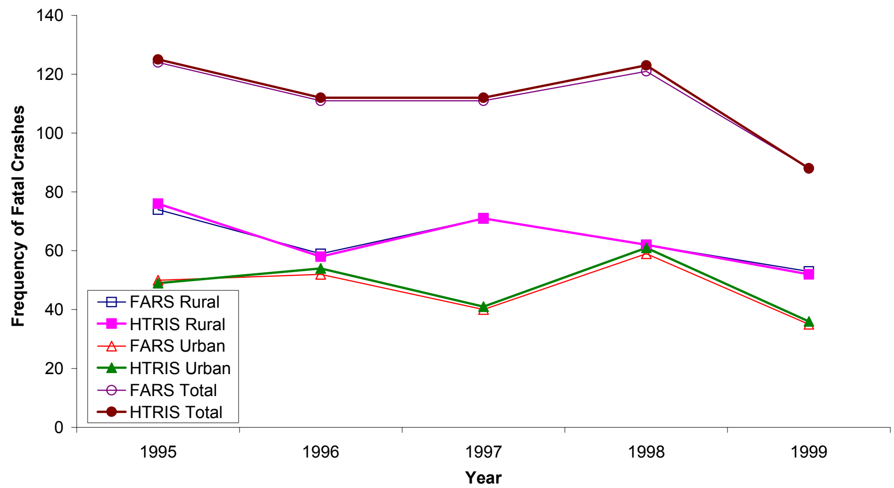

Figure 3: Comparison of HTRIS and FARS Fatal Crash Frequency Estimates

Having ensured the validity and consistency of the various data sources, crash rates were computed for each section for each year in the analysis period. These crash rates were then compared against national and statewide rates to establish the safety level of the Study Area. The computation of the national and statewide crash rate can be computed as the total number of crashes divided by the total VMT. This rate does not distinguish between urban and rural facilities. Because the fatal crash rate on a rural facility is approximately twice that on an urban facility, extreme caution must be utilized in using these crash rates as a benchmark, as will be demonstrated later. Given that the majority of segments along I-81 are rural in nature, a refinement to the approach might be to use national and statewide rural crash rates as the benchmark. Finally, a third refinement would be to compute national and statewide crash rates that are weighted by the percentage of urban and rural components within each section. While this weighted national and statewide crash rate is ensured to be consistent with the section composition, it does mean that a unique benchmark is established for each section. Based on the variability in urban/rural composition of the various study sections, as summarized in Table 8, the third approach was selected for conducting the analysis presented in this report.

Using the percentage urban and rural composition, a weighted benchmark national and statewide crash rate was computed for each of the sections of Table 8. The use of a Weighted National Crash Rate (WNCR), which was computed using Equation 1, ensured that each section benchmark was consistent with the section urban/rural composition.

For example sections 7, 8, and 9 of I-81 are 100% rural so the WNCR in this case would be National Rural Crash Rate (NRCR). Alternatively, in the case of segment 4, the WNCR would equal the NRCR multiplied by 0.86 plus the NUCR multiplied by 0.14.

$$WNCR = NRCR \times PerRural + NUCR \times PerUrban \quad [1]$$

Where:

NRCR	National Rural Crash Rate
NUCR	National Urban Crash Rate
PerRural	Percent of section length that is considered rural
PerUrban	Percent of section length that considered urban

Table 8: Percentages of Urban and Rural Components within Each Section

Section	Urban	Rural
I-81	14.11%	85.89%
I-81 SA	18.82%	81.18%
I-81 Seg 4	12.14%	87.86%
I-81 Seg 5	21.63%	78.37%
I-81 Seg 6	89.50%	10.50%
I-81 Seg 7	0.00%	100.00%
I-81 Seg 8	0.00%	100.00%
I-81 Seg 9	0.00%	100.00%
I-64	3.00%	97.00%
I-64 Seg 1	2.45%	97.55%
I-64 Seg 2	0.88%	99.12%
I-61 Seg 3	5.08%	94.92%
I-77	1.35%	98.65%
I-77 Seg 1	0.00%	100.00%
I-77 Seg 2	3.03%	96.97%

5.4 Comparison of Crash Rates

In order to demonstrate how the calculations were computed, Table 9 summarizes the number of fatal crashes beginning at the national level and continuing down to the segment level for the years 1995 through 1999. As would be expected, the numbers decline as the area of interest grows smaller/shorter. However, areas of different lengths are still comparable when the accident rate is calculated, since this takes into account the number of vehicle miles traveled for each area of interest. For example, in 1999 there were 4,374 fatal crashes on all U.S. interstates (Urban and Rural). There were 648,124,000,000 vehicle miles traveled on U.S. interstates that year, for a fatal crash rate of 0.70 per 100 million vehicle-miles of travel (VMT). Alternatively, in 1999, I-81 in Virginia experienced 25 fatal crashes, with a total of 4,458,496,170 vehicle miles traveled, for a fatal crash rate of 0.42 per 100 million VMT. Finally, for segment 6 of I-81 (within the Study Area), there was 1 fatal crash and 291,492,650 VMT, for a fatal crash rate of 0.34 per 100 million VMT.

It is important at this point to note that as the section length decreases the estimated crash rate varies significantly because fatal crashes are extremely rare events. Specifically, Segment 1 of I-64 experiences a crash frequency that ranges from a low of 2 fatal crashes/year to a high of 10 fatal crashes/year, resulting in a variation in the range of 500%. Alternatively, at the national level the number of fatal crashes ranges from 37,043 to 37,351, which constitutes a fluctuation of only 0.8%. Consequently, caution must be exercised when analyzing the safety level of short highway sections.

This section compares the Study Area crash rate to national and statewide rates considering both fatal and non-fatal crashes over the 5-year analysis period.

Table 9: 1995-1999 FARS Fatal Crash Frequencies

Parameter/Year:	1995	1996	1997	1998	1999	Mean
All U.S. fatal crashes	37,241	37,351	37,280	37,107	37,043	37,204
U.S. fatal crashes, interstate	4,005	4,322	4,374	4,507	4,593	4,360
All Virginia fatal crashes	826	807	900	834	794	832
Virginia fatal crashes, interstate	124	111	111	121	88	111
I-81 Virginia fatal crashes	33	25	24	30	25	27.4
I-81 Va. Study Area fatal crashes	14	8	9	14	9	10.8
I-81 Segment 4 fatal crashes	3	2	1	7	1	2.8
I-81 Segment 5 fatal crashes	1	3	1	1	3	1.8
I-81 Segment 6 fatal crashes	2	0	2	3	1	1.6
I-81 Segment 7 fatal crashes	3	0	1	1	0	1.0
I-81 Segment 8 fatal crashes	0	0	2	1	1	0.8
I-81 Segment 9 fatal crashes	5	3	2	1	3	2.8
I-64 Segment 1 fatal crashes	4	10	10	2	3	5.8
I-64/I-81 overlap fatal crashes	5	0	4	0	0	1.8
I-64 Segment 2 fatal crashes	2	2	3	2	0	1.8
I-64 Segment 3 fatal crashes	6	4	3	3	3	3.8
I-77 Segment 1 fatal crashes	1	3	4	5	2	3.0
I-77/I-81 overlap fatal crashes	0	1	0	0	0	0.2
I-77 Segment 2 fatal crashes	1	0	0	0	3	0.8

5.4.1 Fatal Crashes

One question of great interest concerns how the Study Area compares to national and statewide interstate fatal crash rates. In an attempt to address this question, the national and statewide crash rate for interstate facilities, both urban and rural, was computed, as illustrated in Figure 4. The results indicate that the national crash rate is in the range of 0.75 crashes per 100 million VMT while the Virginia crash rate is in the range of 0.60 crashes per 100 million VMT.

As can be seen in Figure 4, it appears that both I-81 and the Study Area compare favorably with the national fatal crash rate for 1996, 1997, and 1999, while the Study Area experienced a crash rate that exceeded the national fatal crash rate in 1995 and 1998. Note that the national crash rate remained fairly stable over this five-year period, while the Study Area rate fluctuated greatly. This fluctuation is likely due, at least in part, to the small sample of fatal crashes from the Study Area. The Virginia interstate crash rate showed less fluctuation than the Study Area, as would be expected. In general, the I-81 and Study Area fatal crash rate was at the high end, or exceeded the Virginia interstate fatal crash rate. It is important to note that both the national and statewide crash rates that are presented in Figure 4 were computed without distinguishing between urban and rural facilities. Given that the national composition of urban facilities was much higher than the Study Area (40 versus 18 percent urban), the national rates are skewed more towards the lower urban rates. Specifically, in 1999 a total of 4,593 interstate fatal crashes occurred that included 1,959 crashes on urban interstates and 2634 on rural interstates. On the other hand, the interstate VMT was 3870×10^8 for urban interstates compared to $262^*\times10^8$ for rural Interstates. Consequently, because the rural interstate numerator was bigger and the denominator was smaller, the rural fatal crash rate per 100 million VMT was twice that of the urban interstates (1.00 versus 0.51). Similarly, the Virginia Interstate crash rate varies from 0.57 for rural interstates to 0.30 for urban Interstates.

Figure 5 illustrates the variation in the national and statewide rural fatal crash rates. Again, the state of Virginia experienced a lower crash rate compared to the national fatal crash rate. The figure also demonstrates that while I-81 and the Study Area experienced crash rates lower than the national average, they did exceed the Virginia fatal crash rate in 1998. It should be noted that both the statewide and national rates have been inflated in Figure 5 because they assume that both I-81 and the Study Area are rural highways.

Figure 6 uses the weighted crash rate concept, which provides a more accurate means of comparing national and statewide crash rates to local crash rates. The figure clearly demonstrates that I-81 as a whole experienced a fatal crash rate lower than the national average for the entire 5-year analysis period. Alternatively, I-81 experienced a fatal crash rate marginally higher than the statewide rate in 1998 and 1999. The Study Area also experienced a fatal crash rate lower than the national rate except for 1995. Furthermore, the Study Area fatal crash rate is consistent with the Virginia fatal crash rate for 3 of the 5 years that were analyzed.

Consequently, the data suggest that the fatal crash rate along the Study Area is not higher than the national rate for similar interstate facilities.

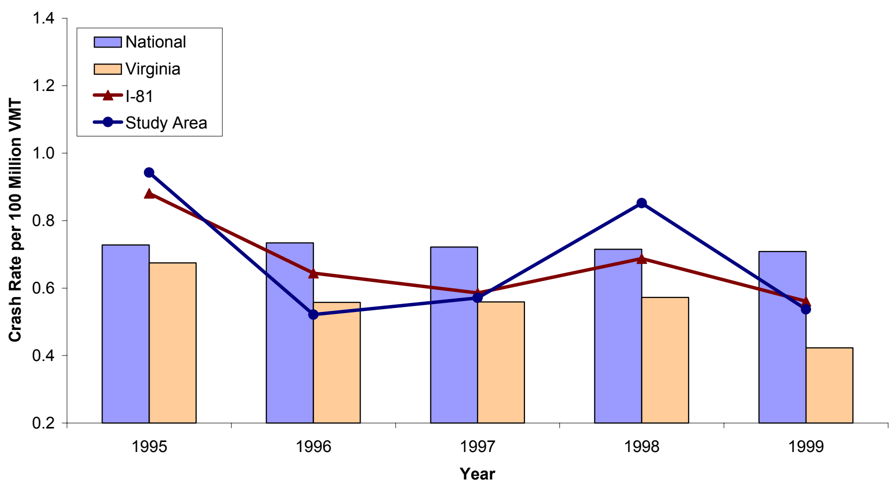

Figure 4: Variation in Fatal Crash Rate for Combined Urban and Rural Classifications (Interstate Roadways)

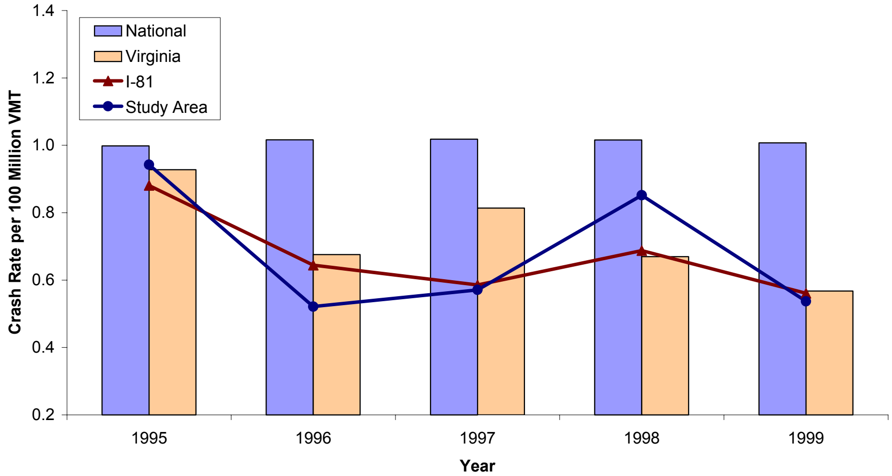

Figure 5: Variation in Fatal Crash Rate for Rural Classifications (Interstate Roadways)

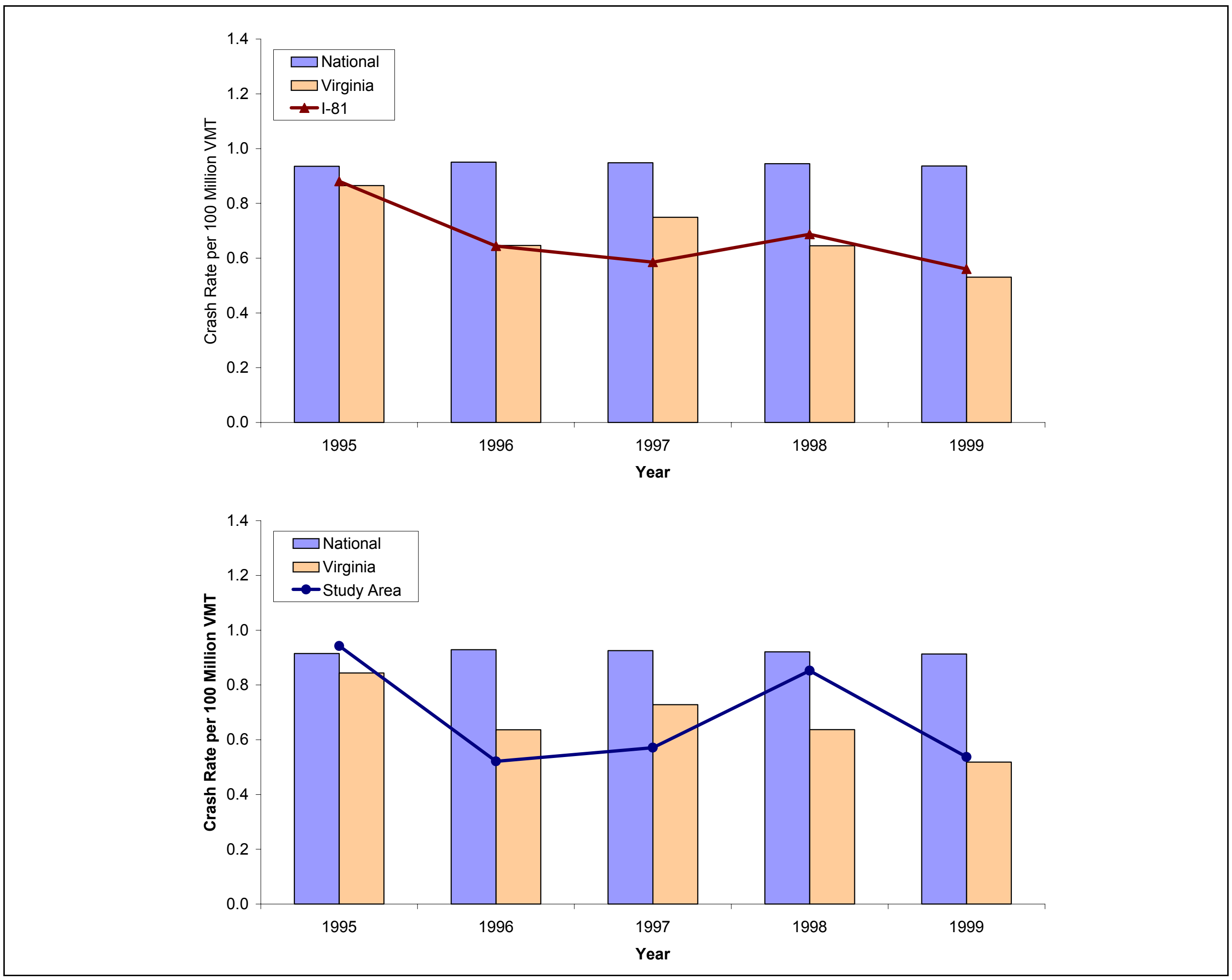

Figure 6: Variation in Fatal Crash Rate for Weighted Urban/Rural Classifications (Interstate Roadways)

5.4.2 Non-Fatal Crash Rates

Having analyzed the fatal crash rate, the next step was to analyze the non-fatal crash rate along the Study Area. As mentioned earlier, the national non-fatal crash estimates produced from the GES database may differ from the true values because they are based on a probability sample of crashes and not a census of all crashes. The standard error of an estimate is a measure of the precision or reliability with which a particular GES sample approximates the results of a census. By adding and subtracting two standard errors, a 95% confidence interval can be created. For example, the estimated number of non-fatal crashes for the U.S. for 1999 was 441,142 crashes with a 95% confidence interval of ±57,711 crashes. Consequently, there is a probability of 95% that the actual number of non-fatal crashes for the U.S. in 1998 is somewhere between 498,853 and 383,431 crashes. For this study the technical team adopted the common approach that if the results are between the confidence interval limits, they are considered acceptable. If they are above the upper confidence limit they are not considered acceptable, while if they are below the lower confidence limit then they appear to be less than the national average.

a. Total Non-Fatal Crashes

The national non-fatal crash rate appears to be fairly constant over the 5-year analysis period, as illustrated in Figure 7. Furthermore, Figure 7 shows that the Study Area compared favorably with the national non-fatal crash rate in all of the five years of analysis. Specifically, all Study Area observations are below the lower confidence limit. Specifically, the national non-fatal crash rate per 100 million VMT varies between 79 (1996) and 52.8 (1998), while the Study Area crash rate varies between 44.5 (1996) and 50.2 (1998). The figure also demonstrates that the Study Area compares favorably to Virginia rates that varied between 64.6 (1997) and 71.3 (1999). In general, the Study Area non-fatal crash rate was consistent with the overall I-81, I-64, and I-77 crash rates.

In order to statistically verify whether the Study Area non-fatal crash rates were lower than national and statewide rates, a statistical t-test was conducted assuming unequal variances. The statistical test indicated that the lower non-fatal crash rate that was observed along the Study Area was statistically significant to a degree of confidence of 95%.

Although the Study Area experienced a slightly higher crash rate than the overall I-81 crash rate in the state of Virginia, the crash rate per 100 million VMT for I-81 oscillated between 39.7 and 44.6). This difference was found to be marginally statistically significant at a degree of confidence of 95%.

A comparison of the non-fatal crash rate between the Study Area and I-64 indicates a lower but statically significant difference at a level of significance of 95%. In comparison to I-77, the Study Area has a lower crash rate for 1997 and 1999 but a higher rate for the other three years. However, these differences were not found to be statically significant at a 95% confidence level. Consequently, the results suggest that the combination of the high truck volume and mountainous terrain along the Study Area does not appear to increase the non-fatal crash rate.

If the Study Area is analyzed in greater detail, the variations of the crash rate between the various constituting segments are clear, as illustrated in Figure 8. The results clearly indicate that the crash rate on segment 6 (milepost 136.5 to 154.4) is higher than the other segments. Segment 6 coincides with section 141 to 143 that operated at a LOS F-D. It should be noted, however, that Figure 8 demonstrates that the non-fatal crash rates for all sections are well below the statewide crash rate and do not exceed the 95% confidence limit for the national rate.

Figure 7 and Figure 8 were generated using total non-fatal national and statewide crash rates, and thus do not reflect differences in urban/rural composition across study sections.

Consequently, a weighted non-fatal crash rate was computed for each section to reflect the urban/rural composition using Equation 1. Figure 9 illustrates how the Study Area non-fatal crash rate compared to national crash rate over the 5-year analysis period. The figure clearly demonstrates that overall the Study Area experienced a significantly lower non-fatal crash rate. Figure 10 demonstrates that Segment 5 (milepost 119.2 to 136.4) experienced a lower than average non-fatal crash rate, while Segment 6 (milepost 136.5 to 154.4) experienced an average non-fatal crash rate for all years except for 1998.

Consequently, it can be concluded that the data do not suggest any safety hazard along the Study Area or for any of the Study Area segments. In fact, the Study Area appears to provide a lower non-fatal crash rate than the national and statewide rates.

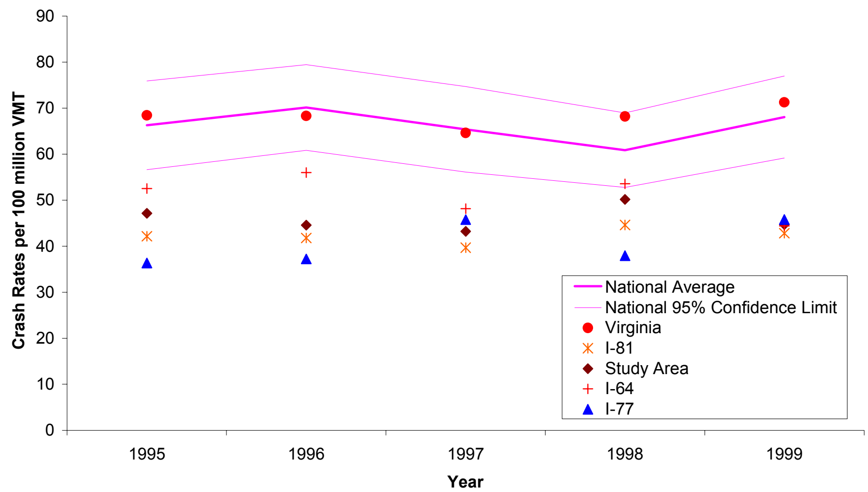

Figure 7: Comparison of Study Area, National, and Statewide Non-Fatal Crash Rates

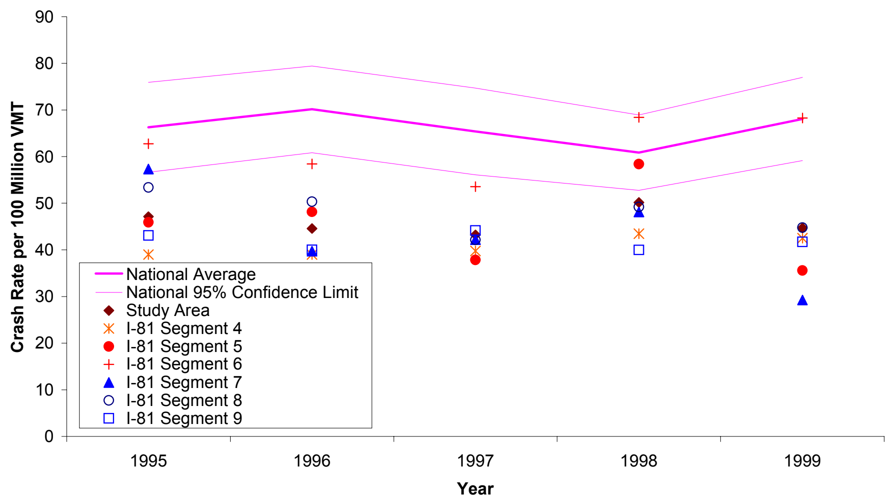

Figure 8: Comparison of Non-Fatal Crash Rates for Study Area Segments

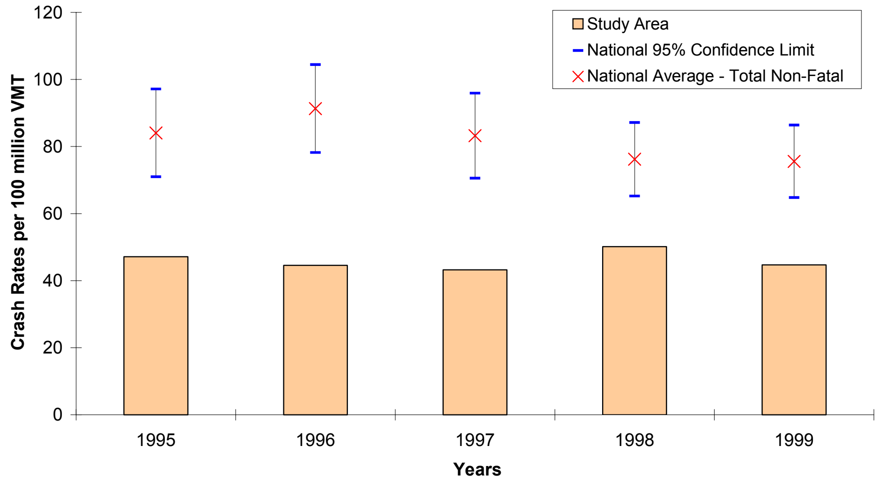

Figure 9: Comparison of Study Area and National Average Non-Fatal Crash Rates

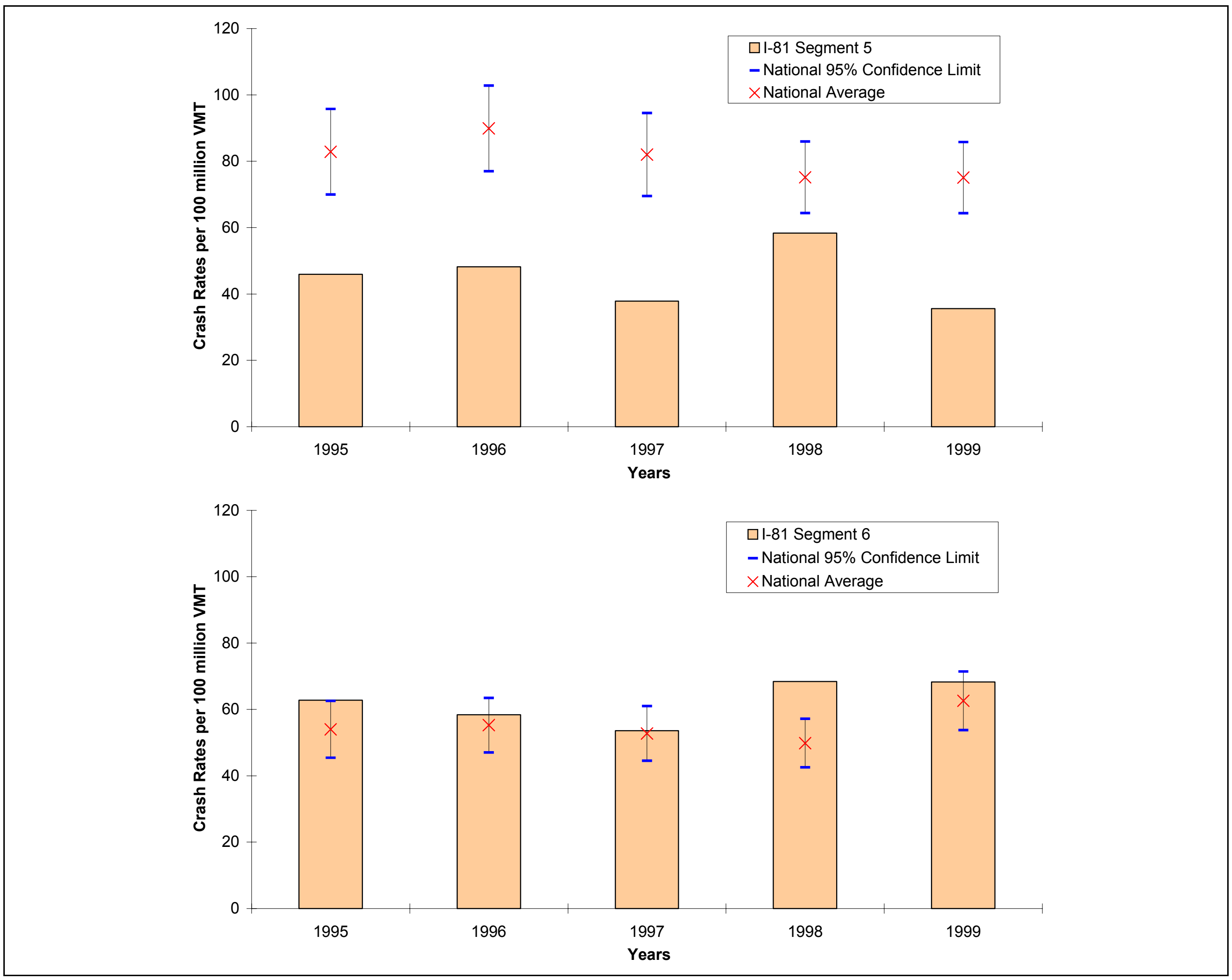

Figure 10: Non-Fatal Crash Rate Variation Between 1995 and 1999 on Segments 5 and 6

b. Injury Non-Fatal Crashes

The non-fatal crash rates were analyzed in further detail by considering both injury and property damage crashes. In general, the state of Virginia experienced a higher than average injury crash rate (crashes that result in at least one person sustaining injuries due to the crash), as illustrated in Figure 11. The Study Area, on the other hand, experienced an injury crash rate that was consistent with the national rate and in most cases below the national rate, as illustrated in Figure 12. Furthermore, the Study Area injury crash rate was found to be consistent with other interstate facilities in the state of Virginia. In addition, I-81 experienced an injury crash rate that was generally lower than the national rate.

When the Injury crash rates (number of injuries/VMT) are analyzed, the Study Area compared favorably with the Virginia injuries, I-64 and I-77. Compared with national injury rates, the Study Area fell within the 95% confidence limits.

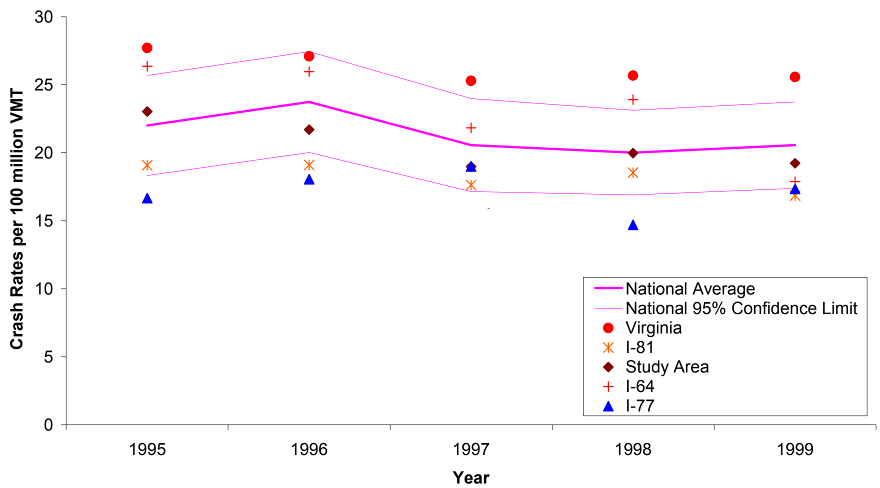

Figure 11: Non-Fatal Injury Crash Rate Variation Between 1995 and 1999

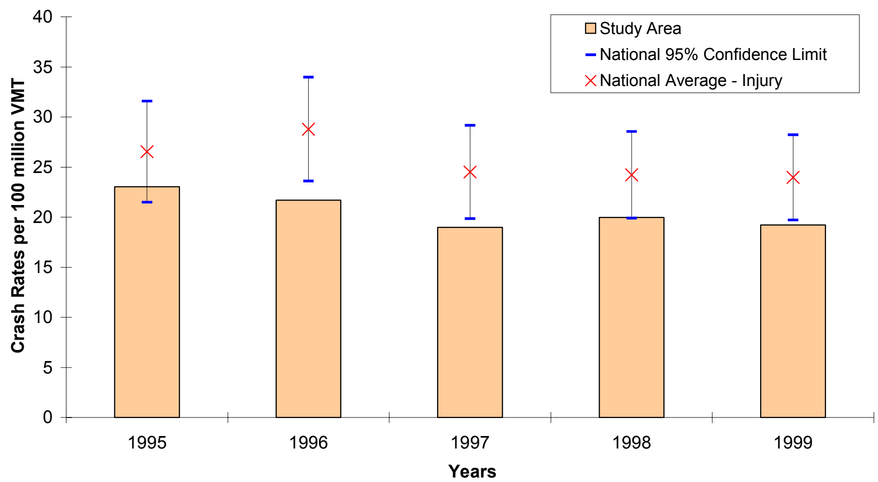

Figure 12: Comparison of Study Area and National Average Injury Crash Rates

c. Property Damage Non-Fatal Crashes

For the case of property damage crash rates, the Study Area compared favorably with the national property damage crash rate and the Virginia property damage crash rate. Also, the Study Area was similar to I-81 and I-77 and better than I-64, as illustrated in Figure 13.

The results clearly demonstrate that the Study Area compared favorably against the national weighted property damage rate, as illustrated in Figure 14. The figure clearly demonstrates a lower than average property damage crash rate along the Study Area.

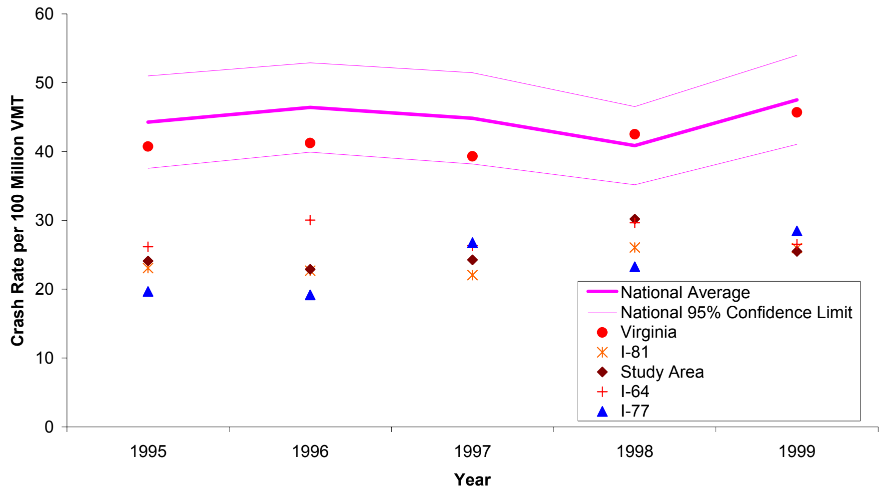

Figure 13: Non-Fatal Property Damage Crash Rate Variation Between 1995 and 1999

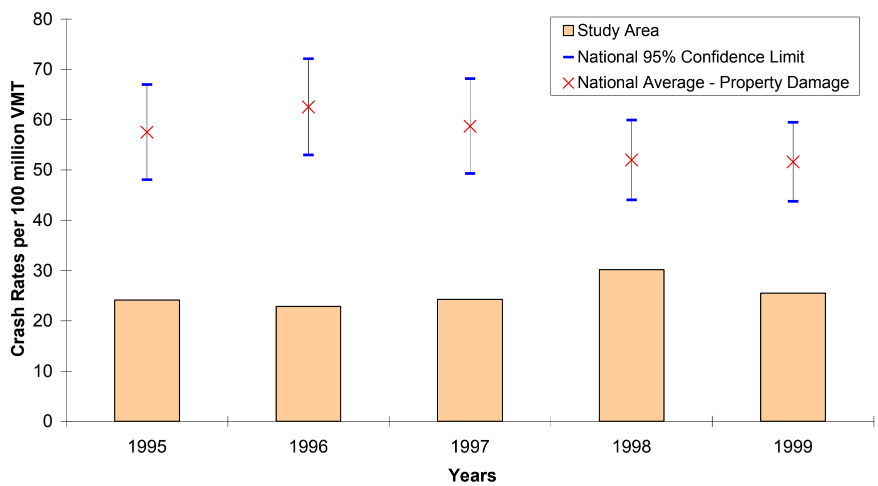

Figure 14: Comparison of Study Area and National Average Property Damage Crash Rates

6. CONCLUSIONS

Prior to presenting the conclusions of the study, it should be noted that the analyses that were conducted as part of this study depended entirely on the accuracy of the crash frequency and VMT data. With this caveat in mind, the following conclusions can be drawn.

First, in terms of the operational evaluation of the Study Area, two conclusions can be drawn:

1. While no speed measurements were conducted as part of this study, driver experience indicates that the current operating speeds generally exceed the design speed of 70 mph.
2. Apart from five sections along the entire I-81 corridor in the state of Virginia, the operational characteristics are within the design level-of-service C. Of concern is the operation of the southbound section of I-81 between mileposts 141 and 143, which is currently operating at a level-of-service F-D. It is recommended that measures be taken to enhance the operation of this section.

Second, in terms of the safety evaluation of the Study Area, the following conclusions can be drawn:

1. The data suggest that the fatal crash rate along the Study Area does not appear to be higher than the national rate for similar interstate facilities.
2. The data do not suggest any non-fatal crash safety hazard along the Study Area or for any of the Study Area segments. In fact, the Study Area appears to provide a lower non-fatal crash rate than the national and statewide rates. It should be noted, however, that Segment 6 (milepost 136.5 to 154.4) experienced a higher than average non-fatal crash rate for one of the five years analyzed (1998).
3. The data suggest that Study Area experiences an injury crash rate that is lower than the national average rate.
4. The data suggest that the Study Area experiences a property damage crash rate that is lower than the national average rate.

7. RECOMMENDATIONS FOR FUTURE WORK

Due to time constraints in producing this report, it was not possible to conduct a comprehensive operational and safety evaluation of the I-81 corridor and the Study Area. Consequently, it is recommended that resources be allocated to extend this study. Suggested future work includes:

1. Conduct a detailed evaluation of the operational behavior of the sections that were identified as operating above the design level-of-service C. Various strategies to enhance the operation of these sections should be tested and compared.
2. Provide a detailed discussion and presentation of other crash rates including passenger injuries and property damages.
3. Conduct a more in-depth and statistical analysis into the findings that are presented in this report. For example, conduct further analysis into isolating truck-related crashes and computing crash rates for various vehicle classifications.
4. Identify potential causes and factors that are related to the vehicle crashes. Potential factors to consider include visibility, weather, traffic, and driver-related factors.
5. Conduct a sensitivity analysis of crash rates given changes and/or errors in VMT estimates and quantify their impact on the conclusions of the study.
6. Conduct an in-depth analysis of various traffic improvement measures (e.g. roadway design, traffic temporal variations, etc.) on the operation and safety of the Study Area.

References

Anderson and Associates (1998), Interstate 81 Improvement Study-Rockbridge and Augusta Counties- Study Area # 7, Virginia, October.

Anderson and Associates (1999*), Interstate 81 Improvement Study- Whyte County- Study Area # 3*, Virginia, May.

AASHTO (1994), *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington DC.

HDR Engineering (1998), *Interstate 81 Improvement Study - Town of Christiansburg, City of Salem, Counties of Montgomery, Roanoke and Botetour-Study Area # 5*, Virginia.

WWW (2000), Http://www.roadstothefuture.com/I81 Va Desc.html, Accessed November.

McShane R, William, and Roess R. (1990), *Traffic Engineering*, Prentice Hall Polytechnic Series in Transportation.

Ruidiger L., Basil P., and Theodor M. (1999), *Highway Design and Traffic Safety Engineering Handbook*, Washington DC.

TRB (1998), *Highway Capacity Manual, Special Report 209*, Third Edition, Transportation Research Board, National Research Council. Washington DC.

USDOT (1996), *Highway Statistics-1995, Federal Highway Administration*, U.S. Department of Transportation, Washington DC.

USDOT (1997), *Highway Statistics-1996*, Federal Highway Administration, U.S. Department of Transportation, Washington DC.

USDOT (1998a), *National Automotive Sampling System (NASS), General Estimates System (GES), Analytical User's Manual 1988-1998*, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington DC.

USDOT (1998b), *Fatal Accident Reporting System Analytic Reference Guide, 1975-1997*, U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, Washington, DC:

USDOT (1998c), *Highway Statistics-1997*, Federal Highway Administration, U.S. Department of Transportation, Washington DC.

USDOT (1999), *Highway Statistics- 1998*, Federal Highway Administration, U.S. Department of Transportation, Washington DC.

USDOT (2000), Highway Statistics-1999, Federal Highway Administration, U.S. Department of Transportation, Washington DC.

VDOT (2000), *HTRIS Database*, Virginia Department of Transportation, Richmond, Virginia.

VDOT (2000a), "I-81 Seg All Crash Data 11-15-00.xls," Virginia Department of Transportation, Richmond, Virginia.

Whitman, R. and Associates, LLP (1998), *Interstate 81 Improvement Study, Wythe, Pulaski and Montgomery County. Study Area # 4*, Virginia.

Wiley & Wilson (1998), *Interstate 81 Improvement Study - Rockbridge and Botetourt Counties - Study Area # 6*, Virginia.