FINAL REPORT

Quantify the Effects of Raising the Minimum Speed on Rural Freeways and the Effects of Restricting the Truck Lanes Only in the Daytime

Volume 1: Evaluating the Relevance of 40 MPH Posted Minimum Speed Limit on Rural Interstate Freeways in Florida

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16. Abstract

The relevance of posting the 40 MPH minimum speed limit signs on rural Interstate freeways in Florida is analyzed by correlating safety and traffic operating characteristics. The operational data showed only that only 0.14 percent of vehicles had speeds below 40 mph while a 4-year data of reported crashes indicated that about 9 percent of vehicles involved in crashes were estimated to be traveling with speeds below 40 mph. The modeling of crashes by Poisson regression showed that increase in the median speed significantly reduced the number of crashes while increase in the variation between fast and slow moving traffic significantly increased the number of crashes. The preliminary recommendation that could be made based on the available data is for Florida to discard the practice of posting of minimum speed limit signs on rural Interstate freeways. This recommendation was partly influenced by the survey results which showed that 25 States do not post minimum speed limit signs on highways.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

The primary purpose for posting minimum speed limits on Interstate freeways is to improve uniformity of traffic flow and the safety of operations by reducing speed variations in a traffic stream. Following the repeal of the federally sanctioned 55 mph maximum speed limit through the enactment of the National Highway System (NHS) Designation Act in 1995, Florida was among the first states to raise the maximum speed limit on Interstate freeways to 70 mph. Prior to raising the maximum speed limit, Florida had a practice of posting 40 mph minimum speed limit on rural Interstate freeways. The minimum speed limit was not revised upward after raising the maximum speed limit.

The existence of 70 mph (maximum) / 40 mph (minimum) creates a wide 30 mph gap between fast and slow vehicles traveling on rural Interstate freeways. This gap may lead to a number of phenomena associated with speed differentials including improper or poor lane changing, tailgating, frustration to drivers desiring to maximize their speed, and the formation of platoons in the traffic stream. These negative effects may result in poor safety and operating characteristics on rural Interstate freeways. This study was conducted to evaluate the relevance of the 40 mph posted minimum speed limits on rural Interstate freeways in Florida through evaluation of individual vehicle speeds collected from various sites on rural Interstate freeways. The study also evaluated crashes that occurred on these sites to determine the influence of low speed vehicles on safety. The theme throughout the analysis was to examine traffic operating speeds at the lower end of the speed distribution, particularly close to the 40 mph minimum speed limit value.

Methodology

Traffic data were collected from rural sites on Interstate 10, Interstate 75, Interstate 95, and Florida Turnpike. Data were not collected on Interstate 4 because the freeway runs through mostly urbanized areas resulting in congested traffic flow conditions not amenable to the collection of free flow speed data. Data were collected from automatic traffic counters that count traffic twenty-four hours a day throughout the year. Various speed measures were extracted from the data for descriptive and inferential statistical analysis. In addition, spot speed data collected in pre-70 mph era were acquired from individual FDOT districts and compared with speed data in post-70 mph era. The crash data were extracted from police reports of crashes occurring on these sites for a 4-year period from January 1998 to December 2001. The attributes of interest in the safety analysis were the level of injury resulting from a crash, the estimated speed of involvement, the type of crash, and the contributing causes for the crash. Poisson regression analysis was used to model the relationship between various regressor variables with crash response variables.

Findings

The following are the major findings of the study based on the traffic operation and crash data analyses:

- The speed data indicated that about 0.14 percent of the vehicles were traveling below the 40 mph posted minimum speed limit and only 1 percent of the vehicles were traveling with speeds below 55 mph. The results further revealed that raising the speed limit from 65 mph to 70 mph did increase average speeds on rural Interstate freeways. The comparison of the 1996 data to 2002 data showed that the average speeds have increased by 5 mph, which is the same amount of statutory speed limit increase. However, speed variance did not change much although the average of 15^{th} percentile speeds on all sites increased by 3 mph.
- While the operational data showed only 0.14 percent of vehicles had speeds below 40 mph, the crash data indicated that about 9 percent of vehicles involved in crashes were estimated to be traveling with speeds less than 40 mph. This finding suggests that while only a small proportion of vehicles might have been traveling with low speeds, they do however have a significant impact on the safety characteristics of these freeways. Thus, any strategy for dealing with the issue of posting of minimum speed limit must take this fact into account.
- A general loglinear model showed that several traffic variables affects the operational safety on these freeways. The modeling results showed that increasing the median speed significantly reduced the number of crashes while increasing the variation between fast and slow moving traffic significantly increased the number of crashes.

Recommendations

The preliminary recommendation that can be made at this point is to discard the posting of minimum speed limit signs on rural Interstate freeways. This recommendation is based on the following pointers revealed by the study:

- The survey of the practice of posting minimum speed limit signs across the United States revealed that 25 States, i.e. half of the country, do not post minimum speed limit signs on their Interstate freeways. These States indicated in the survey that they are not experiencing any problems with slow moving vehicles on their freeways.
- The field data indicated that only one percent of drivers were driving with speeds less than 55 mph bringing into question the significance of the 40 mph minimum speed limit in influencing traffic operations on these freeways. However, this assertion is tentative and needs further research.
- Discussions held with the Florida Highway Patrol officers indicated that law enforcement agencies in Florida rarely give warnings or citations based on the posting of minimum speed limit signs. If the minimum speed limit signs were removed, there are other Florida State Statutes that could be used by an officer to issue citations or tickets to slow moving drivers.
- If the posting of the 40 mph speed limit is discontinued, the public can still be made aware of the State Statute stipulating the 40 mph minimum speed limit through the State's Drivers Handbook and other driving education media.

It is further recommended that research be conducted to ascertain the effect of the current posted minimum speed limit sign on drivers' behavior. The results presented in this study do not have enough predictive power to predict what traffic operations would result if the posting of minimum speed were scrapped. A more definitive answer to this question would require a field evaluation of sites with and without minimum speed limit signs. A multi-state study of such a research paradigm is warranted.

CHAPTER 1--INTRODUCTION

1.1 Overview

The primary purpose for posting minimum speed limits on Interstate freeways has been to improve uniformity of traffic flow and safety of operations. Traditionally, these limits serve to discourage certain vehicles that can not maintain adequate speed levels from using Interstate freeways which are designed for high speed mobility. The effect of speed limit on uniformity of traffic flow is generally revealed by the variability of vehicle speeds while the review of traffic crash experience on a particular highway section can determine the influence of speed limits on highway safety. In addition, posting of minimum speed limit is designed to assist law enforcement in issuing citations and warning drivers.

Rural Interstate freeways in the United States are generally designed with a design speed of 70 mph. Thus, high-speed operation on these freeways under favorable conditions of traffic and roadway environment is generally expected. The posting of minimum speed limits on these freeways seeks to minimize vehicle interactions by reducing vehicle conflicts resulting from high speed variability caused by the presence of significant amount of traffic in the traffic stream. In reducing interaction between vehicles, minimum speed limits improve the uniformity of traffic flow by raising the speed of slow vehicles close to the mean speed of traffic stream and thus decreasing large speed differentials between fast and slow drivers. On freeways, possible conflicts that result from the presence of large speed differentials in a traffic stream include sideswipes, angle collisions (which are caused by poor lane changing and passing maneuvers), and rear end collisions.

While the influence of speed variability on crashes is somewhat clear, the effect of posted minimum speed limit signs on reducing differences in speed of the traffic stream is not well known. Traffic flow resulting from the change of speed limits in the highways may be evaluated in terms of the change in the average vehicle travel speeds, the decrease of total trips travel times, changes in vehicle speeds patterns, and dispersion from the average speed. Comparing vehicle speed distributions before and after changing the speed limit on a highway is usually expected to give some insights on the influence of posted speed limit signs on the traffic using that highway.

Following the Enactment of the National Highway System (NHS) Designation Act of 1995 which repealed the federal sanctioned 55 mph national maximum speed limit on Interstate freeways, many states raised their speed limits on Interstate freeways. Florida was among the first states to raise the maximum speed limit on Interstate freeways to 70 mph for 65 mph. Prior to the passing of NHS Designation Act, a 40 mph minimum speed limit was in effect in rural Interstate freeways in Florida. The minimum speed limit of 40 mph was not changed with the rise in maximum speed limit and is still posted on rural Interstate freeway system and Turnpike. Figure 1.1 shows the speed limit sign posted on Florida Interstate highway.

Figure 1.1 A dual speed limit sign posted on Interstate 10 freeway in Florida

With such a wide gap (30 mph) between maximum and minimum speed limits, the relevance of the posted 40 mph minimum speed limit is increasingly being questioned. The existence of the 40 mph minimum speed limit on Interstate freeways along with the 70 mph maximum speed limit may perhaps lead to a number of negative effects associated with speed differentials, which include poor lane changing, tailgating (driving too close to the slow vehicle in front), frustrations to fast drivers, and formation of platoons of traffic. The results of which could be poor safety of operation and inefficient use of the capacity of these freeways. In this light, it is logical to question the significance of the existing 40 mph minimum speed limit on operation of these freeways.

Evidences obtained from past researches have verified that traffic flows with small speed differentials have resulted into highway safety improvements *(1, 2, 3, 4)*. These studies have indicated that many speeds-related crashes result from both excessive low and high speeds. Despite of the methodological differences of these studies, their results have further suggested that measures to control large variations of vehicle speeds could be an effective component of traffic control in highway safety.

1.2 Objective and Scope of the Project

This project was aimed at evaluating the effect of the 40 mph minimum speed limit on safety and operating characteristics on rural Florida Interstate freeways. In particular, the scope of services for the project included determining how speed characteristics deviate from the 40 mph minimum speed and speed variability that results there from, and determining the effects of current speed characteristics on safety.

Accomplishment of these objectives required answering the following questions: Is it still relevant to post a minimum speed limit of 40 mph in light of the increased maximum speed limit to 70 mph? Has the continued posting of 40 mph increased the speed variability and does it have negative safety effects on these freeways? Should the minimum speed limit be increased to a higher value or should it be abandoned altogether if the review of the current speed distribution show that the 15th percentile speed is much higher than the 40 mph posted minimum speed? Conclusions and recommendations were based on data analysis with these questions forming the basis of data analysis.

1.3 Methodology

The fundamental questions above are answerable by a carefully designed study from which drivers' behavior and their corresponding speed characteristics are observed in a period of time on freeway sections with similar geometrics and traffic characteristics but some with 40 mph minimum speed limit posted and others without minimum speed posted. Such a study would require having control sites with minimum speed limit signs removed or covered. Obviously, such a study would have legal implications which were difficult to overcome at the time this project was conducted. Thus an observational study was suggested and limited to determining how speed characteristics deviate from 40 mph and determining the speed variability resulted therefrom.

In this study individual vehicle speed data were studied in order to observe carefully type and class of vehicles at any instant of time that are traveling at the lower end of speed distribution. The 15th percentile speeds, which are the measure for the slow driving on the highway, were evaluated and then compared with the 40 mph minimum speed limit. In addition, the study evaluated the contribution of slow moving vehicles to the speed variability and safety of operation on these freeways. The following procedure was followed in undertaking the study:

- A number of studies related to speed limits and speed differentials were reviewed to determine good techniques for the evaluation of minimum speed limits on Interstate freeways. Some of the literature reviewed included publications from Transportation Research Board, Accident Analysis and Prevention, and American Economic Review. Several reports from different transportation agencies were also reviewed. In addition, some current rules, regulations, and published standards in setting and posting minimum speed limits on Interstate freeways were reviewed.
- A mail out survey was conducted to solicit information on the nationwide current practice of posting and the use of minimum speed limits on the Interstates and mailed to all fifty States in the United States. The target group was States' traffic operations and/or maintenance engineers since they are responsible for placing and maintaining speed limit signs on freeways.
- A representative sample of the Florida Interstate freeways was selected and 24-hour individual vehicle speed records were collected and analyzed. Detailed quantitative analyses of individual vehicle speeds collected were conducted to obtain traffic flow

characteristics, vehicle speed distribution and platoon characteristics on these highways. Descriptive statistics were computed for the vehicle speeds. Then inferential statistic analyses were used to draw conclusions about the speed characteristics on the Interstate freeways. In addition, historical analysis was conducted by statistical comparison of pre-70 mph maximum speed limit characteristics and current (year 2002) speed characteristics. Safety characteristics of these freeways were analyzed by thorough examination of crash typology and conducting statistical analyses on the effect of several traffic variables on occurrence of crashes by using a log linear model.

CHAPTER 2—REVIEW OF LITERATURE AND CURRENT PRACTICE

2.1 Overview

To understand the operational and safety characteristics resulting from the intent and practice of posting minimum speed limits on a freeway a thorough literature review was conducted. Several published and unpublished studies that focused on the history of minimum speed limits on Interstates freeways and the state-of-the-art were reviewed. Literature search also concentrated on the influence of posted speed limit signs in increasing or reducing speed variability in a traffic stream. The literature review also concentrated on determining the link between speed variability and probability of crash occurrence as well as the influence of slow driving on the efficiency of traffic operations and safety.

One of the earliest speed limit study indicated that posted speed limits came into effect in 1901 when Connecticut imposed speed limits to its roadways *(5)*. After the First World War, development of motor vehicle technology and the construction of modern highways marked the beginning of the efforts to unify speed rules nationwide. Thus, in 1920 a non-government committee of traffic laws was formed and a first draft of the Uniform Vehicle Code (UVC) was proposed in 1923. This code recommended minimum speed regulations on roadways among a number of vehicle and traffic rules to be adopted by State governments and local transportation authorities *(5)*.

The 1964 review of the Traffic Laws Annual, a manuscript prepared to present permanent and complete record of 1963 State legislations related to traffic rules, showed that by the end of 1962 Florida and other 30 states had ‘slow speed’ laws in conformity with the Uniform Vehicle Code *(6)*. The slow speed law stated that it was unlawful to drive at such a slow speed as to impede the normal and reasonable movement of traffic on a highway. At that time, Florida had a 40 mph minimum speed limit established on four-lane freeway system. The manuscript showed that in 1962, Florida, Georgia, and South Dakota had some clauses in their statutes that restricted the minimum speed limit to 40 mph on rural freeways while Michigan and North Carolina had 45 mph minimum speed restriction.

2.2 Procedure for Posting Speed Limits

Establishing speed limits is one of the oldest strategies that have been used to control driving speeds on highways. The responsibility for setting speed limits in the United States lies with State and local agencies where legal speed limits are established by State legislatures and/or local councils on the basis of judgments about the trade-offs among public safety, community concerns, and travel efficiency *(7)*. After the repeal of the National Maximum Speed Limit (NMSL) Law by the Congress in 1995, the responsibility of the U.S. Department of Transportation remains to provide guidance on appropriate methods and procedures on setting and enforcing speeds to States and local governments so that they have speed limits that maximize the efficient and rapid transportation of people and goods while eliminating unnecessary risks of unsafe speed *(8)*.

While maximum speed limits are customarily posted on every roadway, minimum speed limits have been established on some high-speed roadways to deter slow drivers as well as to deter vehicles that cannot maintain adequate speed levels from using these facilities *(7)*. McShane *et al.* (1998) argued that the lower speed limit should be set close to 15th percentile of the vehicle speeds moving in free flow conditions rounded up to the 5 mph because it would likely represent slow driving very well. This percentile speed is normally adjusted by considering the trade off between safety and efficiency of operation. In many States, the minimum speed limit on Interstate freeways is 40 mph or 45 mph. However, the review of the literature conducted as part of this study did not reveal the basis to choosing 40 mph or 45 mph and not any other value for minimum speed.

In 1985, the Federal Highway Administration (FHWA) proposed criterion of setting minimum and maximum speed limits based on percentage of mean speed in order to constrain large variations of speed on highways with large standard deviations *(10)*. The FHWA criterion combined both speed variance and risk of involvement in a crash as shown in Figure 2.1.

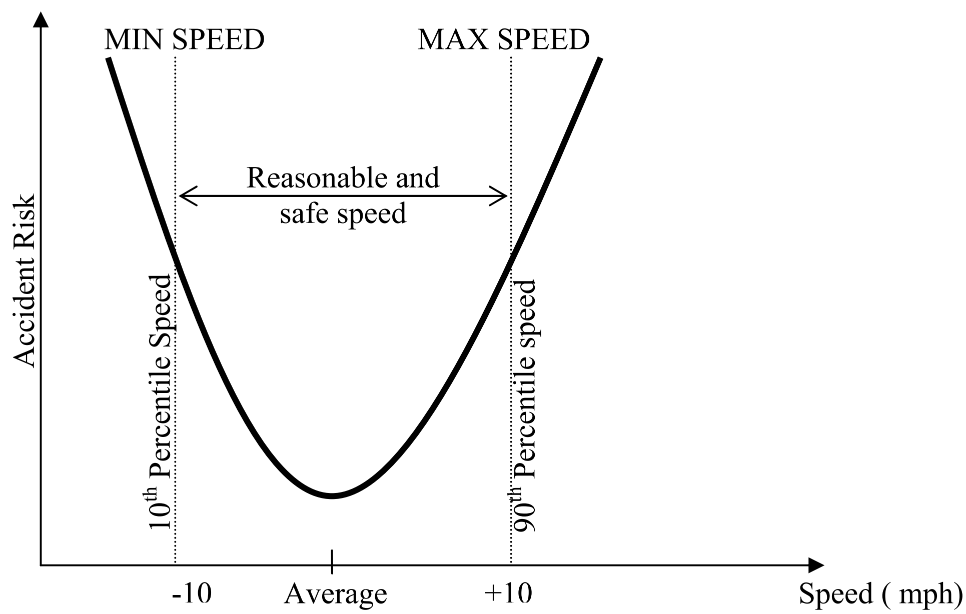

Figure 2.1 Speed limits, mean speed and accident risk [reproduced from Reference *(10)*]

This criterion showed that when the distribution of vehicle speeds is plotted against the accident risk the safe driving speed range lies within 10 mph of the mean speed. This study showed that these thresholds are equivalent to 10th and 90th percentiles of free flowing vehicle speeds in the lower and upper ends of the speed distribution, respectively. These thresholds are based on rounding the speed to the next 5 mph increment. This criterion postulated that setting the speed limit based on accident involvement and speed variance could bring the majority of motorists in compliance with the limits and thus reduce the need for enforcement as well as minimize the risk of crashes by narrowing variations among slow and fast moving vehicles.

In Florida, speed limits are set according to the Florida State Statutes, Chapter 316 which deals with the state uniform traffic control laws. Sections 183 and 187 of this Chapter authorizes the State Department of Transportation to set speed limits on freeways when it is considered safe and advisable after conducting engineering and traffic investigation *(11)*. In addition, the Florida State Statutes specifies that the minimum speed limit is 40 mph on rural Interstate freeways and defense highways.

2.3 Traffic Engineering Studies

Traffic engineering studies conducted in relation to setting speed limits are divided into two categories—operational studies and safety studies. Operational studies involve the evaluation of traffic flow characteristics on the facility while safety studies involve the evaluation of crash characteristics. A combined analysis of these studies generally forms the basis of most engineering decisions including finding types of traffic control devices or any improvement strategies warranted on the highway. In particular, the evaluation of the prevailing speed characteristics determines the size and distance of the traffic control devices that may be warranted to guide or warn traffic of any invisible or unexpected hazard *(12)*. On the other hand, the evaluation of safety characteristics of a particular facility is used to support the development of roadway improvement projects and their prioritization.

2.3.1 Speed Studies

Usually speed studies are done in free flowing conditions when vehicles interactions are minimal. According to the Highway Capacity Manual *(13)*, free flow conditions occur when there is a minimum of 4-second headway between vehicles. A minimum of 500 feet is required from a flow obstruction to the location where the speeds are measured. Also, to avoid bias in the sample data, the speed of traffic should be free from any concentrated law enforcement activities, just before or while taking the speed measurements. Generally, the minimum sample size required is greater than 30 measured spot speeds in order to reduce variations and increase precision. On higher volume roads, the minimum sample size for analysis has to be at least 100 vehicles *(9)*. The following formula is used to determine the minimum sample size, *n* required for any statistical analysis.

$$n = \left(\frac{zs}{E}\right)^2 \qquad [2.4]$$

where z = confidence level, s = estimate of the standard deviation, and E = range of error.

Depending on the type and size of the data needed, spot speeds can be collected by using either manual or automated methods. Manual methods involve collection of speeds using handheld or vehicle-mounted laser guns. These methods are used when a small sample size is needed. When a large amount of speed data is required to perform speed analysis, automated methods are the best option. These methods involve acquiring more than 24 hours of individual vehicle speed data using pneumatic road tubes or permanent counts with vehicle classification capabilities.

The selection of study sites usually involves choosing sites devoid of roadway conditions that might produce different driver behaviors. Consideration is given to several factors that affect driving behaviors on freeways depending on the type of the study. These factors include roadway and geometric characteristics, land use and environmental characteristics, community concerns, and level of enforcement. Conventionally, in order to obtain the maximum speed possible, a spot speed site should be straight and relatively level—that is, a site that does not have steep gradients.

Once speed data are collected, several descriptive statistics are computed to determine the distribution of vehicle speeds. The determination of descriptive statistics involves calculation of measures of central tendency and dispersion. Measures of central tendency indicate how the data are clustered or centered about certain numerical values. These include the mean, mode, percentiles, skewness, and kurtosis. Measures of dispersion indicate the variability of the speed data—how data are spread from the center of distribution. The measures of dispersion include standard deviation, variance, 10-mile per hour pace, percent of vehicles in pace, and coefficients of variation. Correlation and association measures are also required when the interest is to describe relationship between two variables—how one variable affect the other variable. The numerical measure of correlation is the coefficient of correlation that measures the strength of the linear relationship between the two variables. Mathematically, the coefficient of correlation, r, is given by the following expression:

$$r = \frac{SS_{xy}}{\sqrt{SS_{xx} SS_{yy}}} \qquad [2.1]$$

where, SS stands for the sum of squares and they are given by

$$SS_{xy} = \sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i}{n} \qquad [2.2]$$

and

$$SS_{xx} = \sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i^2)}{n} \qquad [2.3]$$

Statistical inference procedures are performed in which the hypothesis tests are conducted. Inferential statistics enable the analysts or decision makers to decide with reasonable confidence whether or not data on the sample are the representative of the whole population of vehicles using that highway facility. Inferential procedures involves comparisons of means done by performing paired t-tests or direct comparison of means of two groups, analysis of variance (ANOVA), analysis of covariance (ANCOVA), or comparison of the speed variances depending on the type and objective of the experiment.

2.3.2 *Safety Studies*

Generally, crashes are important measurable indicators of the safety performance of the roadways and traffic control devices. Safety studies involve studying of both severity levels and types of crashes that occurs on roadways. Understanding of the nature of the speed-related crashes on freeways involves examination of crash typology (distribution of crash types and their circumstances) from which speed characteristics could be correlated with certain types of crashes such as multiple and single vehicle crashes. Several regression methods have been employed to either predict crashes or explain the effect of some variables on the crash experience. Earlier, crashes were modeled by using linear regression techniques but nowdays there is a tendency to user more sofiscated regression techniques such as as logistic regression or gerelalized linear regression.

Sources of crash data are the crash reports which are collected by police officers at the crash scene and stored either locally or in the States databases. These reports describe characteristics of the crash, vehicles and their occupants, and any other objects involved. On the report, the police officers record the results of their investigations by using evidence found at the scene. In addition, by interviewing participants and witnesses, the investigating officers are able to acquire some important clues concerning a particular crash event. The evidences gathered from the witnesses of the crash and the accident reconstruction analysis such as investigation of skid marks on the roadway, damage of the vehicle and scars left on the object, help the police officers to estimate the traveling speed of the vehicle before the crash. Although the accuracy and precision of information reported in the crash forms are increasingly being questioned, one study has indicated that State databases are still a potential source of data on crashes *(14)*. This study also indicated that other national databases like Fatality Analysis Reporting Systems (FARS) and the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) lack representative crash counts of any particular State although they provide detailed crash summaries. Among the discrepancies mentioned is that the reports are based on the officer's judgment at the crash scene and the reports lack professional medical evaluation. In order to be very precise on the crash information, a detail safety study needs to have trained accident reconstruction personnel who would collect information at the scene; however, lack of funds was mentioned as the major constraint to train the personnel.

In Florida, a crash is reported whenever it results in either injury or casualty of a person, or it costs more than $500 total damage to property owned by any one person involved in the crash *(15)*. The use of this law leaves some of the property damage crashes and fender benders unreported in the State crash database. Several crash parameters are listed in Florida traffic crash reports, which include crash severity level, type of crashes and their contributing factors, estimated traveling speed of the vehicle before collision, brief descriptions of the investigating officer which are based on the evidences of the witnesses, and other minor information.

Several factors are known to affect safety evaluation of the roadway. These include segment length, traffic volume, period of analysis, roadway, and environmental conditions. Computation of crash rates is of main concern in safety analysis rather than evaluation of crash frequencies because the former is the normalized statistic and eliminates the influence of exposure information of traffic and segment length and thus improves the overall analysis.

Crash rates in million vehicle miles of travel are normally used as the criteria for identifying hazard locations. The crash rates are calculated by dividing frequency of crashes by amount of exposure as shown in the following equation:

$$Crash\ Rate = \frac{N \times 10^6}{365 \times AADT \times T \times L} \qquad [2.4]$$

where N = Number of crashes occurring on the section, $AADT$ = Average Annual Daily Traffic, L = Length of the section (miles), and T = Period of analysis in years.

When crash rates are computed, a better comparison of crashes within the sites is achieved by applying statistical tests to determine whether it is significantly different from predetermined crash rates. Other inferential and descriptive statistics are also performed during evaluation of safety characteristics of the facility. In addition, crashes that occur on uninterrupted traffic— basic freeway segments— need to be separated from those occurring on interrupted traffic like in weaving and merging areas, as well as those occurring in congested traffic because the later tend to skew the results.

2.4 Rationale for Posting Minimum Speed Limit

The intent of posting minimum speed limit on freeways is to achieve uniform flow of traffic by reducing excessive differences in speed between fast and slow vehicles. Posted minimum speed limit is used to inform motorists of the minimum speed they should travel with in the freeways. The use of minimum speed limit is basically to discourage slow drivers and some vehicles which cannot maintain pace with the rest of driving population from using the Interstate freeways which are meant for high speed mobility. This posting is assumed to increase efficiency of traffic operations based on the thinking that a direct relationship exists between presence of speed limit signs and a change in driver behavior which results in improved operation.

2.4.1 Effect of Slow Moving Vehicles on Highway Safety

Several studies reviewed by Warren (*4*) have indicated that the relationship between traffic flow, speed limits, and crashes has been researched for several decades and suggestions were made on the reduction or elimination of the number of crashes by reducing the spread of vehicle speeds. The spread of vehicle speeds was defined by the variation of speeds from the average speed of vehicles. The higher the variation, the more the dispersion of vehicle speeds from the mean. In the reduction of the spread of vehicle speeds, the question of slower vehicles in the traffic stream come into the discussion because these increase dispersions of speeds at the lower end of speed distribution.

Researches have sought to find out how low speed vehicles have affected highway safety and traffic operations. Earliest known studies that investigated the effects of deviation of vehicle speeds to the highway safety revealed a U-shaped relationship between crash involvements rates and deviations of speeds from the mean speed in which the point of inflexion (minimum value) occurred slightly above the mean speed *(16, 17)*. Solomon *(16)* evaluated the relationship between traffic speed distribution and accident data from a number of sections of two-lane and four-lane divided highways. In the analysis, the author compared free-flowing speed and crash involvements in both high and low speed categories in the speed distribution as shown in Figure 2.2.

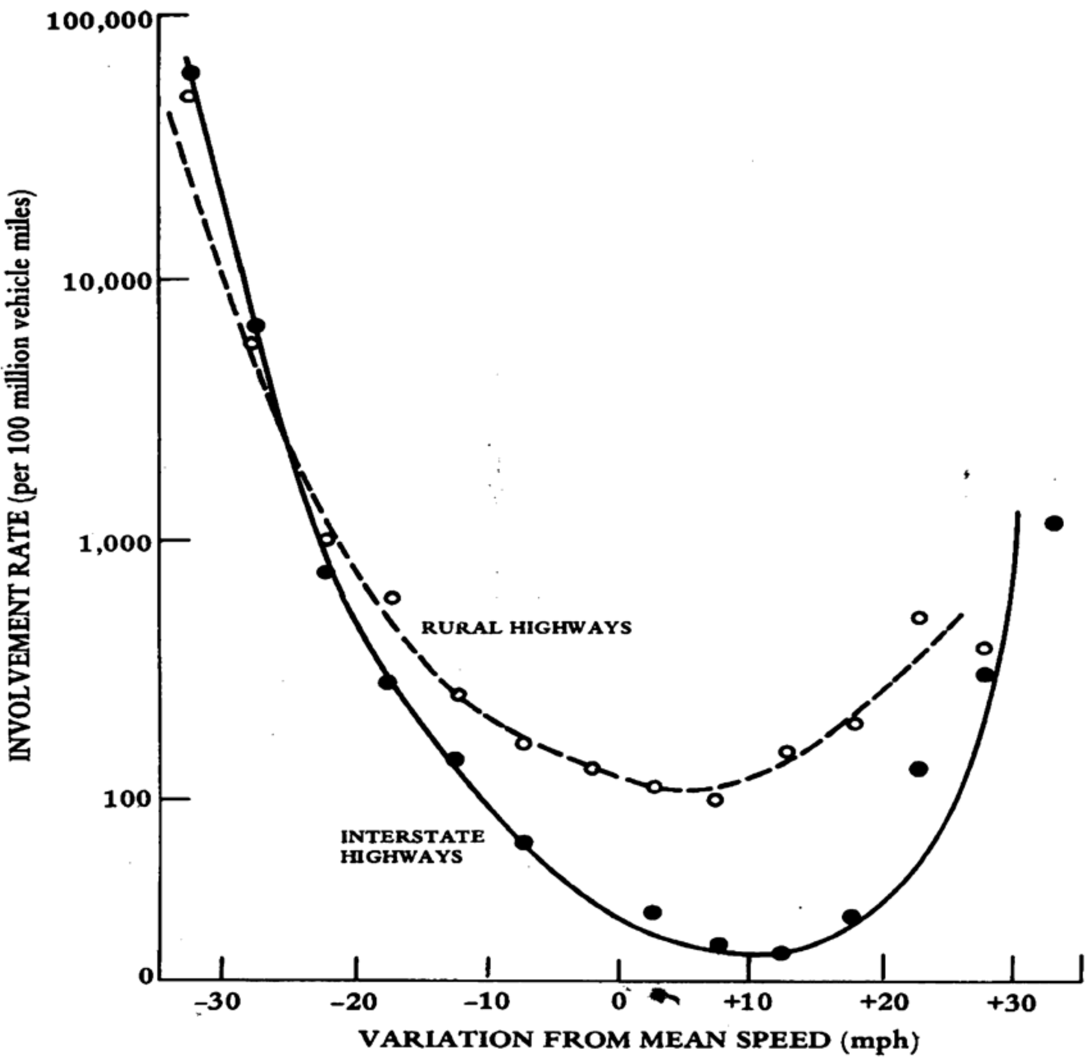

Figure 2.2 Crash involvement rates and variation from the average speed (Solomon, 1964)

The author found that speed variance, not average speed, was the important factor affecting crash involvement rates. After comparing over 1,000 roadway crashes, the author showed that the drivers involved in the crash were concentrated in both high and low sides of the speed distribution both in the day and in the night. In addition, minimum crashes occurred near the average speed. The results of the analyses of Interstate vehicle speeds and traffic crashes conducted by Cirillo *(17)* using data obtained from 20 states indicated that a reduction of speed variations among vehicles significantly reduces crashes. These results were similar to those of

Solomon *(16)*. Both Solomon and Cirillo findings showed that it is safer to drive at the median speed and it becomes dangerous as the speed starts to deviate from median speed in either directions of the speed distribution. Of much importance in these two studies is the hazard resulting from the presence of slow moving vehicles on high-speed highways indicated by a sharp rise in involvement rates for vehicles traveling 10 mph below mean speed as shown in Figure 2.2.

Closer examination of the shape of Figure 2.2 shows that crash involvement rate start to increase sharply when the difference between a vehicle speed and the average speed reaches 10 mph below the average speed. In the higher side of distribution, the involvement raises steeply when the difference reaches 25 mph. This finding suggests that the danger posed by slow moving vehicle is somewhat higher than that of fast moving vehicles. Solomon findings were also well supported by the study conducted by West & Dunn *(18)* on thirty-six crashes that occurred on Indiana highways. This study indicated that crash involvement rates per million vehicle-miles of travel (MVMT) were higher for vehicles whose speed deviations were below the mean speed. After removing all crashes related to turning maneuvers, the authors found that the crash risk associated with vehicles traveling faster or slower was more than six times the involvement rate at mean speed. Furthermore, mathematical models developed by Hauer *(19)* to correlate crash involvement rates and vehicle travel speeds supported both West & Dunn and Solomon findings. Hauer found that imposition of minimum speed limit on highways was as twice or thrice effective as an equivalent maximum speed limit in reducing the frequency of overtaking and thereby crash involvement rates. Hauer suggested that the relationship between vehicle speed deviations and crashes might be due to higher incidence of passing maneuvers from which a vehicle passes or is passed by another vehicle—the situation which is caused by the presence of slower vehicles in the traffic stream. Hauer further suggested that driving in the vicinity of median speed is safe and therefore he recommended the use of "*median speed driving*" advisory traffic signs in highway operation which should go parallel with educating the cummunity that driving below the median speed increases the chances for one being involved in a crash.

Warren *(4)* reviewed numerous researches done on speed zoning and control and found that there was a salient relationship between the rate of crashes and the spread of vehicles from the mean speed. Vehicles traveling with large speed differentials—defined as more than two standard deviations from the mean speed of traffic flow—were likely to be over-involved in crashes. In determining the extent to which the 55 mph limit affected safety, the Transportation Research Board (TRB) in a report entitled "55: A Decade of Experience" found that the probability of crash occurrence increases when the speed variance increases because speed variation reflects significant lane changing maneuvers, passing or stop and go conditions *(20)*. The importance of speed variance was observed after developing a fatality model that included other highway safety characteristics such as traffic density, percentage of vehicles exceeding 65 mph, percentage of teenagers, and enforcement activity. In the fatality models developed by the TRB study, speed variance was found to be statistically significant in affecting the fatality rates—the States that had wider variances in speed, tended to have higher fatality rates. The mean speed was only found to affect the severity of crashes by influencing stopping distances and drivers' perception reaction distances. When the effect of speed variance was held constant in the model, there was no statistical significant relationship between the fatality rate and any other speed variables. This study suggested that controlling speed variance could be an effective method in improving highway safety.

In assessing the benefits obtained after lowering speed limit, Lave *(3)* found that major highway safety benefits obtained after the enactment of the National Maximum Speed Limit (NMSL) law in 1974 that lowered maximum speed limit on freeways to 55 mph was caused by significant reduction of speed variance rather than the average speed. The author argued that a reduction of speed variance was achieved because speed differences between slow and fast vehicles were reduced enough to cause a more or less uniform flow of traffic on Interstate freeways. The observed small speed variances decreased the chances of passing and overtaking maneuvers which eventually led to a significant decrease of possibilities of passing conflicts and crashes. From the twelve fatality models tested by Lave, the effect of average speed was not only insignificant for all models but also a negative sign of the average speed was obtained in ten of the twelve equations when the effect of speed variance was held constant. The negativity of the sign showed that the increase of speed lowered the fatality rates. However, Lave's findings were later challenged by Fowles & Loeb *(21)* and Levy & Asch *(22)* who independently developed models (that were different from that developed by Lave) that included the effect of other variables such as motor vehicle inspection as well as other policy related variables in highway fatalities along with the effect of vehicle speed and variability of speed. The results of these studies showed that the effect of mean speed on fatality rate is positive and significant. Snyder *(23)* also found that the average speed was an important determinant of highway fatalities as is mostly assumed in previous studies. The study argued that the speed variance affects only the fatality rates for the fastest moving vehicles only. Even though the findings of Fowles & Loeb, Levy & Asch, and Snyder, slightly differ from Lave's results, all three studies—that is, Fowles & Loeb *(21)* and Levy & Asch *(22)* and Snyder *(23)*—significantly confirmed that the increase of speed variance was dangerous for the safe operation of highways. When responding to the challenges addressed to his original paper, Lave *(24)*, found that above three studies supported his findings that speed variance is an important determinant of the fatality rates although the dispute about the importance of the speeding per se was not resolved. In addition, Lave pointed out that the shortcoming of these studies were the use of aggregated data for pre and post 55 mph maximum speed limit periods in their statistic analyses.

Garber and Gadiraju *(25)* conducted a study that examined several factors affecting speed variance and quantified the relationship between speed variations and accident rates on Virginia highways. The hypothesis of this study was that the difference between design and posted speed limits was a major factor influencing speed variations and crash rates. Data were collected from thirty-six sections in seven different types of highways in Virginia where each section had a posted speed limit sign of 55 mph. The results of this study indicated that the sections had different average speed and speed variance although they had the same posted speed limit. In addition, unlike average speed, the speed variance was found to decrease with increase of design speed. The authors also found that speed variance was related with the difference between design speed and average speed in a parabolic, U-shaped function, the minimum being at the difference of 6 to 12 mph. These results are somewhat similar to those obtained by Solomon *(16)* and Cirillo *(17)*. A negative relationship between average speed and variance was also observed in this study—speed variance declines with an increase in average speed. Another important finding by Garber & Gadiraju *(25)* was a negative relationship between average speed and crash rates although the authors later cautioned that high average speeds occurred on better roads because motorists tend to drive at increasing speeds as the roadway geometric characteristics improve.

Aljanahi *et al. (2)* investigated the relationship between various measures of traffic speeds under free flow conditions and accident rates in Tyne and Wear, United Kingdom. The authors found that roadway crashes depended strongly on the variability of traffic speeds rather than the average speed. Aljanahi *et al.* developed a model for mean of roadway crashes for five years as the response variable and the explanatory variables were length of the road, traffic flow, percent of heavy vehicles, speed and some exponent parameters which were determined from the data. Statistical analyses conducted by the authors revealed a weak statistical significance for influence of speed measures on accident rates at a 5% significant level when standard deviation and mean speeds were only considered as explanatory variables. However, the overall tendency in the model was a strong relationship between accident rates and the speed variability where other factors were considered. In both sites studies, the hypothesis that the mean crash rate was proportional to the traffic flow was not supported at a 10% significant level.

A study conducted in South Australia by Kloeden *et al. (26)* found statistically significant increase of probability of crash involvement with the increase in traveling speed above speed limit. This study compared speeds of fatal crash involved vehicles with speed of control vehicles traveling in the same direction at the same location, time of the day, day of the week and time of the year under free flow conditions. The crashes that involved 83 passenger vehicles were investigated by accident investigation personnel and were reconstructed using computer-aided crash reconstruction techniques. The authors indicated that when traveling speed exceeded 75 kilometers per hour (45 mph), the risk of crash involvement increased sharply in an exponential function and vehicles traveling below the mean speed were at a low risk of being involved in the fatal crashes.

2.4.2 Effects of Minimum Speed Limit on Traffic Operation

Highway Capacity Manual has indicated that vehicle speeds on freeways are insensitive to flow in low to moderate traffic conditions *(13)*. By examining the flow-speed relationships outlined in this manual, it is clear that speed is not affected by increase in volume up to a critical volume above which it starts to decrease. The critical volume is normally the capacity of the freeway. Published studies revealed that speed limits do not have any significant effects on the traffic flow *(1)*. Wingerd *(28)* conducted the feasibility study of establishing minimum speed on multilane highways, on lane-by-lane basis. This study was conducted in the State of California to quantify the effects of raising minimum speed limit on freeways. The minimum speed limit in four different sites throughout the California freeway system were raised and signs erected. The minimum lane speeds used were 60 mph for the left (median) lane and 45 mph for the right (shoulder) lane while at the three and four lanes sites the middle lanes were posted at 55 mph. Upon analysis of speed characteristics on these sites, the author found that the imposition of minimum speeds by lane showed little or no positive advantage, and had some disadvantages to the traffic operation. The analysis of individual vehicle speeds collected before and after the minimum speed limit changes revealed that:

- there was no or little evidence of the increase of the average speed due to speed signing. There was only one site at I-80 that showed a positive change in speeds,
- the vehicles traveling in the left lane at 60 mph were impeding traffic despite the observed average speed of 67 mph and standard deviation of 4 to 6 mph, and
- the minimum speed signing shifted vehicles to the left lane, for a given traffic volume (Figure 2.3) which increased passing to the right. The results, which are contrary to the original expectation that minimum speed by lane, would cause slow vehicles to travel on the right. There was also an increase of violation of minimum speeds.

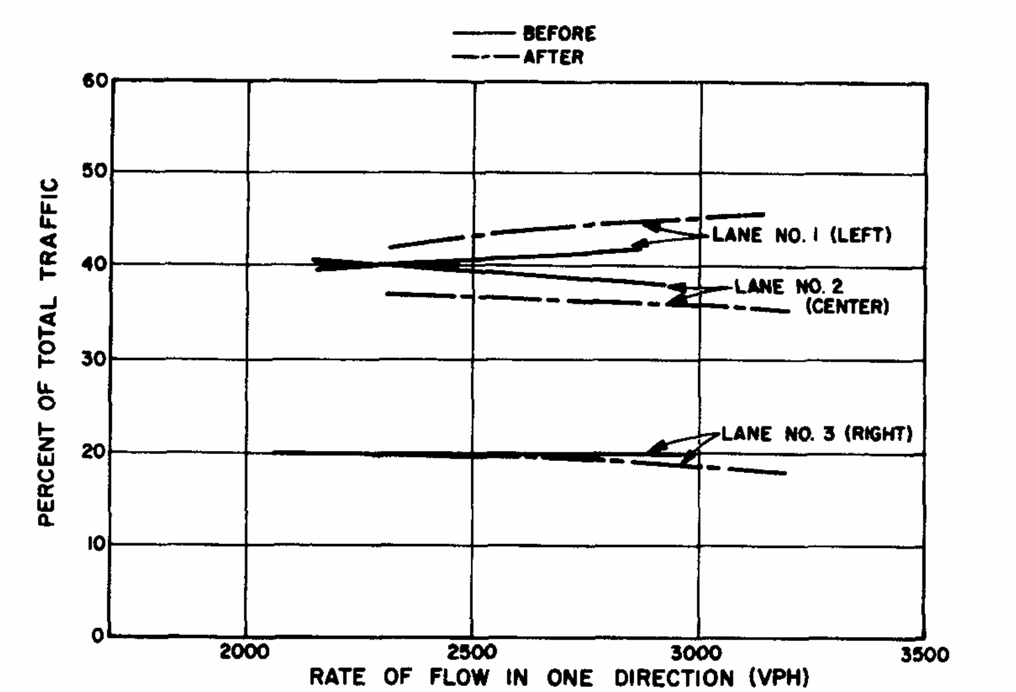

Figure 2.3 Effect of minimum speed sign on volume distribution by lane *(28)*

2.4.3 Lane Changing and Vehicle Platoons

Lane changing maneuvers on the freeway can be categorized as mandatory or discretionary *(27)*. Mandatory lane changing occurs when the current lane is merging to another lane, when the destination necessitates changing to another lane, or when the current lane is blocked. Discretionary lane changing occurs in situations when a driver is forced to pass a slow moving vehicle or yield to another merging vehicle. Under these conditions, headway between two vehicles in the same lane is decreasing more rapidly than the driver of the following car can decelerate. The demand for discretionary lane changing is at a minimum when all drivers travel at about the same speed. As the relative difference in vehicle speeds increases so does the desire to change lanes. The schematic diagram in Figure 2.4 exemplifies the desire to change lanes, which is affected by the increase in traffic intensity although it is contravened by the corresponding decrease in the number of acceptable gaps available in the traffic stream. The availability of acceptable gaps influence the number of discretionary lane changing maneuvers.

In a simple traffic operation condition as presented in Figure 2.4, when the speed of the following vehicle V_2 exceeds that of the lead vehicle V_1, the relative speed between the two increases at the same time the gap between the two decreases. As the gap between two successive vehicles decreases, the driver of vehicle V_2 starts to accept the gap between vehicles V_3 and V_4 in an attempt to change a lane. If the gap between vehicles V_3 and V_4 is large enough, the lane change operation by V_2 can be performed safely. In the other way, when the driver in V_2 accepts a short gap between V_4 and V_3 the probability of being hit by the vehicle V_4 increases. Another situation occurs when vehicles V_1 and V_3 are moving abreast with more or less same speed making it difficult for driver V_2 to perform a safe lane change maneuver. Thus, vehicles start queuing behind each other forming platoons of vehicles.

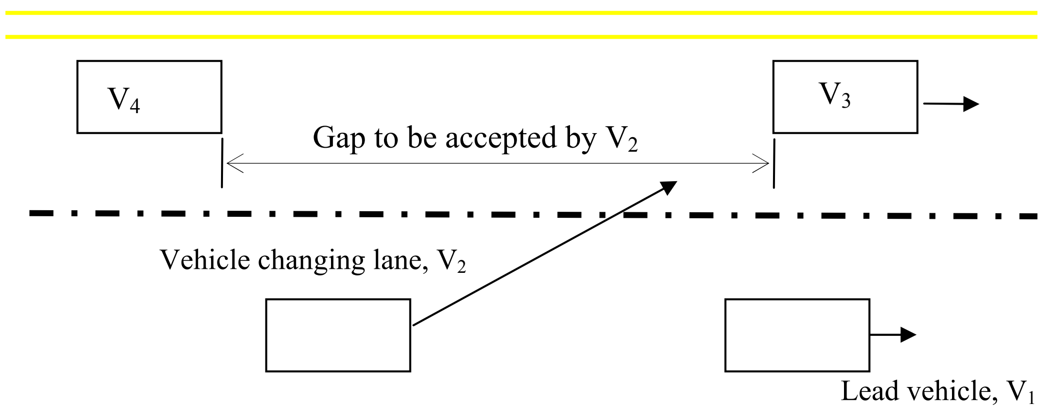

Figure 2.4 Schematic representations of acceptable gaps in lane changing

A vehicle platoon represents bunches of vehicles traveling together in close proximity, at about the same speed. When vehicle platoons are formed the lag driver has no option of passing or overtaking and is influenced to slow down and travel with the speed of the lead driver *(27)*. The existence of vehicle platoons does not indicate a uniform traffic flow because vehicle platoons arise when two slow vehicles are traveling abreast in adjacent lanes, which results in lack of passing opportunities for fast vehicles behind them. The notable effects of vehicle platoons are the reductions of average travel speeds and the increase in travel times. In many cases, these effects create frustration or anger for fast drivers in the course of their journey.

2.5 Speed Limit Sign Design and Placement

The minimum speed limit signs indicate the legal limit below which no motorist is allowed to travel on the highway. The Manual of Uniform Traffic Control Devices (MUTCD) which is published by the Federal Highway Administration (FHWA) requires that the speed limit sign to display the limit that is established by law, or by regulation, after engineering and traffic investigation has been made according to the established traffic engineering practices (*12*). The speed limits are only effective and enforceable when official signs are erected on the roadways. In addition, official signs need to comply with the design standards as specified in the MUTCD. The manual requires the minimum speed limit signs to be posted after the engineering and traffic studies verify that there is significant number of slow moving vehicles in the traffic stream that impede the normal flow of traffic. Figure 2.5 depicts the sign design as specified in the MUTCD.

		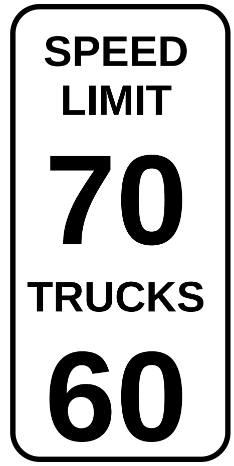
Minimum Speed Limit sign	Maximum and Minimum Speed Limit Sign	Maximum and Trucks Speed Limit Sign

Figure 2.5 Speed limit signs

The standard size of the minimum speed sign as specified in the MUCTD is 24 by 30 inches and in some cases, the minimum speed is displayed in combination with the maximum speed limit (referred as speed limit) on the same post. In some states, different speed limits are used for trucks and passenger vehicles to reflect their different operating characteristics after engineering studies indicated the significant effect of trucks on the normal traffic operation. In these States, the speed laws require trucks to be operated at lower speed than passenger cars. When differential speed limits are used, the legend TRUCKS with its legal speed limit is posted and usually it is shown just below a standard maximum speed limit legend (Figure 2.5) or on a separate small plate. Figure 2.6 also shows the differential speed limits posted in Michigan.

Figure 2-6: Speed limit posted in Michigan

According to the MUTCD, speed limit signs are required to be erected at the points of change from one speed limit to another. On freeways, these signs are normally placed right after the acceleration lanes (post interchange) in order to inform motorist entering the freeway the change in speed characteristics and at other locations where engineering judgments found it necessary to remind motorist of the speed limits. However, no specific interval or spacing of posted speed limit is specified inside the MUTCD manual.

2.6 Summary

The literature has indicated that the practice of posting minimum speed limit signs on freeway has been in existence for many decades. The main objective of posting these signs was to discourage slow moving vehicles on the highways. The evidences obtained from the literature findings discussed above show that minimum speed limit is posted on high speed freeways to deter slow moving vehicles as well as vehicles that cannot maintain adequate speed levels. This practice tries to bring slower drivers close to the median speed and eliminate the number of passing and overtaking maneuvers contributed by presence of slow moving vehicles in the traffic stream. By bringing the majority of the vehicles close to the mean speed, a uniform flow of traffic is attained. In addition, the risk of crash involvement is minimal at speeds that are close to the average speed. This means that as the traveling speeds deviated much from the mean, then number of passing maneuvers increases and eventually increases the chances of passing conflicts and crashes on the freeways. This evidence seems to be supported by earlier studies which have quantified a U-shaped relationship between risk of crash involvement and traveling speed. These curves have further revealed the danger created by slow moving vehicles on freeways which is indicated by the sharp slopes in the lower side of speed distribution. This finding also suggests that a slow moving traffic stream constitutes much more risk in the normal operation of the freeways.

CHAPTER 3—SURVEY ON THE POSTING OF MINIMUM SPEED LIMIT

3.1 Introduction

The 1995 National Highway System (NHS) Designation Act repealed the maximum speed limit law and transferred responsibility of setting speed limits on Interstate highway systems to the States. The 1998 National Highway Traffic Safety Administration report shows that following this Act, 36 States raised the maximum speed limit on Interstate freeways and other highways within their jurisdictions (*29*). However, prior to 1995, a number of States—including Florida—had the practice of posting minimum speed limit signs on rural Interstate freeways. Of interest to most engineers is whether the States that raised the maximum speed limit also revised their minimum speed limits.

The literature review revealed that by 1962 many States had adopted slow speed rule in their State statutes in compliance with the Uniform Vehicle Code (UVC) published by the National Committee of Uniform Traffic Laws and Ordinances (*6*). Most States' statutes now have provisions stipulating that it is illegal for a driver to drive so slowly as to impede the normal and reasonable flow of traffic. Generally, the responsibility of setting minimum speeds in compliance with State statutes falls with State highway agencies that are expected to conduct traffic and engineering studies to determine the need for a speed limit sign.

The objective of the survey reported herein was to determine the current state of practice related to the posting of minimum speed limit signs on Interstate freeway systems. The results of the survey study were intended to assist the design of data collection and the conduct of the research. The survey was conducted using a detailed questionnaire, which was sent to transportation departments in all 50 States. The personnel targeted to respond to the survey questionnaires were traffic and safety engineers within State departments of transportation.

3.2 Questionnaire Design

The survey questionnaire was designed to solicit information on what State statutes say about minimum speed limit and the practice of posting as well as enforcing minimum speed limits on Interstate freeway systems. The questionnaire contained seven questions, which were formulated to discover whether the States have statutory minimum speed rules and whether the existence of these rules affects the posting of minimum speed limit on these highways. One question was particularly designed to gain an understanding on how slow moving vehicles are regulated in case the State statutes do not explicitly state what the minimum speed limit should be. In addition, there were other general questions relating to what changes in minimum and maximum speed limit have been made in the State following the National Highway System Designation Act passed in 1995 and whether engineering studies were conducted prior to effecting speed limit change. The survey questionnaire that was sent to all 50 States is attached as Appendix A.

3.3 Survey Results

The results received from around the country were quite encouraging. Not only were the responses mailed back in a timely manner, but also all 50 States responded to the questionnaire. Most States indicated that they were interested in the results of the survey and requested a copy of the report related to this survey. The following sections discuss the results of the survey for each question that was posed.

Question 1—Does your State have a statutory minimum speed law, i.e., does the State statutes require that minimum speed limit must be posted? —Of all responding agencies, 18 States reported that their State statutes have sections that require the posting of minimum speed limit. The responses from these 18 States can be categorized as follows:

- Seven States indicated that the minimum speed limit is posted at 40 mph. These States are Connecticut, Florida, Iowa, Missouri, Mississippi, Nebraska, and South Dakota.
- Five States indicated that they post a 45 mph minimum speed limit. These States are Arkansas, Ohio, Michigan, New Hampshire, and Utah.
- One State, i.e., North Carolina, indicated that on some highways the minimum speed limit is posted as 40 mph while on some highways the minimum speed limit is posted as 45 mph.
- One State, i.e. Tennessee, indicated that the minimum speed limit on Interstate freeway system is posted at 55 mph and applies to the high-speed lane, i.e., leftmost lane.
- Despite such clause, four States—Arkansas, New Hampshire, New Jersey, and Virginia—reported that they do not post minimum speed limit signs at all on their Interstate freeways.

The remaining 32 States indicated that their State statutes do not have a clause explicitly stating what the minimum speed limit should be. However, almost all statutes in these 32 States have a clause allowing transportation agencies to post minimum speed limit signs if such actions is found necessary based on traffic and engineering studies. Figure 4.1 gives the pictorial view of the results discussed above. In addition, Table 3.1 gives the summary of these results.

Question 2—In some States, the statute does not explicitly state what minimum speed limit should be posted but gives authority to the highway/transportation department to regulate minimum speeds on Interstate freeways. In this light, do you post minimum speed limit on Interstate freeways?: This question was designed in light of the fact that even though some States might not have explicit language in their statutes of what the minimum speed limit should be, they nevertheless might be posting minimum speed limit signs based on other statutes or considerations. Of the 32 States which responded 'No' to the first question discussed above, 12 states said they do post minimum speed limits on their Interstates as follows:

- Six States post a 40 mph minimum speed limit. These States are Alabama, Georgia, Kansas Minnesota, New York and Vermont.
- Five States post a 45 mph minimum speed limit. These States are Hawaii, Illinois, Louisiana, South Carolina, and Texas.
- Colorado has a 55 mph minimum speed limit on some sections of rural Interstate freeways where the maximum speed limit is 75 mph. However, the minimum speed limit on suburban and urban freeways is 45 mph.

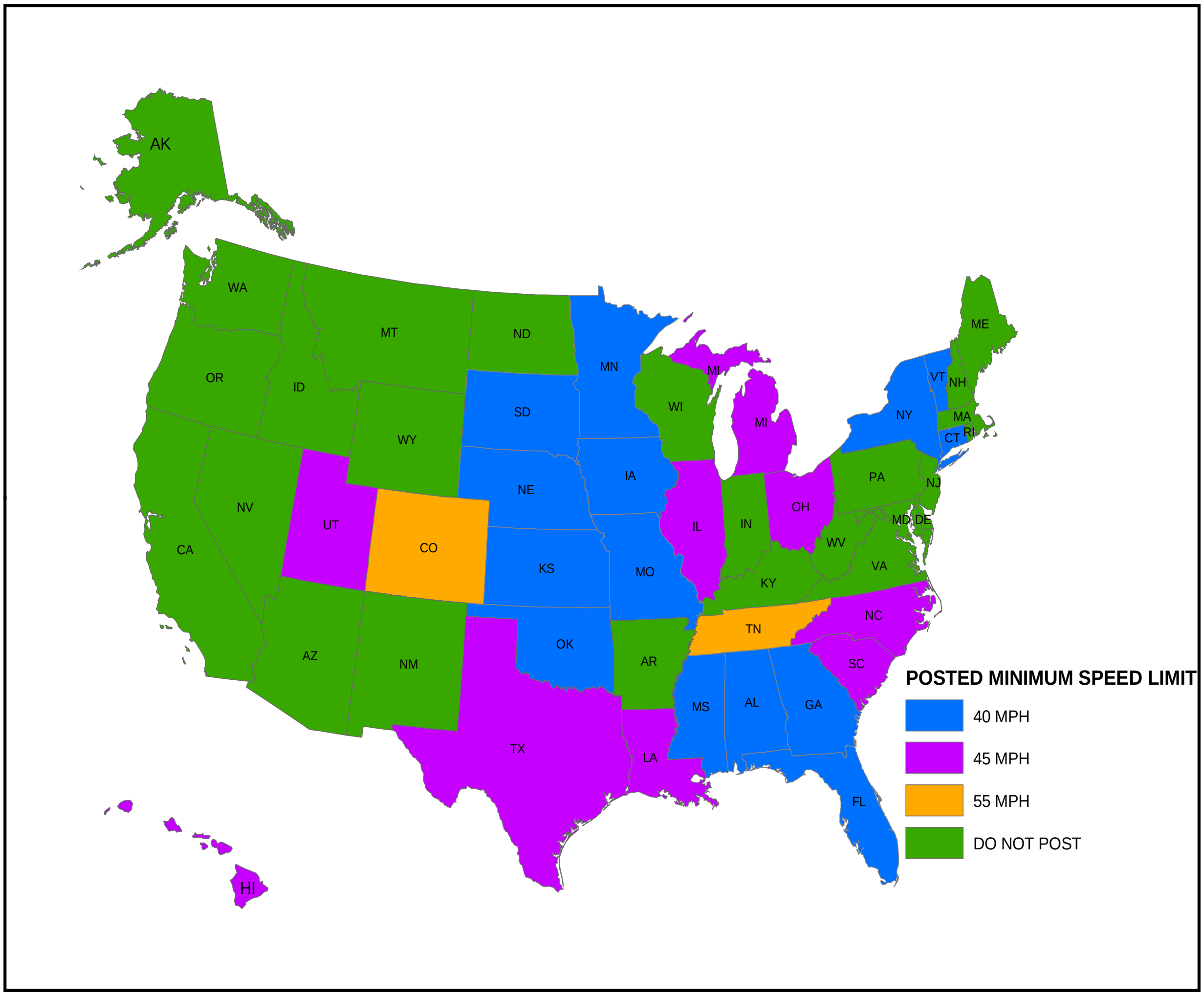

Figure 3.1 The practice of posting minimum speed limit signs in the United States

The remaining 20 States were silent on this question and this seems to imply that they do not post minimum speed limit signs on Interstate freeway system. These States are Alaska, Arizona, California, Delaware, Idaho, Indiana, Kentucky, Massachusetts, Maryland, Maine, Montana, North Dakota, Nevada, Oregon, Pennsylvania, Rhode Island, Washington, Wisconsin, West Virginia, and Wyoming. In addition, of these 20 States, 11 states indicated that slow moving vehicles are regulated at the discretion of the police officers in accordance to some provisions in the States codes that require vehicles to operate at a speed that is appropriate for the roadway and weather conditions. One State (Maryland) indicated that the State code requires vehicles traveling 10 mph or more below the maximum speed limit or prevailing speed to use the rightmost available lane. In addition, the Maryland code has a provision that requires the use of warning lights (4-way flashers) by commercial vehicles traveling 20 mph or more below the posted speed limit.

Table 3-1: Existence of statutes on minimum speed limit

State	Statute Exists?	Is Minimum Speed Posted	What Speed Value
Alabama	No	Yes	40 mph
Alaska	No	No	Nil
Arizona	No	No	Nil
Arkansas	Yes	No	Nil
California	No	No	Nil
Colorado	No	Yes	55 mph
Connecticut	Yes	Yes	40 mph
Delaware	No	No	Nil
Florida	Yes	Yes	40 mph
Georgia	No	Yes	40 mph
Hawaii	No	Yes	45 mph
Idaho	No	No	Nil
Illinois	No	Yes	45 mph
Indiana	No	No	Nil
Iowa	Yes	Yes	40 mph
Kansas	No	Yes	40 mph
Kentucky	No	No	Nil
Louisiana	No	Yes	45 mph
Maine	No	No	Nil
Maryland	No	No	Nil
Massachusetts	No	No	Nil
Michigan	Yes	Yes	45 mph
Minnesota	No	Yes	40 mph
Mississippi	Yes	Yes	40 mph
Missouri	Yes	Yes	40 mph
Montana	No	No	Nil
Nebraska	Yes	Yes	40 mph
Nevada	No	No	Nil
New Hampshire	Yes	No	Nil
New Jersey	Yes (but not explicit)	No	Nil
New Mexico	Yes (but not explicit)	No	Nil
New York	No	Yes	40 mph
North Carolina	Yes	Yes	45 mph
North Dakota	No	No	Nil
Ohio	Yes	Yes	45 MPH
Oklahoma	Yes (but not explicit)	Yes	40 mph
Oregon	No	No	Nil
Pennsylvania	No	No	Nil
Rhode Island	No	No	Nil
South Carolina	No	Yes	45 mph
South Dakota	Yes	Yes	40 mph
Tennessee	Yes	Yes	55 mph
Texas	No	Yes	45 mph
Utah	Yes (but not explicit)	Yes	45 mph
Vermont	No	Yes	40 mph
Virginia	Yes (but not explicit)	No	Nil
Washington	No	No	Nil
West Virginia	No	No	Nil
Wisconsin	No	No	Nil
Wyoming	No	No	Nil

Eight States reported that they are not sure on how slow speed limits are regulated on the Interstate highways within their State. Some of the respondents answered that slow moving vehicles are not a serious problem in the daily operations of their Interstate highways as to necessitate posting of minimum speed limit signs. One State indicated that they use regulatory signs indicating slow moving traffic must use the rightmost lane. It was also indicated that in hilly terrain where slow moving traffic is to be expected, climbing lanes and turnouts are provided for use by slow moving vehicles.

Another interesting outcome of this survey is related to the uniformity of posting minimum speed limit signs. Twenty-one States reported that the posting is uniform along the Interstate freeways while 7 States reported that the posting is not uniform. Various reasons were advanced for lack of uniformity in posting of minimum speed limit signs. Alabama and Utah indicated that minimum speed limit signs were posted only on sections of the Interstate freeway system where experience and history showed that slow moving vehicles were posing safety problems. South Dakota indicated that posting of minimum speed of 40 mph applies only to the outside (shoulder) lane. South Carolina reported that the posting of minimum speed limit was based on traffic engineering studies conducted on some freeway sections. The State of Illinois indicated that the minimum speed limit signs are posted on Interstate freeway sections where the maximum speed limit is 75 mph. The State of Texas indicated that 45 mph minimum speed limit signs were posted on some highway sections using the 15th percentile speed as a guide in establishing the minimum speed limit.

Question 3—Following the National Highway System (NHS) Designation Act of 1995, which repealed federal control of maximum speed limit, did your State raise the maximum speed limit on rural Interstate freeways? The answers to this question showed that 43 states raised the maximum speed limit on Interstate freeways following the repeal of federal maximum speed limit law. Of these 43 States, 22 States indicated that the speed limit change was based on detailed field study of operating speeds while the remaining 21 States indicated that no detailed field analyses of speeds were conducted prior to raising the maximum speed limit. It is noteworthy that the State of Pennsylvania indicated that the revision of the maximum speed limit was taken based on development of the area, traffic congestion, and engineering judgment. The State of Texas reported that the speed limit reverted to 70 mph, which was the statewide maximum law before National Maximum Speed Limit (NMSL) went into effect in 1974. Figure 3.2 shows the States that raised the maximum speed limit and the level at which the speed limit was raised. It is worthy noting that these 43 States that raised maximum speed limit did not have accompanying changes in minimum speed limit.

Question 4—Do you have any speed restriction policy on Interstate freeways? This question was formulated to determine whether or not there exist speed restrictions policies on some types of vehicles, restriction based on roadway conditions, or restriction based on the time of the day. Examination of Figure 3.3 shows 11 States impose restriction on trucks. Restricting the speed of school buses was the second most prevalent speed restriction policy; Eight States reported imposing such restrictions. Two States reported that they impose speed restriction on hazardous grades where the operation of trucks poses danger to the smooth operation of traffic.

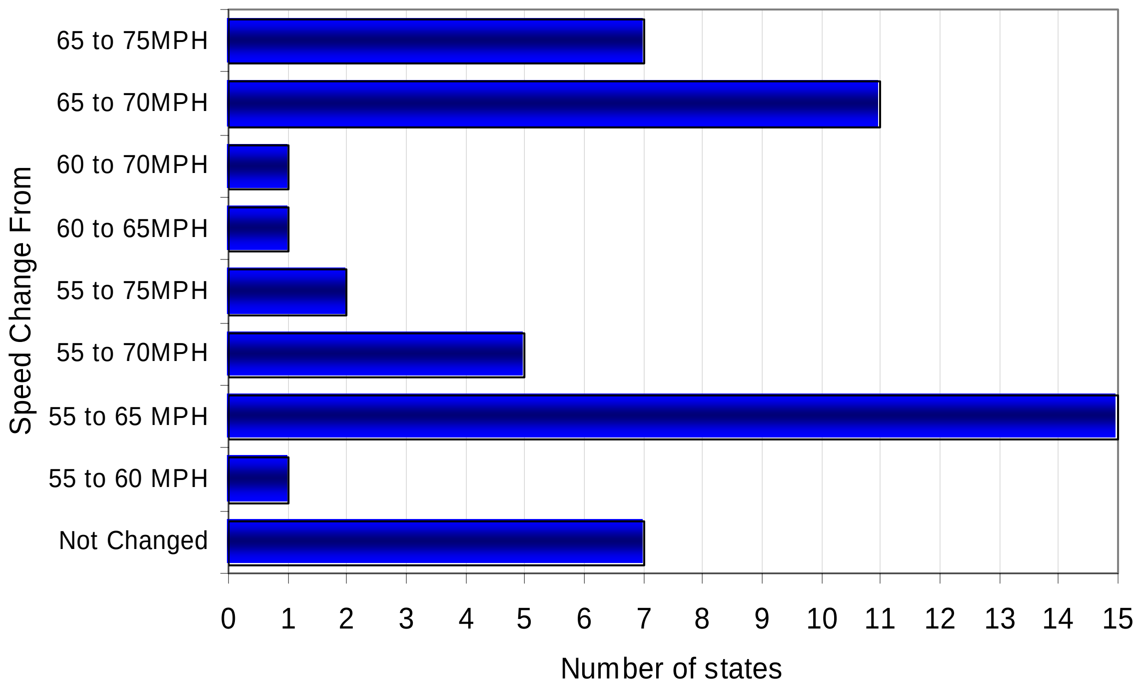

Figure 3.2 Changes in Maximum Speed Limit

States which post different speed limits for trucks and passenger cars are shown in Figure 3.4. Examination of Figure 3.4 shows that the State of Ohio restricts speed of motor vehicles weighing more than 8,000 pounds to 55 mph on all sections of Interstate freeway system. The maximum speed limit on Ohio Interstate freeway system is 65 MPH. Michigan State reported that a maximum speed limit of 55 mph is imposed on trucks where the maximum speed limit for passenger cars is 70 mph. New Jersey indicated that 45 mph is the maximum speed limit for heavy vehicles in section where maximum speed limit for passenger cars is 65 mph. Two States—Indiana and Washington—have a maximum truck speed limit of 60 mph where the maximum speed limits for passenger cars are 65 mph and 70 mph, respectively. Arkansas and South Dakota impose maximum truck speed of 65 mph in areas where the maximum speed limit is 70 mph (Arkansas) and 75 mph (South Dakota). Idaho indicated that the maximum speed limit for trucks is 70 mph while that of passenger cars is 75 mph.

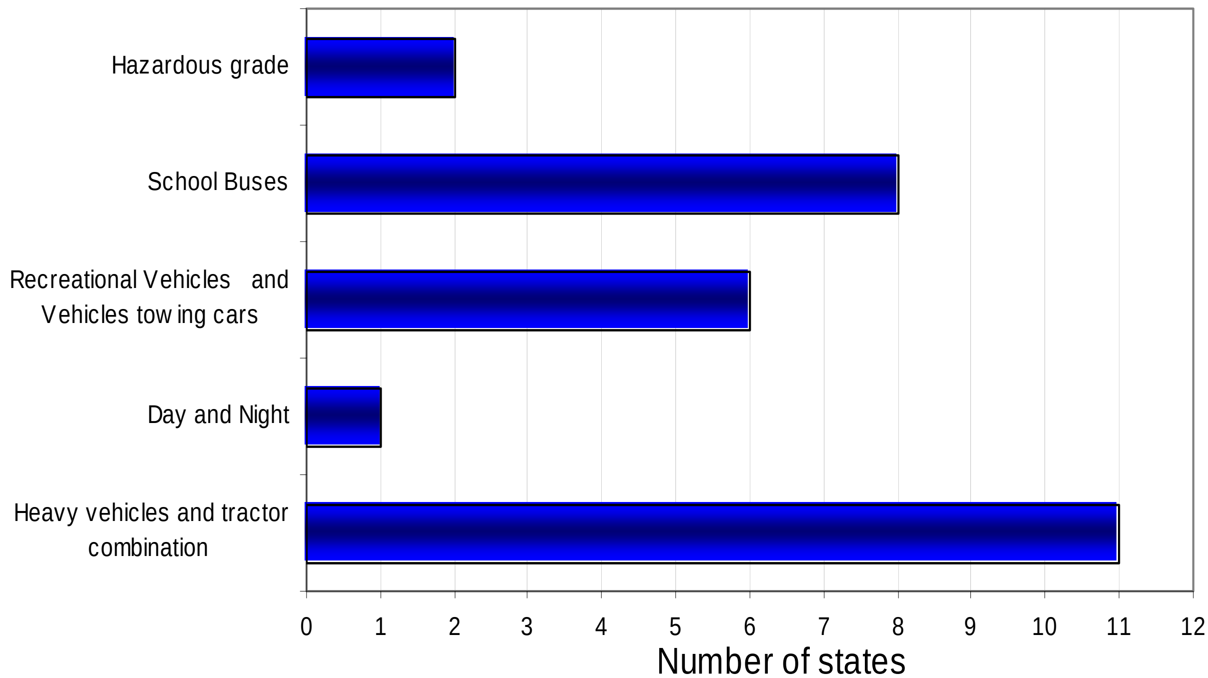

Figure 3.3 Other speed restriction policies

Question 6—Did your State ever conduct a study related to the minimum speed on Interstate freeways? This question sought to find out if studies related to minimum speed were conducted, the results of which could be shared for analysis in this project. The results show that none of the States had conducted a detailed study with sufficient data relevant for this project.

Question 7—Do highway patrol officers regularly enforce the minimum speed limit? This question was designed to determine enforcement practices of minimum speed limit on Interstates freeways around the country. There were 31 States responding to this question. It is possible that the low response rate is because most of the personnel who answered the questionnaire were not affiliated with law enforcement; therefore, they had difficulty getting the required information. Nonetheless, of the 31 respondents 14 States indicated that highway patrol officers enforce minimum speed limits while 17 States were not sure if it was enforced. The States that indicated the minimum speed is enforced in their State reported that minimum speed is enforced according to the appropriate State code or the posted minimum speed limit, if any, or when safety of the traveling public is jeopardized. Other States reported that the enforcement is not regular but the police officer sometimes enforce this limit by giving verbal warnings in instances where slow moving vehicle are obstructing traffic. Other States indicated that the minimum speed limit is not enforced because in their opinion slow moving vehicles are not a significant safety or traffic operations problem.

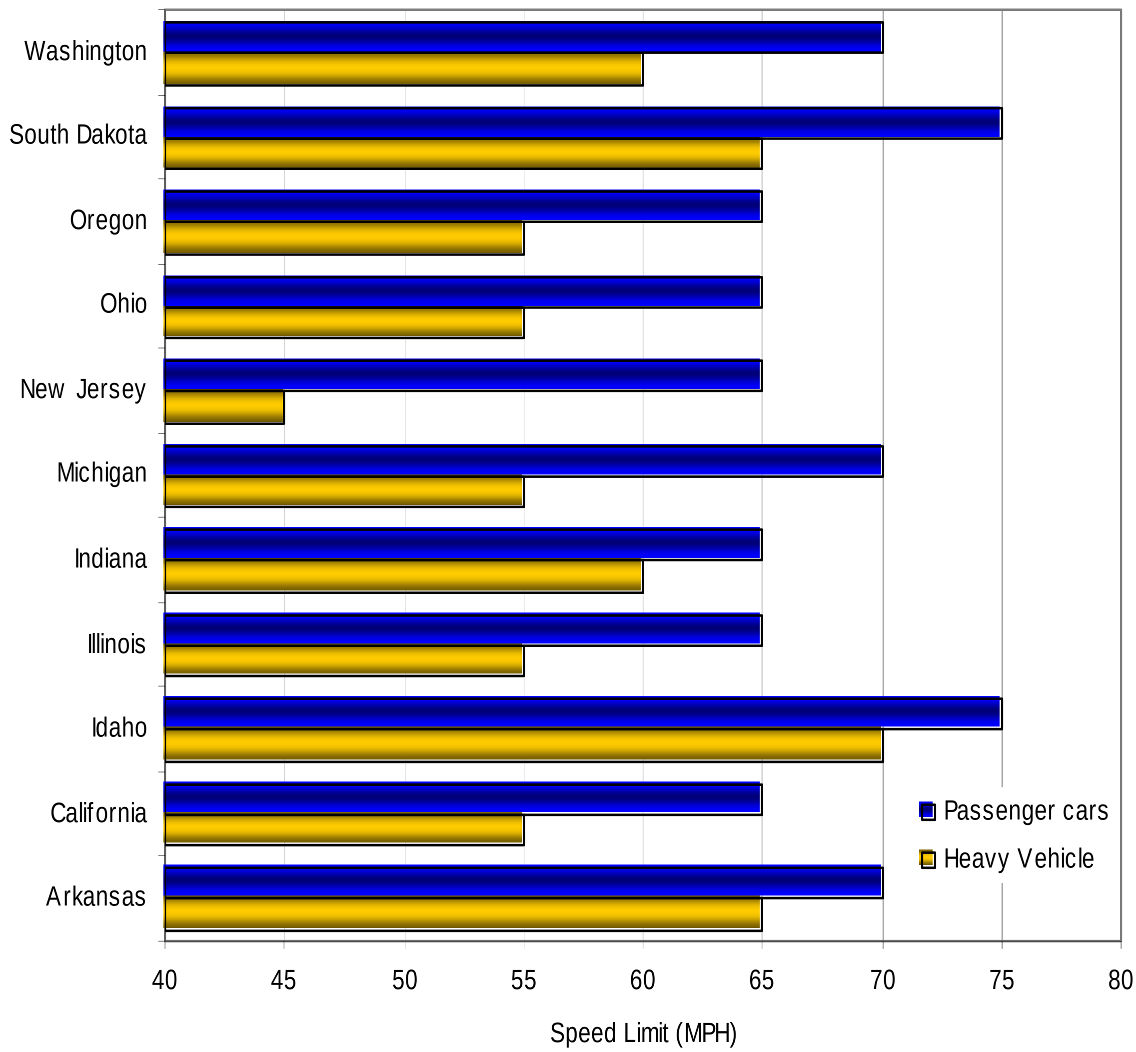

Figure 3.4: States that post different speed limits for trucks and passenger cars

3.4. Summary of the Survey Results

The survey results reported herein indicates a wide variation in how different States handle the issue of posting of minimum speed limit signs on Interstate freeways. While in some States it is explicitly stated in the State Statutes what the minimum speed limit on Interstate freeways should be, other States have clauses in their statutes allowing highway authorities to set minimum speed limit if they deem such action is necessary based on engineering and traffic studies. Some States have indeed set minimum speeds based on such statutes. Further, the survey results show that most States, including those that do not post minimum speed limit signs, rely on the minimum speed rule adopted from the Uniform Vehicle Code (UVC) for enforcement purposes. This rule states that, "No person shall drive a motor vehicle at such a slow speed as to impede the normal and reasonable movement of traffic."

For those States that post minimum speed limit, the most common posting is 40 mph. However, the survey results showed that 45 mph is the next most common minimum speed value and two States, i.e., Colorado and Tennessee, indicated that the minimum speed limit may go up to 55 mph. Another theme running throughout the survey results is the fact that there seems to be no relationship between the minimum speed value and the maximum speed value. The 40 mph minimum speed limits are reportedly posted on freeways where the maximum speed limit is 75 mph, 70 mph, and 65 mph. Similarly, the 45 mph minimum speed limits are reportedly posted on freeways where the maximum speed limit is 75 mph, 70 mph, or 65 mph. This indicates that there seems to be no relationship between the posted minimum and maximum speed limit on Interstate freeways across the country. In addition, it seems that most States raised the maximum speed limits without revising or studying the effect of the raise on the prevailing minimum speed limit. Thus, there is a continued need to study the relevance of the minimum speed limit on speed variability in light of the increases in maximum speed limit.

CHAPTER 4—DATA COLLECTION AND REDUCTION

4.1 Description of the Florida Interstate Freeways

The Florida Interstate highways form part of the Florida Intrastate Highway System (FIHS). Of the 3,935 miles of FHIS, 1,473 miles are Interstate highways. Of these Interstate highways, Interstate 75 and Interstate 95 run from south to north of the state. These two highways run up to the northern parts of the United States. Interstate 10 runs from east to west of the State. Interstate 4 runs in the central Florida and connects Interstate 75 and Interstate 95 in the western and eastern coast, respectively. In addition, Florida Turnpike which is a tollway runs from the central to southern parts of the State. The traffic operating conditions in the Turnpike is the same as Interstate freeways because it is designed at 70 mph with generous curves and wide medians. In addition, like Interstate highways, rural parts of Florida Turnpike are posted with maximum and minimum speed limits of 70 mph and 40 mph, respectively. With the exception of Interstate 4, which runs in the most urbanized central area of the State, most sections of these Interstates freeways and the Florida Turnpike are located in the rural areas.

4.2 Criteria for Site Selection

Since the intent of this research project was to study vehicle operating speeds in the rural sections of Florida Interstate freeway systems, sites for data collection were selected based on the following criteria:

- sites located in a rural area,
- sites located far from access points,
- sites with posted speed limit of 70 mph (maximum) and 40 mph (minimum),
- sites in tangent sections of the freeway for at least one mile,
- sites with no substantial grades (grades less than 1%), and
- availability of continuous count station

4.3 Study Locations

An initial run through all Florida Interstate freeways was conducted as part of field review to observe the current practice of posting minimum speed limit as well as to observe the prevailing geometrics of these freeways. During the field review, sample counts on speeds were taken at various locations in order to determine the speed characteristics. The preliminary analysis of these sampled speed data gave indication of which sites having telemetered traffic monitoring devices were suitable for 24-hr collection of speed data.

The next step in this study was examination of permanent count stations found on Interstate freeways and the Turnpike. The count stations are known as Telemetered traffic monitoring sites. These stations are installed on the highways to collect continuous vehicle data which is used for planning purposes. These sites are mainly maintained by the Planning Office of the Florida Department of Transportation. The sites are generally located on tangent sections with no or generous grades to capture as free flow traffic data as possible.

It was discovered that there were more than 300 telemetered count stations on Florida Intrastate highway system. Of the 300 permanent count stations, 77 were located on the Interstate freeways and the Turnpike. Thus, these 77 stations were candidates for data collection and were evaluated to determine their suitability in relation to the research objective of evaluating speed characteristics. With the help of the Florida Department of Transportation video log system, eight sites were selected. The sites are described in Table 4.1.

Table 4.1 Description of the study sites

Site Code	Freeway	Number of lanes	FDOT District	County	Milepost	Geographical location
0320	I-75	6	2	Columbia	22.4	Between I-10 and US-90
9904	I-75	6	2	Alachua	3.0	Three miles north of Marion County line
9905	I-95	6	2	Duval	4.4	Two miles south of I-295 interchange
9901	I-10	4	3	Jefferson	18.2	One mile east of County Road 257
9928	I-10	4	3	Walton	10.3	1.3 miles west of Boy Scout Road
0351	I-75	4	1	Collier	41.5	At Everglades Boulevard overpass
9919	I-95	4	7	Brevard	9.9	3.5 miles south of State Route 514
9932	Florida Turnpike	4	8	Osceola	30.2	North of County Road 525 underpass

The geographical location of these sites is also depicted in Florida map as Figure 4.1. These eight candidate sites represent rural parts of the Florida Interstate Highway System and the Turnpike. Of these eight sites, seven were located in I-10, I-75, and I-95. One site was located on the Florida Turnpike. These sites represent sections of the freeways with four and six lanes. Of the eight sites selected, five were on four-lane freeway sections and three sites were on six-lane freeways sections. No site was selected along the Interstate-4 because the corridor between Tampa and Daytona Beach in which this freeway passes is mostly urbanized and experiences traffic congestion most of the day. The geometrics of the sites (grades, horizontal alignments, lane and median width) were verified by examining as-built drawings and straight line diagrams (SLD) supplied by the Florida Department of Transportation. The pictorial representation of the study sites is presented in Appendix B.

4.4 Individual Vehicle Records

The 24-hour individual vehicle records were acquired from the telemetered traffic monitoring sites (TTMS) using automatic data recorders (ADR). The equipment recorded vehicle passage time, speed, length, and axle class with respect to the lane of travel for each vehicle. In some stations the individual vehicle axle weights were also recorded. The ADR equipment was capable of recording vehicle speeds to a maximum speed of 120 mph. A cursory review of the speed characteristics on most sites indicated that there were minor differences between weekend and weekday traffic speed distribution. Thus data from all sites were collected in weekdays in good weather conditions and dry pavement.

Figure 4.1 Map of Florida showing location of study sites

Since there was a possibility of data recording errors, it was decided that the first step should be to examine the data files downloaded for any improper recordings or palpable errors by applying logic checks on the recorded data elements. A criterion was initially set such that when the percentage of bad data exceeded five, the whole data file was discarded from further analysis. Examining vehicles recorded with both speed and length checked the accuracy of each individual speed data collected. When the length of the vehicle was missing, it was interpreted that the vehicle did not cross both loops in the lane and hence bad datum was recorded. The number of vehicles with missing speed or length were used to check the percentage of usable counts with respect to raw (recorded) counts and hence to decide the acceptance of the data for that particular day.

Another typical error discovered in the data set was the presence of outliers—defined as data points that do not appear to be consistent with the general trend of the data. The original data set was checked for presence of any outlier and when outliers were found, they were neglected by putting a blank for bad data using a customized computer program. The blanks substituted for bad datum could be discerned by computer software used in the analysis and the number of missing data was treated by ignoring them and reporting the distribution of each variable in terms of the number of complete observations taken for that variable. In addition, all vehicles with recorded speeds more than 120 mph were discarded from the data set as the machines were not capable of recording speeds above this value. Furthermore, vehicles with speed value of 0 mph were removed from the data file by the computer program. Raw vehicle data from each site were analyzed using customized programs developed using SAS statistical software. From these programs, the speed, volume, and headway statistics were calculated by lane and direction basis and summarized in tabular forms. Appendix B presents the results of these statistical analyses.

4.5 Pre-70 mph Speed Data

The repeal of the national maximum speed limit law in 1995 by Congress led to the increase of the speed limit in State of Florida. Thus, comparison of operating characteristics with pre-70 mph data was deemed appropriate if such data were available. Fortunately, various FDOT districts conducted speed studies on various rural Interstate freeways in 1996 before raising the speed limit to 70 mph. The results of the 1996 speed studies is supposed to have led to the justification of raising the maximum speed limit to 70 mph on rural Interstate freeways. The 1996 spot speed data on sites that were very close to sites indicated in Table 4.1 were identified. The data from these sites were requested from the respective FDOT districts. These data were used for before and after evaluation of traffic operation characteristics.

4.6 Crash Data

The hard copies of the police crash reports were obtained from the State Safety Office of the Florida Department of Transportation. In order to have a sufficient sample size to represent crashes that occurs on these freeways, four-year time frame was chosen. Thus, hard copies of crash reports for years 1998, 1999, 2000, and 2001 for a 2-mile segment length on each site were ordered from the State Safety Office. The crash attributes of interest in this study were the crash severity level, type of crash, and the first harmful events. In addition, the estimated traveling speed of the vehicle before collision as well as a brief description of the crash by the investigating office were of interest to the research team. The crashes that occurred in congested traffic were examined and discarded from further analysis because of the possibility of skewing the results. The 9905 site which is on I-95 was eliminated from analysis because the speed limit on this section was lowered to 55 mph in 2001 due to major construction activities. In addition, because it is located in a growing suburban area of Jacksonville, this site was characterized by a significant number of crashes occurring during the peak commuter traffic period. Therefore, the safety characteristics of seven sites were further analyzed with a total length of 14 miles.

CHAPTER FIVE—ANALYSIS OF TRAFFIC OPERATIONS

5.1 Volume Analysis

The amount of traffic demand on Interstate freeways in Florida was analyzed to determine operating characteristics particularly the freedom to maneuver and other factors affecting the quality of service. Traffic volume is expressed by the number of vehicles using the facility in a particular time interval while traffic flow is the hourly rate of traffic that is using that facility. As traffic demand increases on travel lanes so is the need to pass slow moving vehicles thus creating potential sources of conflicts. An hour-by-hour volume analysis was conducted on both facility types (six-lane and four-lane sections) to determine volume distributions across the travel lanes, the vehicle mix on each lane, and the minimum and maximum volumes and their corresponding hours of occurrence. The volume of traffic was expressed in per lane basis because volume was found to vary across the lanes.

5.1.1 Traffic Volume Distribution

Appendix D shows the volume distributions per lane on both six-lane and four-lane sections plotted against time of the day. Examination of the hourly variation in each site showed that the demand flows were at their lowest from midnight to dawn hours while the peak hour demand occurred in the afternoon typically between 3 pm and 5 pm, with a few exceptions. The lane distribution analysis in six-lane freeway sections showed that flow rates in the middle lane were typically higher than on shoulder and median lanes. On four-lane sections, the flow rates on the shoulder lanes were higher than on the median lanes.

The average annual daily traffic (AADT), which is the gross indicator of traffic activity, usage and need on the facility, was estimated based on the traffic counts on the typical days by multiplying the volume of a particular day of study with volume factors for day and month. The adjustment factors are published by the Florida Department of Transportation Statistics Office based on historic data. These factors are available in the Traffic Information CD which is published annually by this office (*30*). Table 5.1 shows the results of the volume analysis in four-lane and six-lane sections. As it was expected, a cursory examination of the AADT revealed that six-lane sections carry large traffic than four-lane sections.

5.1.2 Lane Usage by Vehicle Type

The mix of traffic is one of the vital inputs to the design of any traffic operational control strategy. Thus, data were analyzed to examine how trucks and passenger cars distribute in these freeways. This analysis was important as it was observed during field reviews that some trucks, recreational vehicles, and vehicles towing trailers were typically traveling at the lower end of speed distribution. This resulted into poor operating characteristics due to their high weight-to-horsepower ratios. Trucks create large gaps that cannot be effectively occupied by cars under normal passing maneuvers.

Table 5.1 Results of volume analysis

Site	Direction	Lane	Minimum Hourly Volume and Time of Occurrence		Peak hour				24-hour % Trucks	AADT (vpd)
					Volume (vehicles)	Hour	% Trucks	Level of Service		
Six-freeway sections										
320 (I-75)	Northbound	Shoulder	188	1 – 2 a.m.	458	3 – 4 p.m.	41	A	51	51065
		Middle	140	5 – 6 a.m.	761		17		21	
		Median	17	4 – 5 a.m.	389		3		3	
	Southbound	Shoulder	119	3 – 4 a.m.	496	2 – 3 p.m.	41		47	
		Middle	90	2 – 3 a.m.	851		17		19	
		Median	12	3 – 4 a.m.	459		2		3	
9904 (I-75)	Northbound	Shoulder	128	2 – 3 a.m.	682	3 – 4 p.m.	38	B	51	64172
		Middle	90	1 – 2 a.m.	1015		11		18	
		Median	13	2 – 3 a.m.	576		1		2	
	Southbound	Shoulder	145	1 – 2 a.m.	490	11 – 12 p.m.	52		54	
		Middle	74	1 – 2 a.m.	733		23		20	
		Median	9	1 – 2 a.m.	376		2		2	
9905 (I-95)	Northbound	Shoulder	120	1 – 2 a.m.	640	7 – 8 a.m.	21	B	38	64284
		Middle	102	2 – 3 a.m.	1198		12		21	
		Median	12	2 – 3 a.m.	601		2		6	
	Southbound	Shoulder	152	2 – 3 a.m.	744	5 – 6 p.m.	18		36	
		Middle	95	3 – 4 a.m.	1179		7		18	
		Median	5	3 – 4 a.m.	630		3		6	
Four-lane freeway sections										
9901 (I-10)	Westbound	Shoulder	117	4 – 5 a.m.	756	5 – 6 p.m.	30	A	37	25627
		Median	12	2 – 3 a.m.	224		15		15	
	Eastbound	Shoulder	109	3 – 4 a.m.	234	3 – 4 pm	28		39	
		Median	15	4 – 5 a.m.	523		9		16	
9928 (I-10)	Westbound	Shoulder	73	2 – 3 a.m.	479	3 – 4 p.m.	25	A	34	18728
		Median	9	2 – 3 a.m.	224		15		16	
	Eastbound	Shoulder	81	3 – 4 a.m.	468	1 – 2 p.m.	28		32	
		Median	8	2 – 3 a.m.	184		10		19	
351 (I-75)	Westbound	Shoulder	36	1 – 2 a.m.	424	11 – 12 p.m.	15	A	20	19047
		Median	3	3 – 4 a.m.	165		2		5	
	Eastbound	Shoulder	38	3 – 4 a.m.	439	11 – 12 p.m.	14		20	
		Median	2	3 – 4 a.m.	149		4		5	
9919 (I-95)	Northbound	Shoulder	65	1 – 2 a.m.	564	4 – 5 p.m.	45	A	27	33917
		Median	11	1 – 2 a.m.	451		7		12	
	Southbound	Shoulder	79	1 – 2 a.m.	628	3 – 4 p.m.	30		32	
		Median	7	1 – 2 a.m.	457		11		14	
9932 (TNPK)	Northbound	Shoulder	61	4 – 5 a.m.	486	11 – 12 p.m.	15	A	16	27163
		Median	10	2 – 3 a.m.	262		5		9	
	Southbound	Shoulder	114	1 – 2 a.m.	616	1 – 2 p.m.	12		21	
		Median	24	2 – 3 a.m.	399		6		10	

In this study, vehicles were grouped into two categories based on their weights and functions: (1) passenger cars and (2) trucks, This categorization was aided by the Florida Department of Transportation vehicle classification criterion, which is the same as scheme "F" vehicle classification recommended by the Federal Highway Administration (*31*). Description of Class F scheme is shown in Appendix E. The truck category comprised of vehicles in Class 4 and above while passenger cars category contained vehicles in Class 1, 2, 3—i.e., motorcycles, cars, and pick up trucks, respectively.

The results presented in Table 5.1 shows that on both six-lane and four-lane freeway sections truck percentages are higher on the shoulder lanes. Likewise, on 4-lane freeway sections truck percentages are higher in the shoulder lanes. The percentages of trucks in the median lane on six-lane freeway sections were below five percent while on four-lane sites trucks using the median lanes were between 5 and 19 percent of the total volume. In general, it can be deduced from Table 5.1 that in all sites the percentages of trucks in each lane were lower than passenger vehicle percentages except in the shoulder lanes of sites 320 and 9904 in which the reverse was observed. It is noteworthy that on sites 320 and 9904 on Interstate 75 in central Florida there is a regulation in which trucks are restricted to use the two outermost lanes of three-lane sections.

5.1.3 Level of Service Analysis

Since volume alone is not sufficient to precisely delineate the operational state of traffic in a facility, analysis of quality of service (level of service) was conducted to determine traffic operating conditions in relation to the capacity of these sections under prevailing conditions of traffic and roadway geometrics. Higher operating speeds are generally attainable at level of service A and continually decrease as the speed-volume relationship moves towards level of service F. Thus, densities were calculated on each segment based on the traffic compositions and travel speeds, because density is a derived measure used to compute the level of service. The analysis of level of service was focused on the peak hour since operating conditions, particularly travel speeds, generally deteriorate during the peak hour of traffic. The procedures for determination of the levels of service were obtained from the Highway capacity Manual (*13*). The peak hour volumes were used to calculate the capacity of each site before computing the densities.   The results presented in Table 5.1 show that all four-lane freeway sections were operating at level of service A. While two sites (9904 and 9905) of six-lane freeways were operating at level of service B, one site (320) was operating at level of service A.

However the level of service analysis of 30^{th} highest hourly volume was later conducted because the peak hour volumes obtained in this study were far below the highest 30^{th} hourly volume. The purpose of this analysis was to determine the quality of service during peak hours of the year. It is noteworthy that the design volume is usually30^{th} hourly volume. The results of the analysis of the 30^{th} hourly volume shows that six lane sections were operating at level of service C while four-lane sections were operating at level of B or better.

5.2 Speed Analysis

The analysis of speed is divided into two parts. The first part analyzes the central tendency of the speed data while the second part analyzes the speed variability of the traffic stream. The analysis of both measures of center and dispersion takes into account of the operating volumes, lane of travel, and the type of vehicles in the traffic stream. The types of vehicles are passenger cars and trucks. The analyses were conducted by looking at measures of central tendency of data—that is, the mean, median, mode, and percentiles. The measures of the central tendency are the descriptive statistics, which measure location of the data sample under the concept of the average value of a distribution. The variance measures the variability or dispersion of the sample data—i.e. how scattered or clustered the data are about the center of the distribution. In general terms, the variation statistics measure how much variation is present in the sample. The following sections discuss the measures of central tendency of the speed data and their variability.

5.2.1 Central Tendency Analysis

Several types of analyses were performed to determine the mean speed characteristics of traffic on rural Interstate freeways in Florida. First, the analysis of the mean speeds of all vehicles was calculated. Trimmed mean and weighted mean statistics were also computed. Then pairwise comparisons were conducted to test the significance of the difference between these measures of central tendency of vehicle speeds.

Mean speeds

The first analysis was the determination of mean speed variations of all vehicles in respective lanes. Appendix F shows the 24-hour mean speeds of all vehicles categorized by facility type—that is, 4-lane or 6-lane section. Examination of hourly mean speed variations shows that the average speeds of vehicles varies from shoulder to median lanes with median lanes experiencing higher average speeds than shoulder lanes. On four-lane sections the average speeds ranged between 66 mph and 74 mph on the shoulder lanes and 67 mph and 85 mph on the median lanes. On the six-lane sections, the average speeds of the vehicles on the shoulder, middle and median lanes ranged between 67 mph and 70 mph, 72 mph and 75 mph, and 75 mph and 81 mph, respectively.

Paired t-test was invoked to test the significance of the difference of the mean speeds between the two opposing directions—that is, northbound/southbound and eastbound/westbound. The t-test results showed that there was no statistical significant difference between traffic flow in the two opposing directions ($p = 0.12$). Statistical analysis of the difference between the mean speed between shoulder and median lanes of four-lane sites suggested a discernible difference between the two speeds ($p<0.0001$). Moreover, significant difference in speeds was noted when the difference between the shoulder and middle lanes speeds on six-lane sites was tested ($p<0.0001$). Similar results were obtained when the difference between median and middle lanes speeds were statistically tested. On four lane sections, the results showed a discernible difference between mean speeds on the shoulder and median lanes ($p<0.0001$). Therefore, these results show that the shoulder lanes carry slow moving traffic while fast moving traffic uses the inner lanes.

Trimmed mean

Trimmed mean was calculated by discarding a certain percentage of the lowest and the highest scores in the sample and then computing the mean of the remaining scores. This statistic is less vulnerable to the effects of extreme scores than the mean of the whole sample. The trimmed means 30% were calculated by discarding the lowest and highest 15 percents of vehicle speeds and then compute the means of speeds of the remaining vehicles. This analysis signified the overall effect of the upper and lower percentile speeds on the average speed of the traffic in these freeways. Table 5.2 displays the results of the trimmed mean and arithmetic mean speeds for all vehicles. Arithmetic mean speed is the straightforward average speeds of all vehicles which are equivalent to trimmed mean 0% of all vehicles in the particular lane.

Trimmed mean speed and untrimmed mean speed based on 24-hour data were compared using paired t-test under the hypothesis that there is no difference between them. The statistical t-test returned *p*-values of 0.94 and 0.83 for six-lane and four-lane sections, respectively. These results indicate that there are not significant differences between the trimmed mean speeds and untrimmed mean speeds on both facility types. The lack of the significant difference between trimmed speed and mean speed shows that the presence of upper and lower 15^{th} percentile vehicles in the speed distribution has no significant effect on the overall distribution of speeds in these facilities as the majority of the vehicles are traveling close to the mean speed.

Weighted mean speed

Speed characteristics in these freeway sections were further analyzed by calculating the harmonic mean speed weighted either by lane volume or vehicle type volume. While the former statistic is referred to as lane-based mean speed, the latter is referred to as vehicle type-based mean speeds. This analysis was designed to determine the contribution of lane traffic and truck traffic on the overall central tendency of speeds on these facilities. The lane-based harmonic mean speed was computed as follows:

$$\overline{u}_1 = \frac{\sum v_{l_i}}{\sum \frac{v_{l_i}}{\overline{u}_{l_i}}} \qquad [4.1]$$

where $\overline{u}_1$ is the harmonic mean speed weighted by 24-hr lane volume in lane *i*, $\overline{u}_{l_i}$ is the 24-hr mean speed of all vehicle in lane *i*, and v_{l_i} is the total 24-hr volume in lane *i*. The vehicle type harmonic speed was computed as follows:

TABLE5.2 Trimmed mean speed characteristics

Site Code (Freeway)	Direction of travel	Travel lane	Trimmed mean speed	Average mean speed
Six-lane freeway sections				
320 (I-75)	Northbound	Shoulder	70	70
		Middle	73	74
		Median	79	79
	Southbound	Shoulder	69	70
		Middle	75	75
		Median	80	81
9904 (I-75)	Northbound	Shoulder	69	67
		Middle	73	72
		Median	76	76
	Southbound	Shoulder	69	68
		Middle	75	74
		Median	77	78
9905 (I-95)	Northbound	Shoulder	68	68
		Middle	73	73
		Median	78	77
	Southbound	Shoulder	68	68
		Middle	73	73
		Median	77	77
Four-lane freeway sections				
9901 (I-10)	Westbound	Shoulder	73	73
		Median	78	78
	Eastbound	Shoulder	73	73
		Median	78	78
9928 (I-10)	Westbound	Shoulder	68	68
		Median	73	73
	Eastbound	Shoulder	70	70
		Median	72	72
351 (I-75)	Westbound	Shoulder	72	72
		Median	77	77
	Eastbound	Shoulder	74	74
		Median	85	85
9919 (I-95)	Northbound	Shoulder	70	68
		Median	75	70
	Southbound	Shoulder	68	66
		Median	69	67
9932 (TNPK)	Northbound	Shoulder	70	70
		Median	75	77
	Southbound	Shoulder	70	71
		Median	76	78

$$\bar{u}_2 = \frac{\sum v_{t_i}}{\sum \frac{v_{t_i}}{\bar{u}_{t_i}}} \quad [4.2]$$

where $\bar{u}_2$ is the harmonic mean speed weighted by 24-hr vehicle type *j* volume in lane *i*, $\bar{u}_{t_i}$ is the 24-hr mean speed of all vehicles of type *i,* and v_{t_i} is the total 24-hr volume of vehicle type *i*.

The results of the weighted speed analysis are further shown in Table 5.3. Statistical tests were conducted to check the significance of the difference between the two weighted mean statistics. The results of the statistical tests are presented in Appendix G. The results yielded *p*-values of 0.69 and 0.08 for six-lane and four-lane sections, respectively, which suggests that there is no significant difference between lane-based mean speed and vehicle type-based mean speed at 5 percent significant level. However, on four-lane section the two statistics differed at 10 percent significant level.

The directional mean speeds were also computed to represent the average speeds of all vehicles in each direction and it was later compared with the lane-based mean speed and vehicle type-based mean speed. The results are also presented in Table 5.3. Statistical comparison of the direction mean and lane-based mean speeds indicated no significant difference between the two statistics on six-lane sections ($p=0.78$) while a significant difference was observed on four-lane sections ($p<0.0001$). Similar findings were obtained when vehicle type-based speed was tested against directional mean speed. While no significant difference was observed on six-lane sections ($p = 0.10$), a very strong difference was observed in four-lane sections ($p = 0.002$).

Mean speeds by vehicle type

Appendix Figure H-1 shows the graphical representation of speed characteristics for passenger vehicles and trucks. As indicated earlier, the vehicles were categorized as truck if they fell into Class 4 and above of the "F-Scheme". The comparison between car and truck speed characteristics revealed that cars were traveling at least 1 mph faster than trucks with some few exceptions observed in the northbound lanes of site 9932 and southbound shoulder lane of site 9904. Closer examination of vehicle-type mean speeds showed that the lowest and highest means speeds for passenger vehicles were 67 mph and 85 mph, respectively, while the lowest and highest mean speeds for heavy vehicles were 64 mph and 80 mph. Like the overall speed results, the shoulder mean speeds were lower than the median mean speed in all sites.

Further analysis involved splitting trucks into three groups—single unit trucks, single combination trucks (truck-trailers) and multi-trailer trucks. Single unit trucks included vehicle in Class 4 to Class 7; truck-trailers included vehicles in Class 8, Class 9, and Class 10 while multi-trailer trucks were vehicles in Class 11, Class 12, and Class 13. The mean speeds of these truck categories were computed and the results are presented graphically as Figure H-2 of Appendix H. Examination of the mean speeds for these three truck categories showed no discernable trend. Generally, the average speed for single unit trucks and truck trailers were above 75 mph and in some lanes the average speeds were over 80 mph. The multi-trailer trucks were the only category which was observed to be traveling relatively slow compared to the other two groups.

Table 5.3 Weighted Mean Characteristics

Site Code (Freeway)	Direction of travel	Travel lane	Lane-based mean $\bar{u}_1$	Vehicle -based mean $\bar{u}_2$	Direction mean $\bar{u}$
Six-lane freeway sections					
70 73	Northbound	Shoulder Middle Median	73	73	74
	Southbound	Shoulder Middle Median	74	74	75
9904 (I-75)	Northbound	Shoulder Middle Median	71	73	72
	Southbound	Shoulder Middle Median	73	72	73
9905 (I-95)	Northbound	Shoulder Middle Median	72	72	73
	Southbound	Shoulder Middle Median	72	72	73
Four-lane freeway sections					
9901 (I-10)	Westbound	Shoulder Median	74	74	76
	Eastbound	Shoulder Median	74	74	76
9928 (I-10)	Westbound	Shoulder Median	69	69	71
	Eastbound	Shoulder Median	70	71	71
351 (I-75)	Westbound	Shoulder Median	73	73	75
	Eastbound	Shoulder Median	78	79	80
9919 (I-95)	Northbound	Shoulder Median	69	69	69
	Southbound	Shoulder Median	66	67	67
9932 (TNPK)	Northbound	Shoulder Median	72	72	74
	Southbound	Shoulder Median	73	73	75

Further, one-tailed t-test was performed to check the existence of the difference between passenger cars and truck mean speeds by hypothesizing that the former was traveling faster than the later. The statistical results revealed significant difference between the two groups on both six-lane and four-lane sections (p=0.002 and p<0.0001, respectively). These results indicate that passenger cars are traveling faster than trucks regardless of whether the section is six-lane or four-lane.

5.2.2 Analysis of Measures of Dispersion

The dispersion of vehicle speeds was analyzed both by lane and by vehicle type. The measures used to analyze speed variability were the standard deviation, coefficient of variation, and 10- mph pace. The 10- mph pace is the 10 mph speed range with the highest number of observations of vehicles in the speed distribution. The analysis was further extended to examine the effects of the vehicles in the lower and upper sides of the speed distribution by conducting a trimmed variance analysis. In addition, as is in most traffic engineering design and operational analyses, the 85^{th} and 15^{th} percentile speeds were also calculated and the range between these percentile speeds was used as the proxy for speed variation between fast and slow moving traffic.

Lane speed distribution analysis

The standard deviations of vehicle speeds were computed the results of which are presented in Table 5.4. Also included in Table 5.4 are the coefficients of variation which measure the relative dispersions of vehicle speeds. For comparative purposes, the mean speeds are also included. Closer examination of standard deviation of speeds shows that their values vary depending on the position of the lane. On six-lane facilities, the standard deviations of speeds ranged between 4 mph to 6 mph, while on four-lane sites standard deviation were as high as 10 mph. Specifically, Sites 351 and 9919 which are on four-lane sections had the highest values of standard deviation. The higher values of the standard deviation of speeds at site 351 and 9919 may be attributed in part to where they are located. These sites are located on stretches that are straight for more than ten miles probably causing some commuter drivers to drive at very high speeds.

The relative dispersion of speeds was also determined by expressing the standard deviation of speed as a proportion of the mean speed. This measure is statistically knows as the coefficient of variation (CV). The results of this analysis showed that the coefficients of variations of the speeds in each lane were between 5 and 14 percents. Comparison of the coefficient of variations of adjacent lanes on each site showed that the differences between the two values were less than 2 percent except on the shoulder and middle lanes of Site 9904 where the differences were 3 percent. These results indicate that the dispersion of the vehicle speeds from the mean speed is not so large which suggests that there seems to be a uniform operation of traffic on these rural freeways sections.

Table 5.4 Speed Deviations and Coefficients of Variations

Site (Freeway)	Direction of travel	Travel lane	Mean $\bar{u}$	Std Dev σ	C.V. $(\sigma/\bar{u})$
Six-lane freeway sections					
320 (I-75)	Northbound	Shoulder	70	6	8
		Middle	74	5	6
		Median	79	5	6
	Southbound	Shoulder	70	6	8
		Middle	75	5	6
		Median	81	5	6
9904 (I-75)	Northbound	Shoulder	67	6	8
		Middle	72	4	6
		Median	76	4	5
	Southbound	Shoulder	68	6	8
		Middle	74	4	6
		Median	78	4	6
9905 (I-95)	Northbound	Shoulder	68	6	8
		Middle	73	5	7
		Median	77	6	7
	Southbound	Shoulder	68	5	7
		Middle	73	4	6
		Median	77	4	6
Four-lane freeway sections					
9901 (I-10)	Westbound	Shoulder	73	6	8
		Median	78	5	6
	Eastbound	Shoulder	73	6	8
		Median	78	5	6
9928 (I-10)	Westbound	Shoulder	68	6	8
		Median	73	5	6
	Eastbound	Shoulder	70	5	7
		Median	72	5	6
351 (I-75)	Westbound	Shoulder	72	7	9
		Median	77	7	10
	Eastbound	Shoulder	74	7	10
		Median	85	9	11
9919 (I-95)	Northbound	Shoulder	68	6	9
		Median	70	10	14
	Southbound	Shoulder	66	5	8
		Median	67	4	7
9932 (TNPK)	Northbound	Shoulder	70	6	8
		Median	77	5	7
	Southbound	Shoulder	71	6	8
		Median	78	5	7

Hourly speed variations

The examination of hourly speed variations was important because the results of volume analysis revealed significant day and night variations of traffic volume. Standard deviations of speed in each section was calculated and plotted on per lane basis. Appendix I depicts the hourly speed variations by lane for both six-lane and four-lane sections. Closer examination of the information in Appendix I showed that the hourly variations of the standard deviation were higher on the median lanes than on shoulder lanes of four-lane sites. In the six-lane sites, middle lanes had lower speed variance than shoulder and median lanes. The F-tests showed no significant difference of standard deviations on both directions of travel. Further, four-lane sections showed a very strong significant difference of standard deviations on shoulder and median lanes—with median lanes having higher variations of speed than shoulder lanes (p <0.0001). On six-lane sections, however, there was no significant difference (p<0.001) of standard deviation of speeds between shoulder and middle lanes; shoulder and median lanes; and middle and median lanes with an exception observed at site 320.

Dispersion analysis speed by vehicle-type

Table 5.5 presents the standard deviations of speeds categorized by vehicle type. Also included in Table 5.5 are the coefficients of variation. Closer examination of the standard deviation of trucks and cars on both four- and six-lane sections shows that they ranged between 4 mph and 9 mph except on Sites 351 and 9919—where trucks speeds had higher standard deviations. Equality of variances test using F-statistic showed that the standard deviations of passenger cars and trucks did not differ significantly for both four lane and six lane sections(p=0.05 and 0.227, respectively). The coefficients of variation between passenger cars and truck speeds revealed that the coefficients of variations in either vehicle group did not exceed 10 percent. In some of the lanes, the coefficients of variations were as low as 4 percent.

Percentile and pace speeds characteristics

Table 5.6 presents the 85th and 15th percentile speeds on different lanes on both six-lane and four-lane sections. Also shown in Table 5.6 are the 10- mph pace speeds and the percentages of vehicles in the pace. Analysis of the percentile speeds showed that in both four-lane and six-lane section the 85th percentile speeds ranged from 73 mph to 86 mph while the 15th percentile speeds ranged from 61 mph to 77 mph depending on the location of the lane—inside lanes had higher percentile speeds than outer (shoulder) lanes. Of significant interest in this study was the 85th percentile speed to the 15th percentile speed range because it represents the spread of vehicle speeds. A shorter speed range would suggest vehicles are traveling more uniformly while a larger speed range would suggest a wide spread of vehicle speed—that is, nonuniform operation. The results showed that on six-lane sites, the 15th to 85th percentile speeds were in the range between 7 mph to 10 mph, 8 mph to 10 mph, and 10 mph to 12 mph on the median, middle, and shoulder lanes, respectively.

TABLE 5.5 Vehicle-type speed dispersion results

Site	Direction	Lane	Passenger scar			Trucks		
			Mean	SD	CV	Mean	SD	CV
Six-lane freeway sections								
320	SB	Shoulder	71	6.0	8.5	68	5.1	7.4
		Middle	76	4.8	6.3	73	4.3	5.8
		Median	81	5.0	6.2	81	5.4	6.7
	NB	Shoulder	71	6.1	8.6	70	5.0	7.2
		Middle	74	4.5	6.1	72	4.2	5.8
		Median	79	4.6	5.8	79	5.0	6.3
9904	SB	Shoulder	71	6.3	8.9	71	6.2	8.7
		Middle	72	5.9	8.2	72	5.9	8.1
		Median	73	5.8	8.0	73	5.9	8.2
	NB	Shoulder	72	6.2	8.6	72	6.1	8.5
		Middle	73	5.8	7.9	73	5.9	8.1
		Median	73	5.9	8.0	72	6.8	9.5
9905	SB	Shoulder	69	5.2	7.6	67	4.5	6.7
		Middle	74	4.3	5.9	71	3.9	5.5
		Median	77	4.6	6.0	76	4.2	5.5
	NB	Shoulder	69	6.0	8.6	67	4.8	7.2
		Middle	74	4.9	6.7	70	4.4	6.3
		Median	78	5.3	6.9	73	7.7	10.5
Four-lane freeway sections								
9901	WB	Shoulder	74	5.4	7.3	70	4.9	6.9
		Median	78	4.8	6.2	74	4.2	5.6
	EB	Shoulder	74	5.4	7.3	70	4.9	7.0
		Median	78	4.8	6.1	75	3.9	5.2
9928	WB	Shoulder	69	5.6	8.1	65	4.9	7.6
		Median	73	4.5	6.1	69	4.1	5.9
	EB	Shoulder	71	5.2	7.3	68	4.7	6.9
		Median	73	4.6	6.4	70	4.0	5.8
351	WB	Shoulder	73	6.7	9.1	69	5.9	8.6
		Median	77	7.4	9.7	72	6.1	8.4
	EB	Shoulder	76	7.1	9.4	69	6.0	8.7
		Median	85	9.0	10.5	80	9.6	11.9
9919	SB	Shoulder	68	5.2	7.7	65	4.9	7.5
		Median	67	4.4	6.6	66	4.1	6.1
	NB	Shoulder	69	6.3	9.1	67	6.1	9.0
		Median	72	8.9	12.3	65	10.1	15.5
9932	SB	Shoulder	72	5.9	8.2	68	5.2	7.7
		Median	78	5.4	6.9	78	6.6	8.5
	NB	Shoulder	70	5.5	7.9	71	7.2	10.1
		Median	76	5.1	6.6	79	5.7	7.3

TABLE 5.6 Percentile and pace characteristics

Site (Freeway)	Direction	Lane	85th percentile speed (u_{85})	15th percentile speed (u_{15})	10-mph pace	% in pace
Six-lane freeway sections						
320 (I-75)	Northbound	Shoulder	76	64	66 – 76	66
		Middle	79	69	70 – 80	76
		Median	83	75	74 – 84	76
	Southbound	Shoulder	75	63	66 – 76	66
		Middle	80	70	71 – 81	78
		Median	86	76	76 – 86	70
9904 (I-75)	Northbound	Shoulder	73	62	65 -75	68
		Middle	77	69	67 -77	77
		Median	80	73	71- 81	76
	Southbound	Shoulder	74	64	65 -75	77
		Middle	79	71	68 -78	75
		Median	82	74	70 – 80	70
9905 (I-95)	Northbound	Shoulder	74	63	63 – 73	68
		Middle	78	68	68 – 78	72
		Median	83	72	74 – 84	60
	Southbound	Shoulder	73	63	63 – 73	70
		Middle	78	69	70 – 80	78
		Median	81	73	74 – 84	72
Four-lane freeway sections						
9901 (I-10)	Westbound	Shoulder	78	67	69 – 79	69
		Median	82	73	73 – 83	75
	Eastbound	Shoulder	78	67	69 – 79	70
		Median	82	73	73 – 83	72
9928 (I-10)	Westbound	Shoulder	73	62	64 – 74	66
		Median	78	69	68 – 78	77
	Eastbound	Shoulder	75	65	66 – 76	69
		Median	77	68	67 – 77	77
351 (I-75)	Westbound	Shoulder	79	65	69 – 79	62
		Median	84	70	72 – 82	59
	Eastbound	Shoulder	81	67	70 – 80	57
		Median	94	77	82 – 92	52
9919 (I-95)	Northbound	Shoulder	74	63	67 -77	60
		Median	79	60	72 – 82	49
	Southbound	Shoulder	72	62	64 -74	63
		Median	71	64	64 -74	63
9932 (TNPK)	Northbound	Shoulder	76	64	65 – 75	66
		Median	81	72	72 – 82	70
	Southbound	Shoulder	77	65	68 – 78	60
		Median	84	73	73 – 83	70

The four-lane sites had a 15th to 85th percentile speed range of 7 mph to 11 mph and 11 mph to12 mph on the inside and outside lanes, respectively. However, on sites 351 and 9919 the percentile ranges were longer—on Site 351, the 15th to 85th percentile speed range was as high as 14 mph while on Site 9919 the range was 19 mph. It is worthy noting that these two sites had also the highest standard deviation values.

The pace characteristics were analyzed next. The results shows that the pace speeds were above 60 mph but below 80 mph in both six-lane and four-lane sections. On the six-lane sections, the lowest pace speed observed was 63 mph to 73 mph on the shoulder lanes of site 9905 while on the four-lane sections the lowest pace speed was 64 mph to 74 mph which occurred on the southbound shoulder lane of Site 9919. Direct relationship between the number of lanes in a freeway and pace speeds was not evident in these sites because six-lane sites showed high and slow values of pace characteristics.

The results further revealed that on every lane of the six-lane sections vehicles traveling in pace were at least sixty six percent—these high percentage values show that the degree of dispersion of speeds among slower and fast vehicles in these freeways is reasonably low and seems to have no effect on uniformity of traffic operations. Likewise, similar findings were obtained on four-lane sections with exceptions again obtained on sites 351 and 9919 where low percentages of vehicles in pace were observed.

Trimmed variance analysis

To determine the contribution of slow and fast moving vehicles on overall variations of vehicle speeds on rural Interstate freeways, a trimmed variance analysis was conducted. In this analysis, seven different scenarios were analyzed, i.e., vehicles moving slower than 40 mph, 45 mph, 50 mph, 55 mph, and 60 mph were trimmed from the vehicle population and the variance of the remaining vehicles computed. In addition, vehicles moving with speed lower than the 15th percentile speeds were also removed from the population and the mean speed and standard deviations of the remaining vehicles were computed. Although the purpose of this study was to investigate the effects of slow moving vehicles in the vehicle population, it was found useful to examine the contribution of fast moving vehicles in the speed variation. Thus, on the upper side of speed distribution, vehicles moving with speeds higher the 85th percentile speeds were removed from the population and the mean and speed variance of the remaining vehicles computed. The results of the trimmed variances were later compared with the variance of speed of all vehicles. The standard deviations resulting from the trimmed analysis are shown in Table 5.7. Included in Table 5.7 also are the standard deviations of the all vehicles in each lane indicated by vehicles with speed greater than zero.

Comparison of variances using the method of "variance ratio" test was conducted to gauge the effect of both slow and fast moving vehicles on the speed distribution of the vehicle population. The vehicles moving above 60 mph were tested in this analysis only because percentage wise few vehicles were moving with speed below 55 mph which makes the effect of their elimination negligible. When the variance of the speed of all vehicles were tested against trimmed variance for vehicles with speed above 60 mph, there were no significant difference between them ($p=0.37$ and $p=0.61$, on six- and four-lane section, respectively). These results suggest that vehicles traveling with speed below 60 mph did not significantly contribute to the overall speed variation.

TABLE 5.7 Trimmed variance analysis results

Site	Direction	Lane	Trimmed standard deviation of vehicle with speed							
			>0	≥40	≥45	≥50	≥55	≥60	≥u_{15}	≤u_{85}
Six-lane freeway sections										
320 (I-75)	Northbound	Shoulder	6	6	6	6	5	5	5	5
		Middle	5	4	4	4	4	4	4	4
		Median	5	5	5	5	5	5	4	3
	Southbound	Shoulder	6	6	6	6	6	5	5	5
		Middle	5	5	5	5	5	5	4	4
		Median	5	5	5	5	5	5	4	4
9904 (I-75)	Northbound	Shoulder	6	6	6	6	6	6	5	4
		Middle	4	6	6	6	6	5	4	5
		Median	4	6	6	6	6	5	3	5
	Southbound	Shoulder	6	6	6	6	6	6	5	5
		Middle	4	6	6	6	6	5	4	5
		Median	4	6	6	6	6	5	3	5
9905 (I-95)	Northbound	Shoulder	6	6	6	5	5	5	5	5
		Middle	5	5	5	5	5	5	4	4
		Median	6	6	5	5	5	5	4	5
	Southbound	Shoulder	5	5	5	5	5	5	4	4
		Middle	4	4	4	4	4	4	4	4
		Median	4	4	4	4	4	4	4	4
	Four-lane freeway sections									
9901 (I-10)	Westbound	Shoulder	6	6	5	5	5	5	4	5
		Median	5	5	5	5	4	4	4	4
	Eastbound	Shoulder	6	5	5	5	5	5	4	5
		Median	5	5	4	4	4	4	4	4
9928 (I-10)	Westbound	Shoulder	6	6	6	5	5	5	4	4
		Median	5	5	5	5	5	5	4	4
	Eastbound	Shoulder	5	5	5	5	5	5	4	5
		Median	5	5	5	5	5	5	4	3
351 (I-75)	Westbound	Shoulder	7	7	7	7	6	6	5	5
		Median	7	7	7	7	7	7	5	5
	Eastbound	Shoulder	7	7	7	7	7	7	6	6
		Median	9	9	9	9	9	9	7	7
9919 (I-95)	Northbound	Shoulder	6	6	6	6	6	5	6	5
		Median	10	10	10	9	8	6	4	9
	Southbound	Shoulder	5	5	5	5	5	4	4	4
		Median	4	4	4	4	4	4	3	3
9932 TNPK	Northbound	Shoulder	6	6	6	6	5	5	4	5
		Median	5	5	5	5	5	5	5	4
	Southbound	Shoulder	6	6	6	6	6	5	5	5
		Median	5	5	5	5	5	5	5	4

Statistical comparison of the trimmed variance and the variances of all vehicles are presented in Table 5.8. Examination of the variance ratio tests results obtained after trimming of lower and upper 15 percent vehicles in the speed distribution showed insignificant reductions of speed variations in six-lane sections (*p=0.108* and *p=0.105*, respectively). In the four-lane sections, a significant reduction of variations was observed after trimming the lower 15 percent of vehicles (*p=0.034*). However, trimming of upper 15 percent of vehicles did not show any reduction of speed variations (*p=0.39*). This shows that the speed variations observed in these sites were not necessarily accounted for by vehicles moving either slower or faster than majority of vehicles in pace.

TABLE 5.8 Results of the statistical comparison of trimmed variances

Statistic	**Six-lane freeways sections**			**Four-lane freeways sections**		
	All Vehicles	**>15%**	**<85%**	**All Vehicles**	**>15%**	**<85%**
Mean	5	4.17	4.44	6	4.55	4.8
Variance	0.71	0.38	0.38	2.11	0.89	1.85
Observations	18	18	18	20	20	20
Degrees of freedom	17	17	17	19	19	19
F statistic		1.85	1.86		2.36	1.14
P(F<=f) one-tail		0.108	0.105		0.034	0.392
F Critical		2.27	2.27		2.17	2.17

Analysis of hourly speed variations

Figure 5.1 shows a typical distribution of vehicle speeds on a section of the highway. By dividing vehicles in the speed distribution in percentages, it was expected that for a uniform flow of traffic to be achieved, seventy percent of the vehicles need to be moving in pace (5 mph above and below the average speed). Ideally, if vehicles are moving in pace the total number of vehicles using the highway minus the sum of the 70% of the vehicles which maintain speeds within ±5 mph of the average speed, and the 15% fast drivers, equals the 15th percentile speed, the speed at which 15% of the drivers are moving at or below.

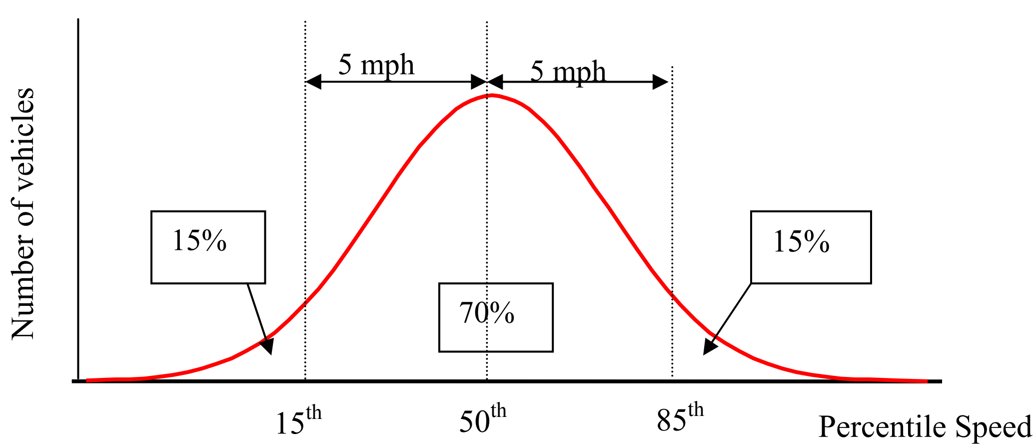

Figure 5.1 Schematic representation of uniform vehicle speed distribution

The percentage of vehicles that are traveling below the pace speed are subject to increase nonuniformity of traffic flow and can cause increased congestion and/or increase of average travel times. While the lower side of speed variation was defined by the difference between the median speed and the 15th percentile speed, the upper side of speed variation was defined by the difference between the 85th percentile speed and the median speed. The results of the hourly speed variation analysis by lane are presented in Appendix J. Closer examination of the difference between the median speed and the percentile speeds showed that the differences were below 7 mph in all sites except on site 351 (a four-lane site) which showed a difference of as high as 10 mph in the median lane of the eastbound direction. This suggests that traffic operating characteristics in these freeways are fairly uniform with the exception of the eastbound lanes of site 351.

The variations between hourly average speeds were statistically tested under the hypothesis that the difference between percentiles and mean speed is equal or below 5 mph. This threshold was selected because one engineering textbook [i.e., McShane *et al.* (*10*)] suggested that this value is frequently observed in field data. In addition, the 5 mph difference can reasonably represent the variations of drivers from the average speed of vehicles both in the upper and lower sides of the speed distribution (See Figure 5.1). One sample χ^2 test for variance was invoked to test if the difference between the lane 15th percentile speeds and median speeds (lower-side variations) does not exceed 5 mph against alternative hypothesis that the deviation is greater than 5 mph. The same comparison was then carried out on the difference between 85th percentile speeds and median speeds (upper-side variations). The statistical test results are presented in the Table 5.9. Examination of the χ^2 results in Table 5.10 show that the upper side variations were less than 5 mph on six-lane sections and greater than 5 mph on four-lane sections. The lower side variations were all above 5 mph in both six-lane and four-lane sections.

Table 5.9 Statistical test results for lane speed variations

Section	Percentile range	Mean	Std Dev.	Chi-square	p-value
6-lane	85th -50th	28.7	6.8	31.2	0.0191
	50th -15th	26.5	3.5	8.2	0.9623
4-lane	85th- 50th	34.6	12.8	123.7	<0.0001
	50th – 15th	33.6	18.3	254.0	<0.0001

15th percentile speeds

The 15th percentile speeds were calculated by lane and compared to the mean speed and the posted 40 mph minimum speed limit. The intent was to compare how many standard deviations the 15th percentile speeds are from the mean speeds and from 40 mph in the speed distribution. Figure 5.2 depicts the explanation of the position of minimum speed with respect to the mean and 40 mph speeds where α and β are the factors of standard deviations from the mean and 40 mph. The results of the comparison are presented in Table 5.10.

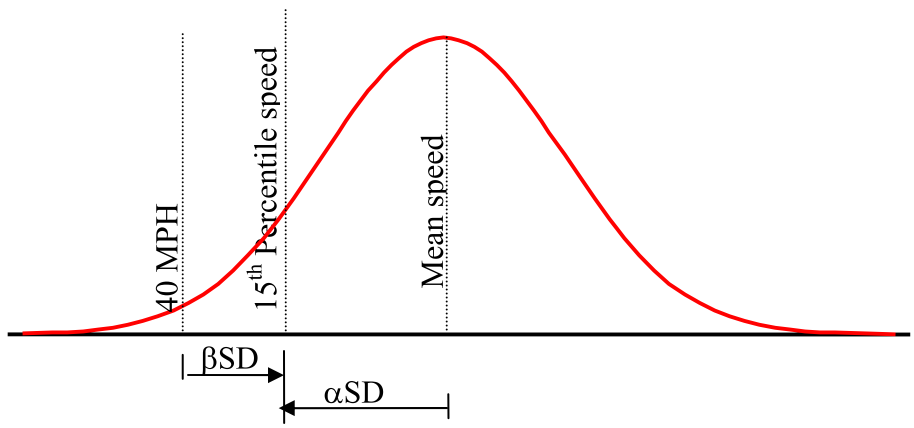

Figure 5.2 15^{th} percentile speed and standard deviation of speeds in speed distribution

Examination of Table 5.10 shows that on six-lane sections, the 15^{th} percentile speeds were in the range from 63 mph to 67 mph, 67 mph to70 mph, and 67 mph to 76 mph on the outside, middle, and inside lanes, respectively. On four-lane freeway sections, the 15^{th} percentile speeds on outside and inside lanes were in the speed range of 61 mph to 67 mph and 62 mph to 75 mph, respectively. Further analysis indicated that the 15^{th} percentile speeds on six-lane sections were between 0.2 to 1.7 standard deviations from the mean—with small deviations occurring on the shoulder lanes. On the four-lane sections the 15^{th} percentile speed were between 0.2 and 2.4 standard deviations from the mean—with small deviations again being observed on the shoulder lanes. In both six-and four-lane sections, the 15^{th} percentile speeds were significantly far from the posted minimum speed limit—β were in the range of 4.6 to 6.2 and 4 to 9.4 on six-and four-lane sections, respectively.

5.3 Analysis of Slow Moving Vehicles

The analysis discussed in this section involved identifying vehicles that were recorded to have speeds significantly below the average speed on both six-lane and four-lane facility types. Of importance in the analysis was the identification of vehicles with speeds slightly above the 40 mph posted minimum speed limit. The reasoning for this analysis was to determine the categories of speeds that could be set as the minimum speed should the Florida Department of Transportation decide to raise the current posted minimum speed limit of 40 mph. The vehicles speeds at the lower end of the speed distribution were grouped into four different intervals: vehicles traveling with speed below 40 mph; below 50 mph; below 55 mph; and below 60 mph. These vehicles were expressed as the percentage of daily traffic volumes recorded on the study sections. The results of this analysis are depicted in Table 5.11. Examination of Table 5.11 shows that the percentage of vehicles traveling with speeds below the posted minimum speed limit were 0.2 percent or less in each site while percent of vehicles traveling with speeds below 50 mph did not exceed 1.5 percent. The data displayed in Table 5.11 shows that, on average, less than 5 percent of the vehicles were recorded to have speeds less than 60 mph.

Table 5.10 The 15th percentile speed characteristics

Site	Direction	Lane	15th Pctl	Std. Dev from		α.	β
				Mean	40 mph		
Six-lane freeway sections							
320	SB	Shoulder	63	70	5.84	1.2	3.9
		Middle	70	74	4.8	0.8	6.3
		Median	76	79	5.34	0.6	6.7
	NB	Shoulder	64	70	5.7	1.1	4.2
		Middle	68	75	4.61	1.5	6.1
		Median	74	81	4.83	1.4	7
9904	SB	Shoulder	65	67	6.2	0.3	4
		Middle	68	72	6.1	0.7	4.6
		Median	67	76	6	1.5	4.5
	NB	Shoulder	67	68	6.3	0.2	4.3
		Middle	68	74	6.1	1	4.6
		Median	68	78	6	1.7	4.7
9905	SB	Shoulder	63	68	5.5	0.9	4.2
		Middle	69	73	4.7	0.9	6.2
		Median	72	77	4.6	1.1	7
	NB	Shoulder	63	68	5.6	0.9	4.1
		Middle	67	73	5.2	1.2	5.2
		Median	71	77	5.9	1	5.3
Four-lane freeway section							
9901	WB	Shoulder	65	73	5.6	1.5	4.4
		Median	73	78	4.9	1.1	6.7
	EB	Shoulder	67	73	5.7	1.1	4.7
		Median	73	78	5.4	1	6
9928	WB	Shoulder	62	68	5.7	1.1	3.8
		Median	68	73	5.1	1.1	5.4
	EB	Shoulder	65	70	5.3	0.9	4.8
		Median	67	72	5	1	5.4
351	WB	Shoulder	66	72	7.4	0.9	3.5
		Median	75	77	7.4	0.2	4.8
	EB	Shoulder	67	74	7	1.1	3.8
		Median	75	85	4	2.4	8.9
9919	SB	Shoulder	62	68	9.4	0.6	2.3
		Median	62	70	9.1	0.9	2.4
	NB	Shoulder	61	66	6.7	0.7	3.1
		Median	64	67	6.6	0.5	3.6
9932	SB	Shoulder	64	70	6.3	0.9	3.9
		Median	72	77	6.4	0.9	4.9
	NB	Shoulder	64	71	6.1	1.1	3.9
		Median	71	78	5.3	1.3	5.9

Although results presented in Table 5.11 revealed that less than 5 percent of the vehicles were traveling with speeds below 60 mph (except at site 9919), it was of interest to determine the type of vehicles that travel at low speeds and which lane they are traveling in. Field observations were used to make inferences on the reasons for this phenomenon. Since the speed analysis showed that on the average less than 5 percent of the vehicles were traveling with speeds at least 60 mph, any vehicle moving with a speed below 60 mph in the speed distribution was identified as being a slow moving vehicle. The number of vehicles moving with speeds below 40 mph, 50 mph, 55 mph, and 60 mph were expressed as the percentage of daily volumes of traffic in each lane. Average speeds and the corresponding coefficients of variation for both categories were also evaluated. The results of this analysis are summarized in Figure 5.3.

Table 5.11 Percent of slow moving vehicles in each site

Site	Percent vehicles moving below			
	40 mph	50 mph	55 mph	60 mph
Six-lane freeway sections				
320	0.1	0.2	0.5	2.6
9904	0.1	0.2	0.6	3.6
9905	0.2	0.4	0.6	2.9
Four-lane freeway sections				
9901	0.1	0.2	0.6	1.9
9928	0.2	0.4	1.2	4.9
351	0.2	0.4	1.0	3.4
9919	0.2	1.5	4.7	10.0
9932	0.2	0.3	0.7	2.9

Examination of the vehicles moving below 60 mph shows that the average speeds of both passenger cars and trucks moving below 60 mph on six-lane sections were above 55 mph. On four-lane sections the average speeds for vehicles moving below 60 mph were above 50 mph.

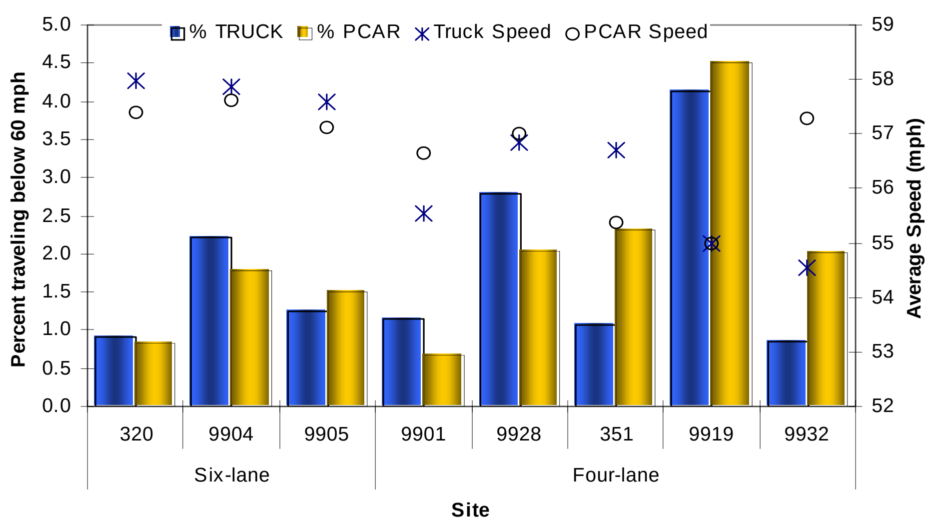

Figure 5.3 Distribution of vehicles traveling below 60 mph

In addition, Figure 5.3 shows that more trucks on four-lane sections had speeds below 60 mph compared to passenger cars at Sites 9901, 9919 and 9928 while more passenger cars were traveling with speeds below 60 mph on Sites 351 and 9932. On six-lane sections the results were different from those of four-lane sections. On Sites 320 and 9904, which are approximately 70 miles apart, different patterns of vehicles with speed below 60 mph were observed. While on Site 9904 more passenger cars were traveling with speeds below 60 mph, on Site 320 more trucks than passenger cars were traveling with speeds below 60 mph. On Site 9905, more passenger cars than trucks had speed below 60 mph. It can be surmised that, for both six-lane and four-lane sections, most of the slow vehicles comply with the traffic rule which requires them to use the rightmost lane.

5.4 Headway Distributions and Close Following Behavior

To understand the relationship between headway distribution and traffic flow parameters, a headway analysis was conducted. Headway is the time gap between two successive vehicles on the highway. First, the effects of traffic volume on gap distribution were studied. The aim of this analysis was to investigate the effect the volume has on the formation of short headways in these freeways. Subsequently, a platoon analysis was conducted by investigating vehicles that were traveling in close proximity to each other. In addition, the effects of platoon formation on the mean speed and variations of traffic speeds were analyzed.

5.4.1 Impacts of Volumes on Short Headways

The relationship between prevailing traffic volume and the headways was examined with special attention being paid to the short headways. The presence of short headways in a traffic stream is characterized by the proximity of vehicles traveling very close to each other or tailgating behavior. Several factors are known to affect car following behavior. These factors include the risk tolerance by the following driver, vehicle type, driver type, and traffic volumes. One limitation of this study is that data on driver type and risk were not collected. The time headways for all vehicles were calculated by lane and the percentages of vehicles traveling at short headways (4 seconds or less) were then extracted. Percentages of vehicles following another vehicle at headways of 4 seconds or less and their corresponding hourly volumes were plotted against the time of the day the results of which are depicted in Appendix K.

Analysis of the results of the variation of hourly volumes and percentage of vehicles moving with short headways showed that as the volume of traffic increases the number of vehicles traveling with short headways increases. In four-lane sections, the shoulder lanes were observed to have high percentages of short headways compare to the median lanes. This is because of large volumes that were observed on the shoulder lanes. Data from six-lanes sites showed similar patterns except that higher percentages of vehicles moving with short headways were observed in the middle lanes. There seems to be a correlation between the percentage of slow moving vehicles with the prevailing traffic volume. The increase in traffic volumes reduces the number of acceptable gaps required by following vehicles to effect passing maneuvers in traffic stream probably leading to tailgating. The results of the field observations revealed that passing opportunities are impacted on either lane. Sometimes this made slower vehicles to be caught in the left lanes. In some situations when slower vehicles were leading vehicles in both lanes, fast vehicles behind them queue up to form platoons and therefore reduce speed. This eventually increases chances of short headways. This situation occurs mostly during peak traffic conditions.

5.4.2 Relationship between Short Headways and Speeds

Vehicles traveling together in close proximity at about the same speed were analyzed. Vehicles were defined to be in platoon whenever the time headway between two successive vehicles traveling on the same lane was 4 seconds or less otherwise they were deemed to be free flowing. When the headway between vehicles decreases towards 4 seconds, fast vehicles start queuing up behind slow moving vehicles and form bunches whenever passing opportunities are not available. Time headways were calculated on each lane and the percentages of vehicles following another vehicle were computed.

Table 5.12 presents the results of platoon analysis. These results reveal that six-lane sections carry large proportions of platooned vehicles compared to the four-lane sites. In addition, the middle lanes on the six–lane sections had larger percentage of platooned vehicles than other lanes. The large traffic volumes observed in the middle lanes is correlated to the formation of these platoons as discussed earlier.

Given the interest in determining the effect of platooned vehicles on the speed of traffic, the mean speeds of platooned vehicles were tested against the mean speed of nonplatooned vehicles by using a two-sample paired *t*-tests for mean speeds of the two categories under the null hypothesis that there is no difference between the mean speeds of the two categories at 5 percent significance level. Inferential statistics results are summarized in Table 5.12.

Table 5.12 shows that the statistical analyses yielded *p*-values of 0.16 and 0.78 for six-lane and four-lane sites, respectively. These results suggest that the difference between the speeds of platooned and non-platooned vehicles were insignificant at 5 percent significance level. The standard deviations of speeds of traffic flowing in free flow conditions were higher that those of traffic moving in platoons by 1 mph to 4 mph. Variance ratio tests results presented were performed and are presented in Table 5.13. The results show that the difference between the standard deviations is not significant on both six-lane and four-lane sections ($p= 0.104$, $p= 0.39$). Examination of the coefficient of variations also shows that there is no discernible difference between platooned and free flowing vehicles.

Although one can anticipate free flow traffic to have high average speeds and high variations of speeds because of the ability of drivers to choose speeds they want to travel with, these results have showed that the existence of the platoons does not result in the reduction of operating speeds on these freeways. These results closely matchs the findings of the quality of service discussed earlier where all study sites were found to be operating at levels of service of B or better.

Table 5.12 Platoon analysis results

Site	Direction	Lane	Vehicles moving in Platoon				Free flowing vehicles			
			%	Mean	SD	*CV*	%	Mean	SD	*CV*
Six-lane freeway sections										
320 (I-75)	Northbound	Shoulder	29	70	5	8	71	70	6	8
		Middle	47	74	4	6	53	74	5	6
		Median	34	79	4	5	66	79	5	6
	Southbound	Shoulder	30	69	6	8	70	70	6	8
		Middle	51	75	5	6	49	75	5	6
		Median	43	81	5	6	57	81	5	6
9904 (I-75)	Northbound	Shoulder	32	72	6	9	67	72	6	8
		Middle	56	73	6	8	43	73	6	8
		Median	48	73	6	8	52	73	6	8
	Southbound	Shoulder	28	71	6	9	71	71	6	9
		Middle	50	72	6	8	50	73	6	8
		Median	38	73	6	8	62	73	6	8
9905 (I-95)	Northbound	Shoulder	36	68	6	8	64	68	6	8
		Middle	65	73	5	7	35	73	5	7
		Median	48	77	5	7	52	77	6	7
	Southbound	Shoulder	42	68	5	7	58	68	5	8
		Middle	61	73	4	6	39	73	5	6
		Median	47	77	5	6	52	77	5	6
Four-lane freeway sections										
9901 (I-10)	Westbound	Shoulder	33	73	5	7	67	73	6	8
		Median	33	77	5	7	67	78	5	6
	Eastbound	Shoulder	32	73	5	7	68	72	6	8
		Median	29	77	5	6	71	78	5	6
9928 (I-10)	Westbound	Shoulder	29	68	6	9	70	68	6	8
		Median	25	73	5	6	75	73	5	6
	Eastbound	Shoulder	32	71	5	7	68	70	5	8
		Median	23	72	5	7	77	72	5	6
351 (I-75)	Westbound	Shoulder	28	72	7	9	72	72	7	9
		Median	24	75	8	11	76	77	7	9
	Eastbound	Shoulder	26	75	7	9	74	74	7	10
		Median	25	86	9	10	75	85	9	11
9919 (I-95)	Northbound	Shoulder	43	69	6	9	57	68	6	10
		Median	43	70	10	14	56	70	10	14
	Southbound	Shoulder	38	67	5	7	62	66	5	8
		Median	44	67	4	6	56	67	4	7
9932 (TNPK)	Northbound	Shoulder	10	70	6	8	90	70	6	8
		Median	7	76	5	6	93	77	5	7
	Southbound	Shoulder	12	71	6	8	88	71	6	8
		Median	8	78	5	7	92	78	6	7

Table 5.13 F-test results for platooned and free flowing traffic

Statistic	Six-lane freeway sections		Four-lane freeway sections	
	Platoon	Free flow	Platoon	Free flow
Mean	28.39	31.11	37.65	38.55
Variance	59.08	31.63	463.08	407.63
Observations	18	18	20	20
Degrees of freedom	17	17	19	19
F Statistic	1.87		1.14	
p-value	0.104		0.392	
F_{crit}	2.27		2.17	

5.5 Correlation Studies

To understand the relationship between traffic volume and speed, correlation studies were conducted. First to be studied were the correlation between the volume and mean speeds and thereafter the correlation between the volume and the standard deviation of speed. The intent was to investigate the variation of traffic speed in relation to the fluctuation of traffic volume with the assumption that the effect of posted minimum speed limit in congested traffic conditions is negligible. In congested traffic conditions the speed of vehicles are controlled by the speed of the lead vehicles.

5.5.1 Hourly Volume and Mean Speed

The hourly mean speeds were plotted against hourly volume in the same graphs. There were 24 data points in each data set given that data were collected for a 24-hour period. Appendix L shows figures of the variations of hourly traffic speed and volume plotted in the same axes. The figures presented in Appendix L show that there is no distinct relationship between these two traffic variables. The average speeds were observed to be constant irrespective of the variation of the volume in both peak and off peak traffic conditions—during peak traffic conditions, average speeds did not change much when compared to the off-peak periods. It should be recalled that the freeway sections studied operated below capacity with significant high average speeds and the levels of service were B or better. Therefore, the influence of traffic flow on motorists' speeds was relatively small in all sites.

Further analysis was conducted on the scatter of speeds. The results of this analysis is presented in Appendix M. These scatterplots were prepared in order to get insight into the relationships between speed and hourly volume. Examination of the scatterplots revealed no specific trend on the variations of speed and volume of traffic. Since the levels of service on these sections were B and better, it can be surmized that the operating volumes do not have significant effects on the speed of traffic.

Table 5.14 Correlation of volumes and speeds

Site	Volume and mean speed		Volume and Std. deviation	
	r	p-value	r	p-value
Six–lane freeway sections				
320	0.24	0.0035	-0.24	0.0036
9904	0.09	0.2713	0.01	0.8784
9905	-0.18	0.0286	0.22	0.0079
Four-lane freeway sections				
9901	-0.54	<0.0001	0.15	0.13
9928	-0.32	0.00149	0.07	0.5039
351	-0.29	0.0044	0.15	0.1537
9919	0.48	<0.0001	-0.12	0.2771
9932	-0.15	0.122	-0.21	0.0387

The hourly volume and average speeds in each site were then statistically tested under the null hypothesis that there was no association between the two variables. The intent was to measure how strong the correlation is. Since the scatterplots have indicated that the variation of volume did not correlate with the variation of speed, the the use of Pearson correlation coefficients was discarded. Thus, the Spearman rank coefficients, *r,* which are distribution-free (nonparameteric) statistics were used to measure the monotonic association between the speeds and hourly volumes. To assess the significance of the correlations obtained, *p*-values were also calculated. Presented in Table 5.14 are the coefficients of correlation and their respective *p*-values. It is noteworthy that the calculated *p*-values reflect not only the strength of the relationship but also the randomness of the sample size and other parameters such as the type of flow or the headway variations. This is why both correlation coefficients and *p*-values are reported.

Table 5.14 reveal that there is a weak association between volume and speed of traffic in both six-lane and four-lane sections—i.e. the Spearman rank coefficients were below 0.60. Sites 320 and 9904 which are six-lane sections showed a positive weak correlation while site 9905 showed negative weak correlation. The four-lane sections showed negative and weak correlation between volume and speed. However, the results of correlation at Site 9919 indicated a positive correlation between speed and volume. The *p*-values reported in Table 5.14 indicate the existence of statistically significant weak associations between hourly speeds and volumes at Sites 320 and 9905 of six-lane sections. Similarly, on four-lane sections the observed correlations were statistically significant at all sites except at Site 9932.

5.5.2 Hourly volume and Standard Deviations

To understand how the volumes of traffic using these freeways affect the variations of speeds, scatterplots of volume against standard deviations were prepared. The plots are presented in Appendix N. The scatterplots of each site showed that at low volume the there is more variations of speed than during high traffic volume. The standard deviations start to cluster together when the hourly volumes exceed 500 vehicles per hour per lane (vphpl) and 300 vphpl on six- and four-lane sections, respectively. Correlations between hourly volumes and standard deviation of speeds were also computed. The results are also presented in Table 5.14. The Spearman correlation coefficients displayed in Table 5.14 reveal a weak association between volume and standard deviation of speed of traffic using these freeways. In the six-lane sections, Sites 9904 and 9905 showed a positive weak association while Site 320 showed a negative weak association. On the four-lane sections, Sites 9901, 9928 and 351 showed positive weak association between volume of traffic and standard deviation of speed while the rest showed a negative correlation. The *p*-values indicated that the correlations observed in four-lane sites are not statistically significant. On Sites 320 and 9905, which are six-lane sections, the observed correlations were statistically significant.

5.6 Pre- and Post-70 mph Speed Evaluation

The results presented in this section compare speed characteristics on Interstate freeways before and after raising the maximum speed limit to 70 mph. Before 70 mph went into effect on Florida rural Interstate freeways in 1997, the maximum posted speed limit on these freeways was 65 mph. The posted minimum speed limit was 40 mph and did not change after the maximum speed limit was raised. It is noteworthy that the 2002 speed characteristics used in this section were computed by direction in order to match with the 1996 speed data. The sites that were sampled in 1996 were very close to the sites that were sampled in 2002. Therefore, for all practical purposes, the data come from sites with similar geometric characteristics.

5.6.1 1996 Speed Characteristics

The data presented in Table 5.15 shows that in 1996, the 15^{th} percentile speeds on six-lane sites were between 60 mph and 65 mph while average speeds were between 63 mph and 69 mph. The standard deviations in these sites were below 6 mph. In addition, the coefficients of variations were less than 10%, which suggest that vehicle speeds on these sites were fairly uniform. The results in Table 5.15 further show that on four-lane sections the 15^{th} percentile speeds ranged from 61 mph to 64 mph while mean speeds were in the range between 66 mph and 69 mph. The standard deviations were below 5 mph. Statistical tests of the difference between the 15^{th} percentile speeds of the six-lane and four-lane sections returned a *p*-value of 0.09, which suggested lack of significant difference between the 15^{th} percentile speeds at six-lane and four-lane sections.

5.6.2 Comparison with 2002 Speed Characteristics

The 1996 speed characteristics were compared with the current speed characteristics. The results show that the average speeds at all sites have increased by 5 mph to 72 mph while the 15^{th} percentile speeds have increase by 2 mph to 65 mph. The standard deviations of speeds also have increase by 1.7 mph to 6.4 mph. Comparison of the 1996 and current mean speeds revealed that the mean speeds have significantly increased ($p<0.0001$); likewise, the 15^{th} percentile speeds also showed a significant increase ($p<0.0001$).

Table 5.15 1996 Spot Speed characteristics

Freeway	Location, Direction and Year	Mean Speed (MPH)	Standard Deviation (MPH)	Coefficient of Variation (%)	15th Percentile Speed (MPH)
Six-lane freeway sections					
I-75	Between I-10 & CR136, NB, 1996	66	4	6	63
	Site 320, NB, 2002	73	6	8	67
	Between I-10 & CR136, SB, 1996	66	5	8	61
	Site 320, SB, 2002	74	7	9	66
	Between CR234 & SR21, NB, 1996	68	5	7	63
	Site 9904, NB, 2002	71	6	8	64
	Between CR234 & SR21, SB, 1996	67	5	7	63
	Site 9904, SB, 2002	71	6	8	64
I-95	Between CR210 and I-295, NB, 1996	67	4	6	64
	Site 9905, NB, 2002	72	7	10	65
	Midpoint CR210 and I-295, SB, 1996	63	6	10	60
	Site 9905, SB, 2002	72	6	8	65
	Near Flagler CL, NB, 1996	69	4	6	65
	Site 9905, NB, 2002	72	7	10	65
	Near Flagler CL, SB, 1996	64	5	8	63
	Site 9905, SB, 2002	72	6	10	65
Four-lane freeway sections					
I-75	At Mile marker 89, WB, 1996	66	4	6	61
	Site 351,WB, 2002	74	7	9	66
	At Mile marker 89, EB, 1996	68	6	9	63
	Site 351, EB, 2002	78	9	11	68
I-10	Overpass E. of SR 85, WB, 1996	67	4	6	64
	Site 9901, WB, 2002	74	6	8	68
	Overpass E. of SR 85, EB, 1996	69	4	6	64
	Site 9901, EB, 2002	74	6	8	68
	C- 280 overpass, WB, 1996	68	5	7	65
	Site 9901, WB, 2002	74	6	8	68
	C- 280 overpass, EB, 1996	67	4	6	64
	Site 9901, EB, 2002	74	6	8	68
	Between SR257 & US221, WB, 1996	67	5	7	62
	Site 9928, WB, 2002	70	6	9	66
	Between SR257 & US221, EB, 1996	69	5	7	65
	Site 9928, EB, 2002	71	5	7	68
	East End of Aucilla river, WB, 1996	67	5	7	62
	Site 9928, WB, 2002	70	6	8	66
	East End of Aucilla river, EB, 1996	69	4	6	64
	Site 9928, EB, 2002	71	5	7	68

In order to compare speed variation for the pre- and post-70 mph speed limit, two-sample variance ratio test (F-test) on the variance of the two groups was conducted. The results of the variance ratio test conducted in six-lane sites returned a significant value of 0.2, which suggest no any statistical significant difference of the speed variances between the two groups supported at 0.05 significant level. In four-lane sections, however the results of the variance ratio test indicated a significant increase of the speed variance ($p=0.0003$). This result seems to indicate that raising the maximum speed limit to 70 mph in these freeways had contributed to the increase of the dispersion of vehicle speeds among slow and fast vehicles by increasing the average speed of the fast drivers only on four-lane freeway sections.

Examination of the coefficients of variation indicated that the 2002 speed data had higher coefficients of variation on both six-lane and four-lane sections. Thus, there is an indication that raising the maximum speed limit has increased the dispersion of vehicle speeds. Further analysis of the dispersion of vehicle speeds indicated that in 1996 the average speed on six-lane sections was 4.75 standard deviations above the minimum posted speed limit of 40 mph. In 2002, it was 5 standard deviations above the 40 mph minimum speed limit. In four-lane sections, the results show that the average speeds are 6 and 5 standard deviations above the 40 mph in 1996 and 2002 respectively. Examination of the coefficient of variation between the two data sets indicated that current data show significantly large variations compared to the 1996 data.

CHAPTER SIX—ANALYSIS OF SAFETY CHARACTERISTICS

6.1 Analysis of Crash Typology

Analysis of crash typology involved the examination of motor vehicle crash types and their circumstances. In this section, crashes that occurred in seven study sites on Florida Interstate freeways are analyzed. The crash information gathered from the police reports was summarized based on the severity of crashes, traveling speed of vehicle before the crash which is referred as involvement speed, and major crash contributing factors.

6.1.1 Severity of Crashes

The uniform Florida crash report form reports four major severity levels. However, in this study, the crashes are grouped into three levels of severity: (1) fatal, (2) injury which included non-incapacitating injury and incapacitating injury, and (3) property damage only (PDO). Fatal crashes are crashes that involve at least a death of one person occurring within 30 days after the crash. Injury crashes are all crashes resulting in the injury of at least one person while PDO crashes are crashes involving minor damages to a vehicle or property without harming any person involved in the crash.

Table 6.1 summarizes the severity of crashes at each site. Examination of Table 6.1 shows that during the four-year period under investigation, 169 crashes occurred on these freeway sections. Of 169 crashes, 8 were fatal crashes, 99 were injury crashes, and 62 were PDO crashes. Sites 320 and 9904 which are six-lane sections had more fatalities than other sites. Site 9904 had also more injury crashes than other sites. In addition, six-lane sections had more number of crashes per site than four-lane sections.

To account the effect of exposure, crash rates per million vehicle miles traveled for the segments were calculated. The calculation of crash rates improved the analysis of safety analysis by accounting the influence of volume of traffic on the segments concerned. The crash rates were calculated by dividing crash frequency by the amount of exposure as shown below:

$$Crash \quad Rate = \frac{N \times 10^6}{365 \times T \times AADT \times L} \qquad \textbf{[6.1]}$$

where N is the number of crashes that occurred on the section, $AADT$ is the annual average daily traffic of the fourth year, T is the 4-year period of study in years, and L is the section length.

Crash rates per million vehicle miles of travel are also shown in Table 6.1. Examination of Table 6.1 shows that in all sites the crash rates per million vehicle miles of travel were below 0.5. Site 351 (a four-lane section) and Site 9904 (a six-lane section) had higher crash rates than others. This suggests that the two sites are more hazardous than other sites. Further examination of the crash rates reveals that Site 9932 which is a four-lane section is the least hazardous site because it has the lowest crash rate. In addition no fatal crashes were recorded on Site 9932.

Table 6.1 Summary of the crashes by severity

Statistic	Six-lane sections		Four-lane sections				
	Site 320	Site 9904	Site 9901	Site 9928	Site 351	Site 9919	Site 9932
Total number of crashes, N	24	62	15	15	22	22	9
Number of fatal crashes, N_F	2	3	0	1	1	1	0
Number of injury crashes, N_{INJ}	14	33	7	11	14	14	6
Number of property damage only, N_{PDO}	8	26	8	3	7	7	3
Annual Average daily Traffic, *AADT*	51065	64172	25627	18728	19047	33917	27163
Crash rate per million vehicle mile, *CR*	0.160	0.330	0.200	0.274	0.396	0.222	0.113

6.1.2 Crash Involvement Speeds

The relationship between crash involvement speeds and frequency of vehicle involvements was performed in order to compare vehicles involved in the crash at both upper and lower ends of speed distribution. The intent of this analysis was to determine the correlation of crash speeds and normal travel speeds of vehicles. Involvement speed which is the traveling speed before the crash occurrence was obtained by the officer investigating the crash based on the evidences gathered from the victims, witnesses and posted speed limit. If evidence from victims or witnesses was missing the officer also estimated the speed through examination of skid marks on the roadway, damage of the vehicle, and scars left on the objects hit. It is noteworthy that the involvement speed is not the speed at impact but the estimated vehicle traveling speed before the crash. In many situations, the speed at impact is expected to be lower than the traveling speeds because if the drivers happen to anticipate the danger on the road then they start to decelerate.

Each crash report was examined and the speed of the vehicle before crash as estimated by the investigating officer was noted. The relative frequency of vehicles involved in the crash was plotted against the estimated speeds before the crash. The results are presented in Figure 6.1. Also included also in Figure 6.1 is the speed distribution of all actual traveling speeds of vehicles collected in this study. Examination of Figure 6.1 shows that the majority of the vehicles were involved in the crashes when traveling with speed between 66 mph and 70 mph. Of 244 vehicles involved in the crash in these sections, about 62 percent (154 vehicles) were traveling with speeds between 60 and 70 mph. Examining the speed distribution of the speed data collected in these sites shows that majority of the vehicles were driving between 68 and 78 mph. To further understand the distribution of involvement speeds, a cumulative frequency distribution of speeds was plotted as shown in Figure 6.2.

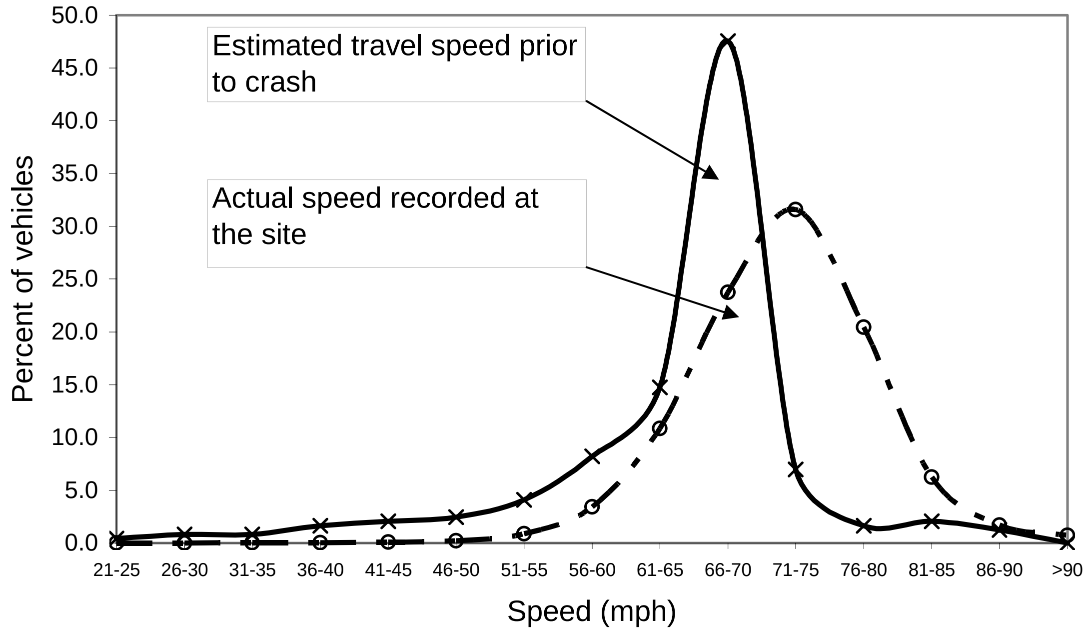

Figure 6.1 Comparison of operational and crash speed

One can examine the curves in Figure 6.2 in different ways including looking at the 10-mph speed range with highest number of crashes. Figure 6.2 shows that this 10- mph range is 60 to 70 mph encompassing 66 percent of the reported crashes. However, the curve representing actual field data of vehicle speeds shows that the pace—the 10- mph speed range with the highest number of observations—is between 69 and 79 mph with 65 percent of observations. Analysis of the lower end of the speed distribution shows that the percent of vehicles involved in the crashes with speeds below 55 mph were significantly higher than the overall percents of vehicles observed in the field to be traveling below 55 mph. While the vehicles traveling below 55 mph were 1.3 percent of all vehicles, crash-involved vehicles with traveling speeds below 55 mph were 17.6 percent of the total crashes. As indicated earlier, the field data showed that only 0.14 percent of the observed vehicles were traveling with speeds below 40 mph (the posted minimum speed limit), while Figure 6.2 reveals that about 9 percent of vehicles involved in the crashes had traveling speeds below 40 mph. These results suggest that relatively slow driving is, on average, dangerous in these freeway sections and that even though the proportion of slow moving vehicles might be low, they nevertheless pose a bigger risk of crash involvement for the rest of the traffic stream.

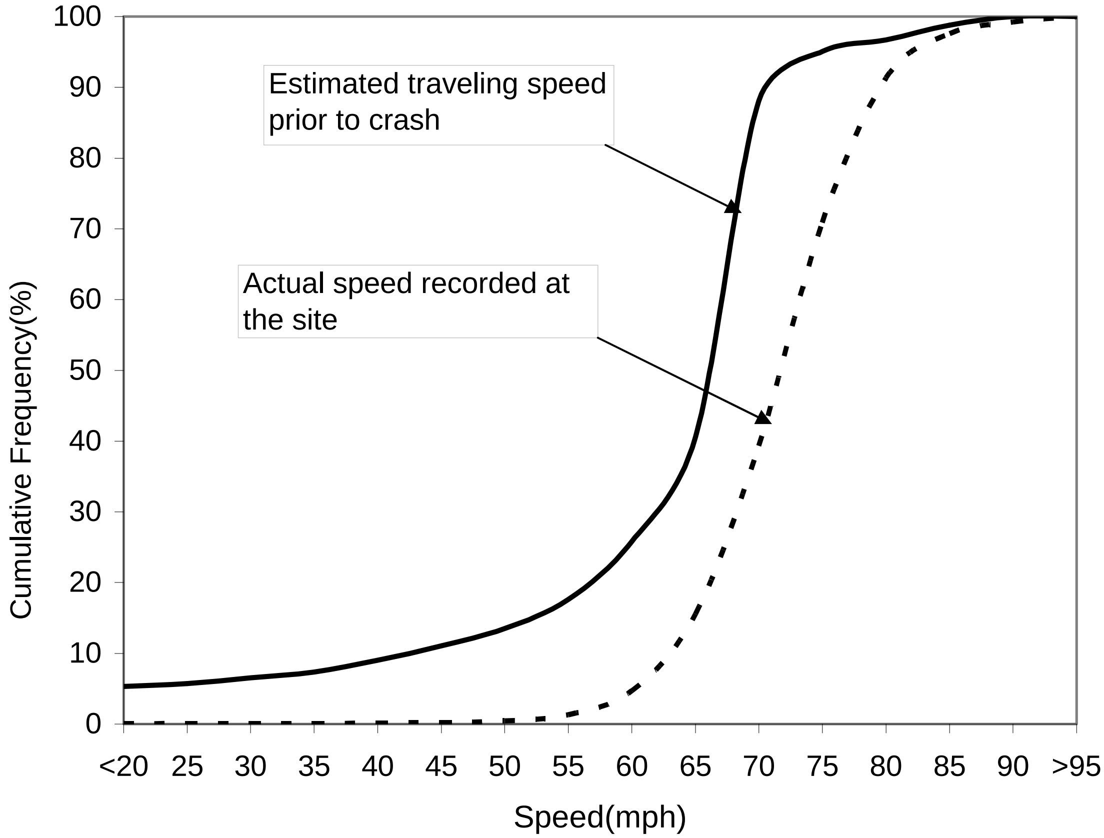

Figure 6.2 Cumulative frequency distribution of operational speed data versus crash speed data

The crash involvement rates were then computed by weighting the number of crash involved vehicles by the total mileage for each speed range as shown below:

$$Crash\ \ Involvement\ \ Rate = \frac{Number\ \ of\ \ crashes\ \ occured\ \ with\ \ speed, S_i}{Vehicle\ \ miles\ \ of\ \ travel\ \ at\ \ speed, S_i} \qquad \textbf{[6.2]}$$

The involvement rate measures the risk that a driver may be involved in the crash in a given traveling speed. The traveling speed was then expressed as the deviation from the average speed of traffic obtained from the operational data. To understand the variations of risk of being involved in the crash against the variation of traveling speed, the crash involvement rates were plotted against the deviation from the average speed of the traffic stream as shown in Figure 6.3. Figure 6.3 reveals a parabolic (U-shape) relationship between the crash risk and deviation from the mean speed. The shape of crash involvement rate depicted in Figure 6.3 also revealed that the lowest point on the curve which defines the lowest involvement rate is 123 involvements per million vehicle miles of travel. This minimum involvement rate occurs at about 10 mph above the mean speed of 73 mph. These findings support prior research findings in which the minimum risk of being involved a crash was above the average speed (*10*, *16*, and *17*). Solomon

(*16*) and Cirillo (*17*) found that the minimum crash risk at rural Interstate freeways was about 10 mph above the average speed. The cumulative speed distribution curve with respect to the deviation of actual vehicle speed from the mean speed was later superimposed in Figure 6.3. Of much interest in this curve were the percentile speeds and their proportional risk of the vehicle being involved in the crash.

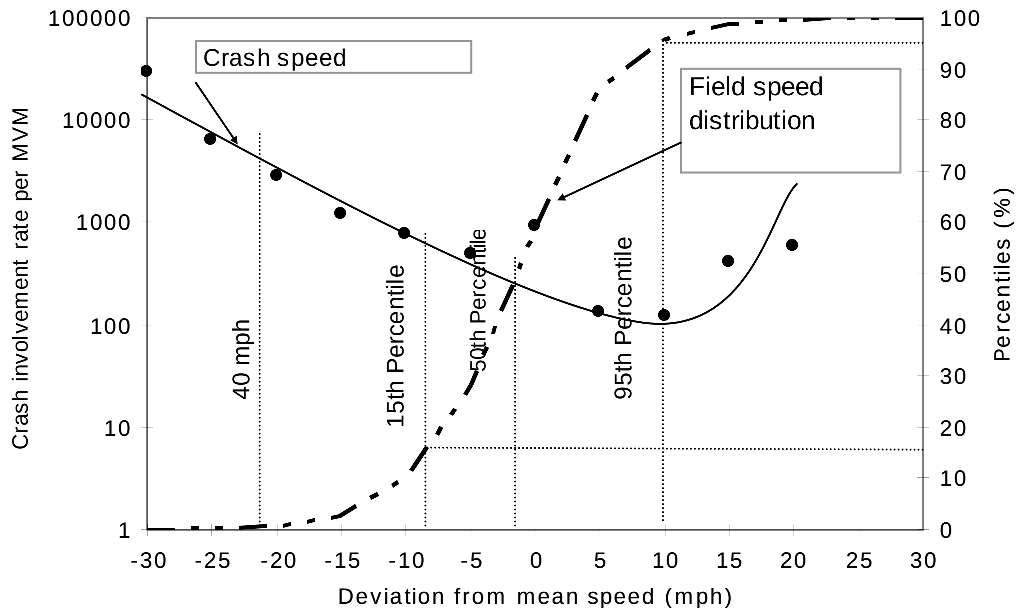

Figure 6.3 Crash involvement rate and deviation from the mean speed of traffic stream

Correlation of crash involvement rate with the distribution of actual traveling speeds shows that the crash involvement risk is minimal at about 95th percentile of the travel speeds. From the results presented in Figure 6.3 it can be surmised that as the traveling speed deviates from the point of minimum risk, the risk of vehicles being involved in a crash increases. Further, Figure 6.5 shows that even vehicles which are traveling at the average speed are at high risk of being involved in the crash. The risk is higher when the speed is around 40 mph—the posted minimum speed limit—which is about 23 mph below the average speed. Earlier research which examined the risk of being involved in a crash against traveling speed did not associate the percentile speed distribution in their findings. The inclusion of distribution of field data in Figure 6.3 puts in perspective the recommendation made by FHWA study (1985) that the minimum and maximum speed limits should be set at 10 mph below and above the average speed, respectively. This study asserted that the speed that is 10 mph below the average represented the 10th percentile while the speed that is 10 mph above the average represented the 90th percentile.

6.1.3 Involvement Speed and Crash Severity

It might be anticipated that if speed was a major factor affecting crashes then certain crash characteristics would occur more often than others. From laws of physics it can be assumed that as the vehicle traveling speed increases, the risk of the crash to result into injury or fatality also increases. This is because just before the crash occurs, the vehicle and its occupants have the kinetic energy which is dissipated in the crash. Since the kinetic energy is proportional to the square of the traveling speed then the greater the energy that is dissipated, the greater the chances of severe crash to result. Although other factors such as size and weight of the vehicle, type of braking systems, restraints systems and airbags affect the severity of the crash, traveling at high speed increases the stopping distance traveled by the victim vehicle after the driver perceive the danger on the road. The crashes that occur when the vehicle traveling speeds are low are likely to result into PDO crashes. The relative frequencies of crash involved vehicles against the involvement speeds were plotted. The results are presented in Figure 6.4.

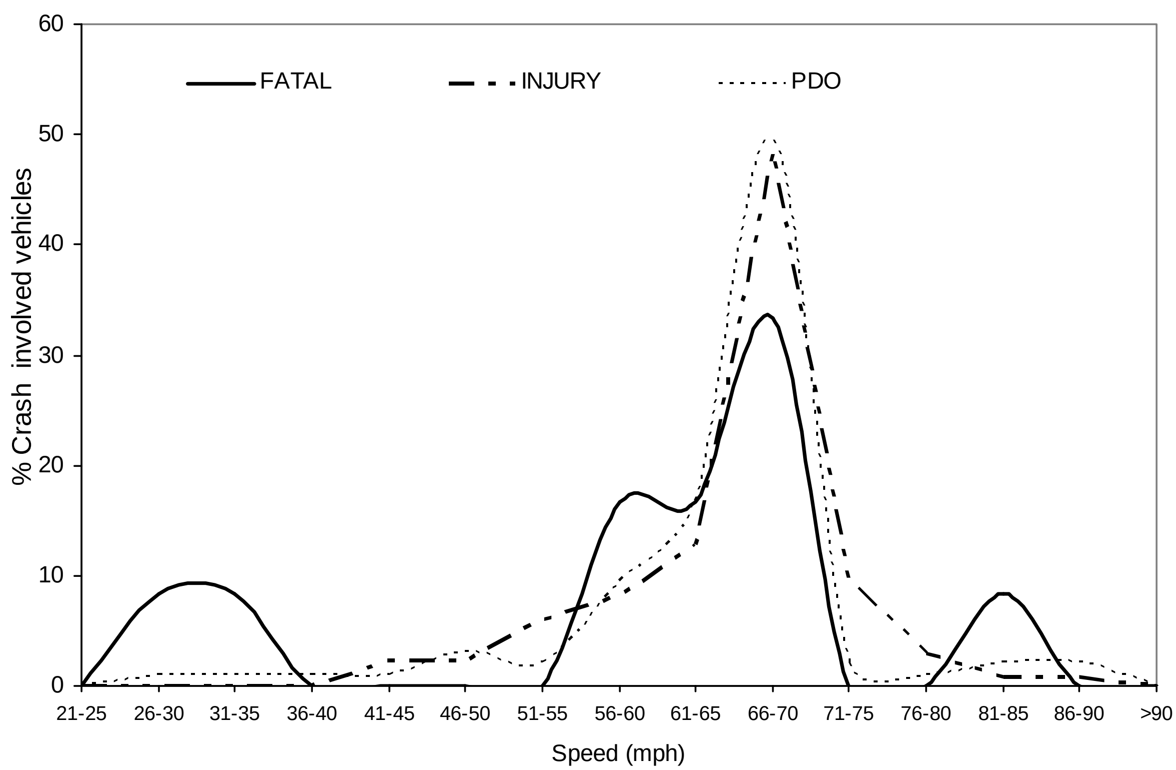

Figure 6.4 Severity of crashes and their involvement speeds

These results are for the three severity levels—fatal injury and PDO crashes. Figure 6.4 shows that most crashes occurred when vehicles were traveling between 60 mph and 70 mph regardless of the resulted severity level. This indicates that there are likely equal chances of a crash to result in any severity level when the victim vehicles are traveling between 60 mph and 70 mph. It is noteworthy that the results of the speed analysis shows that this range is contained by the 15th percentile speed, thus most crashes occurred when the vehicles are traveling below the mean speed.

The crashes analyzed in this study show that the tendency of the driver to be involved in the crash of either severity level tends to decrease as the traveling speeds exceed the average speed of the traffic stream. At the higher end of speed distribution, crashes that occurred between 81 mph and 85 mph were predominant. However, at the lower end of speed distribution, most crashes occurred between 26 mph and 35 mph resulted in fatality. This result seems to defy the laws of physics but the small number of crashes that were reported in these sites could be the cause of the skewed results.

When a pairwise comparison was performed to test the significance of the difference between the three severity levels, the *p*-values supported the conclusion that there is no significant difference between them. The *p*-values of the difference between fatal and injury crashes, fatal and PDO crashes, injury and PDO crashes were 0.17, 0.22, and 0.28, respectively. The relationship between severity level and the involvement speeds is shown in Figure 6.5. The results presented in Figure 6.5 also show the 95% confidence bounds on crash involvement speeds.

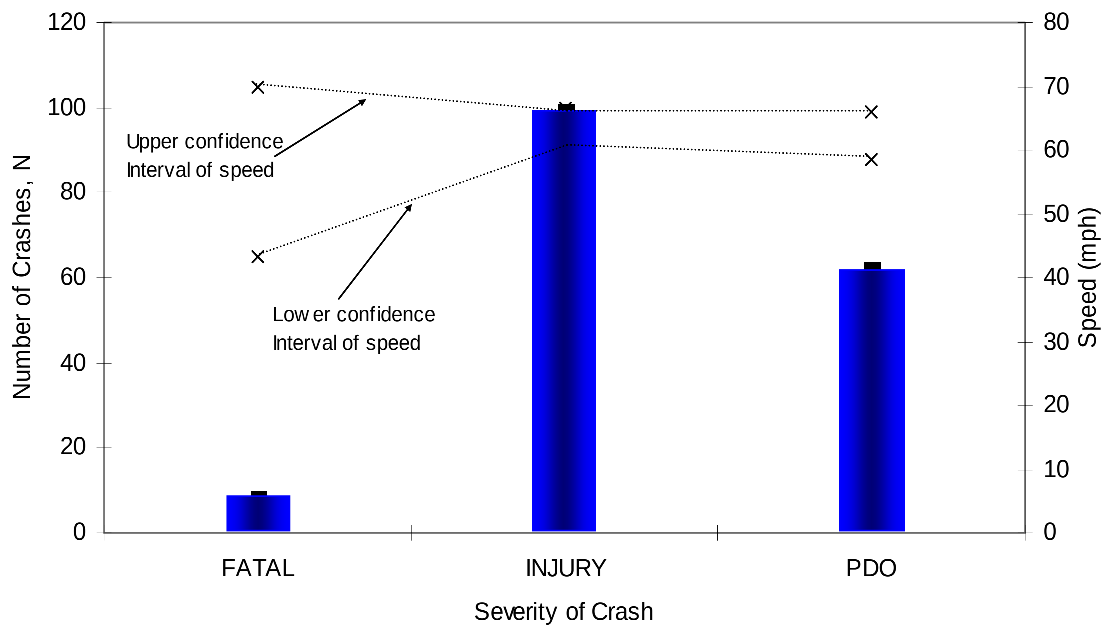

Figure 6.5 Frequency of crashes for fatality, injury, and PDO with their confidence bounds on involvement speeds.

The upper and lower confidence interval on crash involvement speeds were calculated by adding and subtracting the standard errors of speeds from the mean speed, respectively. The intent behind this analysis was to show how speed variability affects the severity of the crash occurrence. The results presented in Figure 6.5 shows that crashes that occurred between low and considerably high speeds are likely to result into fatalities—this is revealed by the large confidence interval of their speed of involvements. The data collected in this study also shows that injuries and property damage only crashes occurred in low confidence bounds compared to fatal crashes. This indicates that a crash which occurred with small variations of vehicle speeds is likely to result into injury or PDO.

6.1.4 Analysis by Crash Type

Figure 6.6 shows the stratification of the crashes by crash type. Crash types that are reported in the crash reports were grouped into four major types; i.e., single vehicle crashes in which a vehicle ran-off the road, hit road side object or overturned, rear end crashes, angle/sideswipe crashes, and overturned vehicles. All other types were grouped into "other" category. Two crash types—rear end and sideswipe/angle—were of particular importance as one study suggested that these crash types are mostly associated with speed differentials between vehicles in the traffic stream *(25)*.

Figure 6.6 shows that single vehicle crashes occurred more frequently on the freeway sections that were studied. These crashes accounted for over 53 percent of the total crashes. The rear end and sideswipe crashes were the second and third most occurring crashes, respectively. Examination of the confidence bounds of speed involvement shows that single vehicle crashes occurred when the variability of crashes was smaller than for rear-end and sideswipe crashes. One interpretation of this result might be that single vehicle crashes do not necessarily result from high variation of speeds. Figure 6.6 further shows no discernible difference between the confidence intervals of speeds for the rear end and sideswipe crashes.

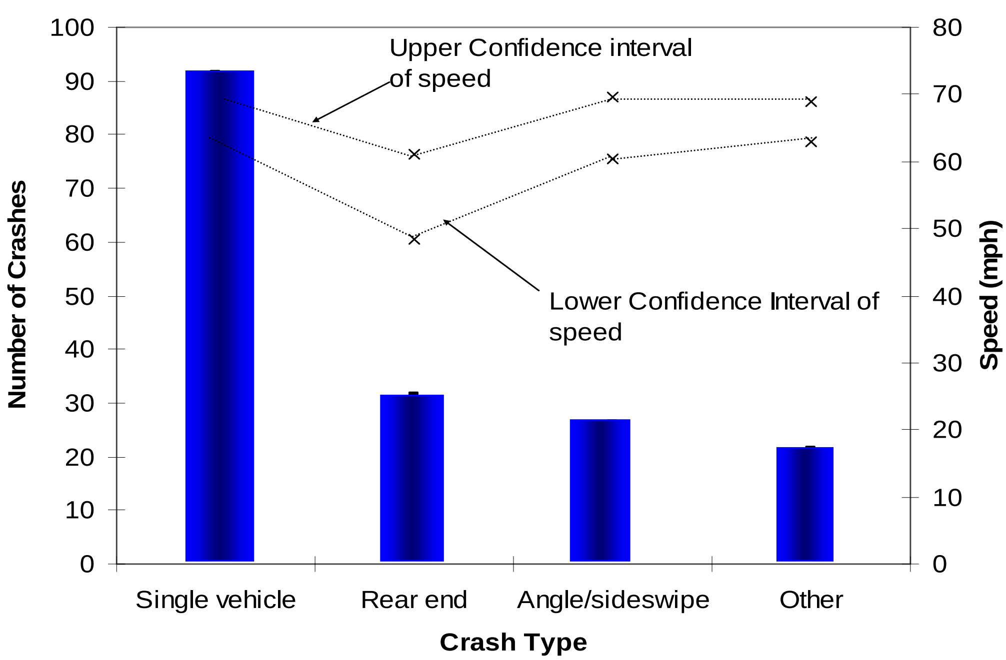

Figure 6.6 Frequency of crash types and their involvement speeds

6.1.5 Analysis of Crash Contributing Causes

Twenty-three different contributing causes related to the drivers are indicated in the Florida crash report form. This study examined three major contributing causes which were frequently cited in the police reports. Examination of the crash reports revealed that most occurring contributing causes were careless driving, improper lane change, and unsafe speed for the prevailing conditions. Depicted in Figure 6.7 are the frequencies of major contributing causes superimposed with their confidence level on the mean involvement speed.

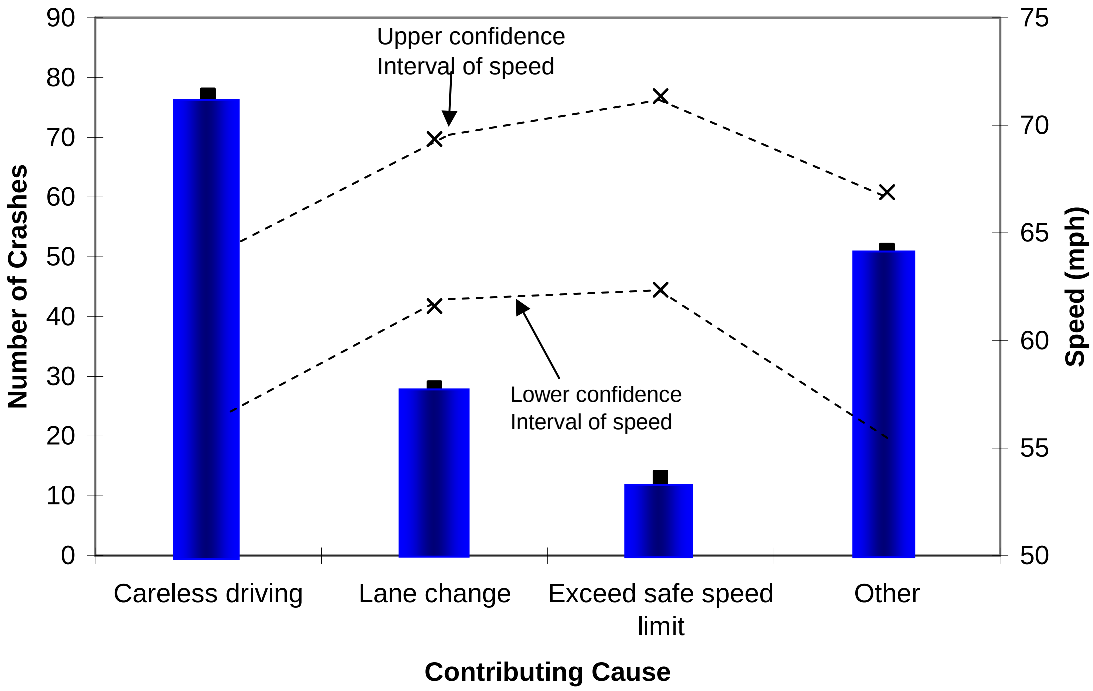

Figure 6.7 Contributing causes of crashes and involvement speeds

Figure 6.7 shows that careless driving dominated the contributing causes followed by improper lane change and exceeding safe speed limit. Careless driving is defined as driving without proper care and attention to the driving task. Improper lane change is defined as failing to merge properly, or fail to accept adequate gap in an attempt to execute passing maneuver which in most cases results into sideswipe, angle, or rear end conflicts. Most of the crashes which were caused by unsafe speed occurred in bad weather conditions where the victim driver failed to drive at the safe speed for the prevailing condition. Of 169 crashes which were reported in these sections, 77 crashes were caused by careless driving, while improper lane change and driving at unsafe speed accounted for 28 and 13 crashes, respectively. The confidence bounds on the mean involvement speed did not show a discernible relationship between the contributing cause and the variation of the speed.

6.2 Relating Operational Characteristics with Safety by Regression

Regression analysis was used to test a number of hypotheses on the relationship between crash experiences at these sites with the speed characteristics recorded from the sites. As indicated earlier, a 4-year crash data was used in the analysis from 1998 to 2001. However, traffic operating data was collected in 2002 since review of the previous traffic records did not reveal significant deviation of speed trends over the five years under review. Stochastic process was assumed to explain the variations in traffic crashes because by the nature of occurrence, traffic crashes on freeway segments are rare events and are subject to random variations. Given that road crashes are countable and they occurred independently, Poisson distribution was initially assumed provided the variance and the mean of the crash data were equal. The justification of this assumption was given by the overdispersion factor which is the mean deviance. The mean deviance for a Poisson distribution is equal to one.

When crash data are overdispersed from the mean, the variance and mean of the underlying distribution are not equal; thus, the use of Poisson distribution could lead to over estimation of the response variable. The dispersions among the data elements may arise because the experimental conditions are not perfectly under control which in turn causes the estimated parameters to vary with latent or any uncontrolled factors besides the measured covariates. When there is some evidence of the overdispersion in the postulated Poisson distribution, the negative binomial distribution can be assumed. Ordinary least square regression (or normal distribution assumption) which is the deterministic process was inappropriate because the underlying probability distribution of crashes is significantly skewed to the right (*32*).

6.2.1 Model Formulation

The following general regression model was used to derive the relationship between an i^{th} response variable and a set of explanatory variables x_i.

$$y_i = f(x_i) + \varepsilon \qquad [6.2]$$

where $f(x_i) = e^{\beta x_i}$ such that β is the vector of x_i, which are estimated by the model. The exponential function is assumed because crashes are countable and continuous. The parameter ε is the error term for uncorrelated random variables with zero mean and a common variance.

By assuming that the dependent variable, y_i, represent the number of occurrences of crashes for the i^{th} site, then the number of crash occurrences in an interval of a given length has a Poisson distribution with mean, μ, given by the following equation:

$$P(Y = a \mid x_1, x_2, ..., x_n) = \begin{cases} e^{-\mu}\mu^a / a! & a = 0, 1, 2, \dots, k \\ 0 & \text{Otherwise} \end{cases} \qquad [6.3]$$

A statistical model was developed to provide a relationship between a function of the expected number of crashes, E[Yi]= μ at the i^{th} site and the independent variables, $x_{1,}\ x_2, \ldots x_{m,}$ such that the natural logarithm of the mean, μ, is the linear function of the independent variables. This formulated loglinear relationship takes the following form:

$$ln(\mu) = \sum \beta_i * xi + \beta_o \qquad [6.4]$$

where β_o is the intercept of the model. The mean and variance of the Poisson model for crashes is given by:

$$Mean = Variance = E(Y) = \mu_i \qquad [6.5]$$

6.2.2 Response and Explainatory Variables

Four different models were analyzed. The first model is the full model which contains total number of crashes that occurred in these sections. The other three models were obtained by considering the three levels of severity of crashes—i.e., fatal, injuries, and property damage only crashes separately. The intent behind disaggregating the crash model was to compare the effects of the explanatory variables on specific type of crashes. In each of the model developed in this analysis the response variable in the model was the number of crashes. The number of crashes was used as the response variable instead of crash rate per million vehicle miles of travel because crash rate already has a volume variable as the exposure variable and therefore could confound the effect of traffic volume on safety in the model. In addition, previous studies (*33*, *34*), showed that traffic volume and crashes vary in nonlinear fashion; thus necessitating the inclusion of the volume in the crash as the covariate.

The explanatory variables that were used in the modeling were the average annual daily traffic, *V*, the 50th percentile speed, *S*, the 15th percentile speed, P_{15}, the differencce between the 85th and the 15th percentile speed, *PD*. Since only 1.3 percent of the vehicles were traveling below 55 mph and approximately zero were traveling with speed below 40 mph (the posted minimum speed limit), the percent of vehicles traveling below 60 mph, P_{60} was used as a variable to represent the lower side of the speed distribution since 4 percent of the vehicle population had speeds below 60 mph. Table 6.2 identifies the explanatory variables and the interaction selected for modeling crash frequencies. The form of the model proposed is outlined in the following equation:

$$N = Exp\ (Intercept + \beta_1 V + \beta_2 S + \beta_3 P_{15} + \beta_4 P_{60} + \beta_6 PD) \qquad [6.6]$$

6.2.3 Modeling Procedure

The loglinear regression analysis was performed using the SAS's generalized model procedure, PROC GENMOD. This procedure was customized to fit the Poisson models. The main advantage of PROC GENMOD is its capability to fit complex models which cannot be fitted in other linear model procedures such as GLM (generalized linear model) or logistic (*35*).

Table 6.2 Summary statistics of the variables used in modeling

Variable	Minimum	Average	Maximum
Number of crashes, *N*	9	24	62
Number of fatalities, N_F	0	1	3
Number of injuries, N_{INJ}	11	14	33
Number of PDOs, N_{PDO}	3	9	26
AADT, *V*	19047	34245	64172
Average Speed, *S*	68	72	76
15th Percentile Speed, P_{15}	61	65	68
Percent below 60 mph, P_{60}	4.6	1.9	10
85th minus 15th Percentile speed, *PD*	11.5	13.6	17

In this procedure, the expected number of crashes was related to the linear function of the predictors through an exponential function (link = log). The following GENMOD procedure was invoked to simulate number of crashes:

```
proc genmod data=full model;
    make 'modelfit' out=A;
    model N = S V P15 P60 PD  / dist   = P
                                link   = log
                                scale = DEVIANCE;
run;
```

The model statement specifies *N*, the response variable and *S*, *V*, P_{15}, P_{60}, and *PD* as covariates. The response distribution is specified as Poisson by a statement dist = P. The link function is the natural logarithm indicated by log. The scale option made the dispersion parameter to be estimated by the deviance divided by its degrees of freedom. Estimation of model parameters as well as the overdispersion parameter were performed by maximizing the log-likelihood function. The likelihood is defined by the probability of observing the data given a model with certain parameters. The log-likelihood function of the negative binomial model expressed in terms of the mean μ_i and the vector *a* of the response variables is given by:

$$L(\beta) = \sum_i (y_i \ln \mu_i - \mu_i - \ln y_i!) \qquad [6.7]$$

The significance of the parameter estimates is tested by the GENMOD procedure which utilizes the asymptotic normality of maximum likelihood estimates. The procedure also yielded estimates of the standard error for each coefficient. The *p*-values are computed from the estimated coefficients to test the the the null hypothesis that the coefficient is zero.

Model evaluation was performed by the assessing the goodness-of-fit and overdispersion by using scaled deviance and Pearson's Chi square statistics. The scaled deviance is the square root of deviance (residual sum of squares for the fitted model) divided by the degrees of freedom. Pearson's Chi-square statistics is calculated by summing of the standardized squared residuals divided by the degrees of freedom. These statistics approach one asymptotically.

6.2.4 Analysis of Parameter Estimates

Table 6.3 presents the results obtained from the analysis of parameter estimates for four different models developed by the PROC GENMOD. Also, included in the Table 6.3 are the 95% confidence intervals, and *p*-values for each parameter. The significance of each reported coeficient is explained by the reported *p*-values while the significance of the model is explained by the scaled deviance.

Table 6.3 Results of analysis of parameter estimates

Model	Parameter	Estimate	Standard Error	95% Confidence Limits		Chi-Square	p-value
Full model	Intercept	-7.7461	1.3513	-10.3947	-5.0975	32.86	<.0001
	Median speed	-1.8648	0.0640	-1.9903	-1.7394	848.82	<.0001
	AADT	0.0001	0.0000	0.0001	0.0001	2860.75	<.0001
	15^{th} Percentile	2.0844	0.0763	1.9349	2.2339	746.63	<.0001
	Percent below 60 mph	29.4506	1.9180	25.6913	33.2098	235.77	<.0001
	85^{th}minus15^{th} percentile	0.5113	0.0178	0.4765	0.5461	829.37	<.0001
Fatality	Intercept	-1408.76	0.0005	-1408.76	-1408.76	7.63E12	<.0001
	Median speed	-31.5887	0.0000	-31.5887	-31.5887	5.53E13	<.0001
	AADT	0.0011	0.0000	0.0011	0.0011	1.26E13	<.0001
	15^{th} Percentile	53.2955	0.0000	53.2954	53.2955	2.23E13	<.0001
	Percent below 60 mph	2016.463	0.0007	2016.462	2016.464	9.08E12	<.0001
	85^{th}minus15^{th} percentile	6.3620	0.0000	6.3620	6.3620	7.63E12	<.0001
Injuries	Intercept	-18.8898	11.7949	-42.0074	4.2279	2.56	0.1093
	Median speed	-1.7713	0.5558	-2.8607	-0.6818	10.15	0.0014
	AADT	0.0001	0.0000	0.0000	0.0001	33.49	<.0001
	15^{th} Percentile	2.1444	0.6597	0.8514	3.4374	10.57	0.0012
	Percent below 60 mph	41.0773	16.7495	8.2488	73.9058	6.01	0.0142
	85^{th}minus15^{th} percentile	0.4712	0.1542	0.1690	0.7733	9.34	0.0022
PDOs	Intercept	19.4417	15.0827	-10.1198	49.0031	1.66	0.1974
	Median speed	-1.9239	0.7136	-3.3224	-0.5253	7.27	0.0070
	AADT	0.0001	0.0000	0.0000	0.0001	25.28	<.0001
	15^{th} Percentile	1.7256	0.8551	0.0497	3.4016	4.07	0.0436
	Percent below 60 mph	-2.9454	21.0336	-44.1706	38.2797	0.02	0.8886
	85^{th}minus15^{th} percentile	0.5884	0.1997	0.1970	0.9798	8.68	0.0032

The full crash model

The appropriateness of this model is revealed by the scaled deviance (i.e., is equal to one). The results displayed in Table 6.3 suggest that the mean number of crashes at a particular site can be estimated by the following equation:

$$N = \text{Exp}(-7.7461+0.000055V-1.8648S+2.0844P_{15}+29.4506P_{60}+0.5113PD) \quad [6.8]$$

Further analysis showed that all covariates were statistically significant ($p \leq 0.0001$). Closer examination of Equation (6.8) and the results presented in Table 6.3 reveals the following pointers. The estimated coefficients for volume, V, the 15th percentile speed, P_{15}, the percentage of vehicles traveling below 60 mph, P_{60}, and PD are positive and statistically significant implying that as these variables increase the mean number of crashes also increase. In particular, the estimated parameter for percent traveling with speed below 60 mph, P_{60}, is much larger than one implying that the mean number of crashes is very responsive to small changes in P_{60}.

The fatal crash model

The results presented in Table 6.3 shows that the number of fatal crashes occuring on these rural freeway sections can be estimated using the following equation:

$$N = \text{Exp}(1408.76+0.0011V-31.5887S+53.2955P_{15}+2016.463P_{60}+6.3620PD) \quad [6.9]$$

The p-values shown in Table 6.3 indicate that there is a positive association between fatal crashes and four covariates, i.e., volume, 15th percentile speed, percent with speed below 60 mph, and the difference between 85th and 15th percentile speeds. However, the effect of the median speed on fatal crashes was found to be negative and significant.

The injury crash model

The results shown in Table 6.3 suggest that the number of injury crashes can be estimated by using the following equation:

$$N = \text{Exp}(-18.8898+0.0001V-1.7713S+2.1444P_{15}+41.0773P_{60}+0.4712PD) \quad [6.10]$$

Analysis of model parameters in Table 6.3 shows that the effects of the traffic volume, the 15th percentile speed, percent of vehicles traveling with speeds below 60 mph, and the percentile difference, PD, on the occurrence of injury crashes were also positive and significant. The effect of the median speed on fatal crashes was found to be negative and significant. Unlike the foregoing models, the intercept of this model is negative and statistically insignificant ($p=0.1093$).

The property damage only model

The results presented in Table 6.3 leads to the following regression model:

$$N = \text{Exp}(19.4417+0.0001V-1.9239S+1.7256P_{15}-2.9454P_{60}+0.5884PD) \quad [6.11]$$

Equation (6.11) shows that the effects of the traffic volume, 15th percentile speed, and the percentile difference, PD, were positive and significant. The intercept of the model was positive but not significant (*p=0.1974*). The median speed was found to be negative and statistically significant while the percent of vehicle moving below 60 mph was found to be negative and statistically insiginificant (*p= 0.8886*). Since the the number of vehicles traveling below 60 mph was insigificant, the PDO model was reanalysed without this variable. The resulting model is

$$N = \text{Exp}(17.4261+0.0001V-1.98045S+1.8147P_{15}+0.5979PD) \qquad [6.12]$$

This revised model shows that all covariates were highly significant with *p*-values of less than 0.0001. The effect of median speed on PDO crashes was negative, while the effects of volume, 15^{th} percentile speed, and percentile difference were positive.

6.2.5 Discussion on safety modeling

While it is evident in this research as in previous researches reported in the literature that the increase in volume increase crashes, the same can not be said when considering speed. The modeling exercise discussed above shows some mixed results in interpreting the overall effect of speed distribution on crash involvement on rural Interstate freeways in Florida. A constant theme in all four models is that as the 15^{th} percentile speed increases, the frequency of all crashes (regardless of severity level) increases. This seems counterintuitive since operationally as the 15^{th} percentile speed increases, speeds become more uniform thus reducing conflicts caused by speed variability. However, one can also speculate that drivers whose speeds are at the lower end of the speed distribution are not regular commuters hence they choose to travel slow on these freeways. Thus, when these drivers increase their speeds as revealed by the 15^{th} percentile value, incidences of driver error might also increase.

Furthermore, the results in Table 6.3 showed that the number of crashes on these rural Interstate freeway sections increased with the increase in the difference between 85^{th} and 15^{th} percentile speeds. This result is plausible because the larger the difference in speeds between fast and slow moving vehicles the more the potential of conflicts due to passing manouvers. There were mixed results though when the influence of the percent of vehicles traveling with speeds below 60 mph was considered. As this percentage increased, fatal and injury crashes also increased. However, as this percentage increased, property damage only crashes decreased. One can interpret this phenomenon as follows; if all crashes were to be treated as a unit, the more the slow moving vehicles are on the freeway the bigger the proportion of fatal and injury crash occurrences relative to property damage only crash occurences.

CHAPTER 7—CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The results of the safety and traffic operations review discussed in the previous chapters have given an extensive look into the performance of rural Interstate freeways in Florida. Various analytical techniques were used to determine speed characteristics and especially to determine how traffic is behaving in relation to the posted minimum speed limit of 40 mph. The theme throughout the analyses was the examination of the relevance of the minimum speed limit of 40 mph in light of the change in operating speeds brought about by the rise in speed limit from 65 mph to 70 mph. Coupled with speed analysis, safety analysis was conducted. The safety analysis was geared towards determining the safety characteristics in relation to the operating speeds.

The foregoing analyses indicate that raising the maximum speed limit in Florida from 65 mph to 70 mph has resulted into increase in average speeds on rural Interstate freeways. The comparison of the 1996 to 2002 speed data showed that the average speeds have increased by 5 mph, which is the same amount of the speed limit increase—that is, from 65 mph to 70 mph. The comparison further showed that there has been a slight increase in the coefficient of variation in the after-conditions; however, the increase is statistically insignificant and is under 10 percent, a threshold that can be considered to indicate uniform operations. In addition, the 15th percentile speed analysis showed on the average an increase of 3 mph across all sites. In relation to 40 mph posted minimum speed, the 2002 average speed on all sections was 5 standard deviations above this minimum speed compared to 5.8 standard deviations for the 1996 data.

In light of the above data and analyses, from the operational standpoint, can it be surmised that the 40 mph posted minimum speed is irrelevant or successful in ensuring that vehicles do not travel below 40 mph? Should the 40 mph posted minimum speed limit be scrapped or should it be raised to a higher value? If it is to be raised, what value should it be raised to? These are important questions that could not be adequately answered through the research paradigm reported herein. However, the data reveal a few pointers. First, the 40 mph posted minimum speed limit might not be having a significant influence on driver behavior given that the number of vehicles traveling below 55 mph at all sites was negligible (i.e., 1 percent). If drivers were influenced by these signs one would expect a lot more vehicles to have speeds in the range of 40 mph to 50 mph. The logic of this reasoning is that on the upper side of the speed distribution there was a large percentage of drivers driving in the range of 70 mph to 80 mph—that is, within 10 mph above the posted maximum speed limit of 70 mph. Further, McShane *et al*. (*9*) suggested that the 15th percentile speed can be used as a guide in setting minimum speed limit. The analysis of traffic operations have revealed that the 15th percentile on all sections studied, on the aggregate, ranged from 60 mph to 70 mph, which is 20 mph to 30 mph above the posted minimum speed limit value.

However, the posting of minimum speed limit should also be judged from the safety standpoint. The results obtained from the analysis of the safety characteristics on these freeways have indicated that most of the crashes were estimated to have occurred in the 60 to 70 mph range. In addition, the results show that crashes that occurred when the estimated vehicle speed was below 40 mph were overrepresented in the overall crash data. While the operational data showed only 0.14 percent of vehicles had speeds below 40 mph, the crash data indicated that about 9 percent of vehicles involved in crashes were estimated to be traveling with speeds less than 40 mph. This finding suggests that while only a small proportion of vehicles might have been traveling with low speeds they do, however, have a significant impact on the safety characteristics of these freeways. Thus, any strategy for dealing with the issue of posting of minimum speed limit must take this fact into account.

Further safety analysis using a general loglinear model showed that increase in the median speed lowered the number of crashes significantly while increase in the variation between fast and slow moving vehicles significantly increased the number of crashes. In addition, it was pointed out that the increase in the percent of vehicles with speeds below 60 mph increased the number of fatal and injury crashes—a plausible phenomenon because of the likelihood of increasing the difference in speed between fast and slow vehicles. However, percent of vehicles traveling below 60 mph was not correlated with the occurance of property damage only (PDO) crashes. These results indicate that the danger created by slow moving vehicles in the safety of operations on these freeways is significant.

7.2 Recommendations

7.2.1 Scrapping the Practice of Posting Minimum Speed Limit

Three types of recommendations can be considered in light of the data reported herein—that is, leaving the 40 mph posted minimum speed as is, revising the minimum speed limit to a higher value, or scrapping the practice of posting minimum speed limit signs on Florida rural Interstate freeways. The operational and safety analysis conducted in this study seem to suggest that the 40 mph minimum speed limit might be too low for the prevailing speed characteristics on Florida rural Interstate freeways. The safety analysis also seem to suggest that crash involvment rate at around 40 mph is more than seven times the involvement rate at 60 mph. However, although raising the minimum speed to a higher value such as 60 mph might bring more uniform speed operations, there are ramifications that should be considered. For example, the Florida State Statutes states that "no school bus shall exceed the posted speed limit or 55 mph" (*36)*. Thus, if the minimum speed limit is to be increased beyond 55 mph then this Statute would need to be changed. Also, as a tourist State, Florida has visitors some of whom drive recreational vehicles sometimes towing a trailer or motor homes. Field review indicated that it is these types of vehicles that were in the majority within the lowest 15 percent of speed distribution at all sites.

The preliminary recommendation that can be made at this point is to discard the posting of minimum speed limit signs on rural Interstate freeways. This recommendation is based on the following pointers revealed by the study:

- The survey results showed that 25 States, almost half of the country, do not post minimum speed limit signs on their Interstate freeways. Despite not posting minimum speed signs, these States reported that they are not experiencing any problems with slow moving vehicles on their freeways.
- The field data indicated that only one percent of drivers were driving with speeds less than 55 mph which suggests that the 40 mph minimum speed limit is not significant in influencing traffic operations. However, this assertion is tentative and needs further research as discussed in Section 7.2.2.
- The discussion held with the Florida Highway Patrol indicated that law enforcement agencies in Florida rarely give warnings or citations based on the posting of minimum speed limit signs. If the minimum speed limit signs were not posted, there are other Florida State Statutes that could be used by an officer to issue citations or tickets to slow moving drivers.
- If the posting of the 40 mph speed limit is scrapped, the public can still be made aware of the existing State Statute (stipulating the 40 mph minimum speed limit) through the Driver's Handbook and other driving education media.

7.2.2 Further Research Needed

There are a number of limitations in this study that warrants additional work. First research is needed to ascertain the effect of the current posted minimum speed limit sign on drivers' behavior. While the data seem to indicate that the 40 mph minimum speed might not be that relevant based on prevailing operating speed distribution, it is not entirely clear what would be the effect on driver behavior if the minimum speed limit were to be increased to 60 mph or if the signs were to be removed from rural Interstate freeways. The answer to these questions requires field evaluation as simulation analysis alone would not be able to appropriately depict driver behavior. Additional research undertakings could involve collecting data on Interstate freeway sections in States that do not have minimum speed limit posted but have similar geometric and driver characteristics. The comparison of multi-state data might give more insight on the relevance of posting minimum speed limit signs.

Although the results of the Poisson regression models developed in this research were in line with the results reported in literature, nevertheless, the data used in the development of the models were not sufficient. Operational and crash data from additional sites need to be collected to build and validate more robust models. If crash and operational data were to be collected from freeways in different States with and without minimum speed limit signs, a dummy variable could be incorporated in the new model to account for the effect of posting minimum speed limit signs on speed and crash occurrences.

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APPENDIX A--SURVEY ON THE USE OF POSTED MINIMUM SPEED LIMIT SIGN ON INTERSTATE FREEWAYS

The Florida Department of Transportation is evaluating the relevance of continuing to post minimum speed limit signs on Interstate freeways. The department has been posting a minimum speed limit sign of 40 mph on rural Interstate freeways since 1960s. Following the raising of maximum speed limit on rural Interstate freeways from 65 mph to 70 mph in 1996, it is logical to ask whether the current posted minimum speed limit of 40 mph should be increased or rescinded altogether. This survey is designed to solicit information on other states' practices and experiences on this subject. We encourage your organization to fill this form and return it to the address shown below. We will share the results of this survey with your organization.

A. Does your state have a statutory minimum speed law, i.e., does the state statutes require that minimum speed limit must be posted? ❒ Yes ❒ No

If yes, does the statute state what should be the minimum speed limit (Florida statute explicitly states the minimum speed limit must be 40 mph)? ❒ Yes ❒ No

If yes, what is the state statutory minimum speed on Interstate freeways? _____ mph.

B. In some states, the statute does not explicitly state what minimum speed limit should be posted but gives authority to the highway/transportation department to regulate minimum speeds on Interstate freeways. In this light, do you post minimum speed limit on Interstate freeways? ❒ Yes ❒ No

If yes, what is the posted minimum speed limit? ________ mph. Is this posting uniform on all Interstate freeways? ❒ Yes ❒No

If no, how does your state regulate slow moving vehicles on your Interstate freeway system?

____

____

C. Following the National Highway System (NHS) Designation Act of 1995, which repealed the federal control of maximum speed limit, did your state raise the maximum speed limit on rural Interstate freeways? ❒ Yes ❒ No

If yes, the maximum speed limit was raised from ________ mph to ___________ MPH

Was the raising of maximum speed limit on rural Interstate freeways done based on a detailed speed analysis? ❒ Yes ❒ No

Did the study or revision of maximum speed limit also resulted in revision of minimum speed limit? ❒ Yes ❒ No

If Yes, What is the new minimum speed limit regulation? ________________________________

D. Do you have any speed restriction policy on Interstate freeways? ❒ Yes ❒No

If yes, what kind of restriction? Check appropriate box and fill in the speed.

- ❒ Vehicle towing cars/trailers: __________ mph
- ❒ Heavy trucks: __________ mph
- ❒ School buses: __________ mph
- ❒ Day and Night: __________ mph
- ❒ Other (specify) ____

E. Does your state conduct periodic reviews of speed characteristics on Interstate freeways system?
❒ Yes ❒ No

If yes, we would appreciate if you send us the study report of the most recent review.

F. Did your state ever conduct a study related to the minimum speed on Interstate freeways?

❒ Yes ❒ No

If yes, we would appreciate if you share with us the results of such a study.

G. Is the minimum speed limit regularly enforced by highway patrol officers?
❒ Yes ❒ No

H. Contact Person
Filled by ____
Mailing address ____
____
Phone ____________________ Email ______________________________

Thanks for sharing information with Florida DOT. Please send this form by mail, fax, or email to the following principal investigator who is conducting the study for Florida DOT:

Dr. Renatus Mussa
Assistant Professor
FAMU-FSU College of Engineering
2525 Pottsdamer Street, Room 129
Tallahassee, FL 32310
Tel: 850-410-6191 / Fax: 850-410-6142
Email: mussa@eng.fsu.edu

APPENDIX B--PICTORIAL LOCATION OF THE STUDY SITES

Figure B-1: Site 320 Northbound lanes on the right

Figure B-2: Site 9904 Northbound lanes on the right

Figure B-3: 9901 Eastbound lanes on the left

Figure B-4:   Site 9928 Eastbound lanes on the left

Figure B-5:   Site 351 Eastbound lanes on the left

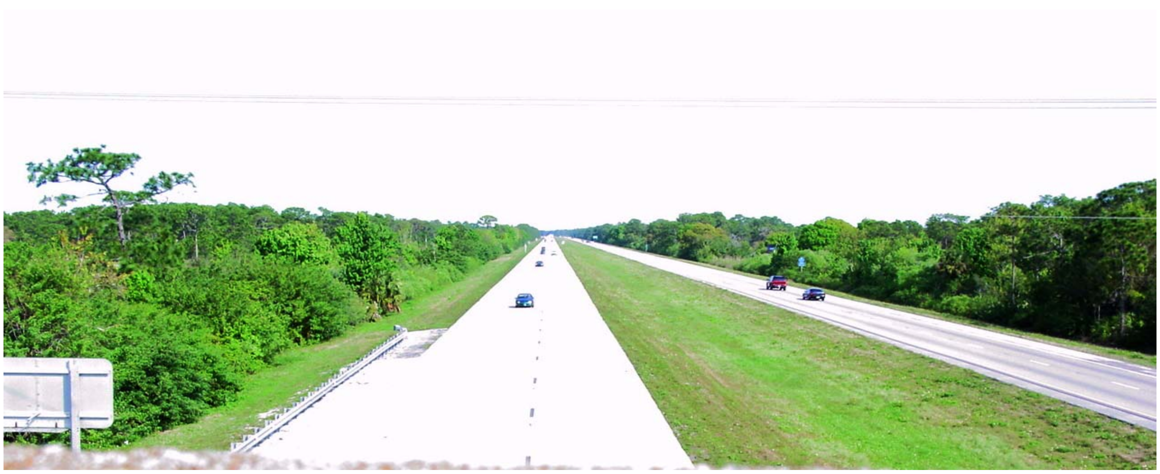


Figure B-6:   Site 9919 Northbound lanes on the right

Figure B-7: Site 9932 Northbound lanes on the left

APPENDIX C --SUMMARY OF SPEED STATISTICS

Table C-1: Speed statistics for site 320-Southbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	193	69.08	5.32	53	82	64	69	75
2	140	70.02	5.59	54	85	64	71	75
3	119	69.06	5.97	52	83	62	69	75
4	139	68.24	5.77	54	83	61	68	75
5	189	68.26	5.46	54	89	63	68	74
6	250	68.36	5.67	53	89	63	68	74
7	311	69.18	5.59	56	89	62	69	75
8	381	70.18	5.15	53	85	65	71	75
9	412	70.78	6.34	28	100	65	71	77
10	491	69.6	5.54	50	85	64	69	75
11	496	69.89	5.35	56	87	64	69	75
12	483	69.14	5.82	35	87	63	69	75
13	518	70.44	5.99	32	92	65	71	77
14	496	70.31	5.63	56	94	64	71	77
15	479	70.2	6.1	55	92	63	70	77
16	439	69.83	6.28	45	87	63	69	77
17	434	69.7	5.92	52	100	63	69	76
18	411	69	6.63	20	87	63	69	75
19	384	69.11	6.29	25	87	63	69	75
20	359	69.33	5.98	50	92	63	69	75
21	302	69.64	5.99	51	92	63	69	75
22	329	69.18	5.72	50	104	63	69	75
23	239	69.2	5.88	45	89	62	69	75
24	209	70.35	6.2	22	87	65	71	77

Table C-2: Speed statistics for site 320-Southbound middle lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	140	73.78	5.03	59	101	69	73	78
2	90	73.42	4.59	63	85	68	73.5	79
3	99	74.68	4.99	59	89	70	75	79
4	107	75.29	4.89	60	89	70	75	81
5	145	73.64	4.96	62	87	68	74	79
6	237	75.43	4.72	65	95	70	75	80
7	402	75.39	4.44	63	95	72	75	79
8	567	75.5	4.67	52	92	71	75	80
9	669	75.29	4.38	61	97	71	75	79
10	830	75.3	4.3	64	102	71	75	79
11	813	75.43	4.57	61	98	71	75	81
12	768	75.26	4.59	60	92	71	75	80
13	809	75.33	4.53	43	92	72	75	80
14	851	75.92	4.52	63	95	72	76	81
15	769	76.02	4.88	63	101	72	76	81
16	693	75.37	4.86	54	92	70	75	81
17	613	75.81	4.98	65	120	71	75	81
18	616	76.1	4.91	61	95	72	76	81
19	474	75.29	4.95	46	94	70	75	81
20	420	74.9	5.05	47	101	70	75	79
21	354	74.23	4.48	63	89	69	75	79
22	355	73.63	4.83	53	95	69	73	77
23	285	74.24	5.47	30	92	69	75	79
24	177	73.79	5.49	59	105	69	73	79

Table C-3: Speed statistics for site 320-Southbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	21	80.67	7.21	70	97	74	78	91
2	19	79.68	4.81	73	92	75	78	85
3	12	80.17	7.4	69	92	74	78	89
4	21	81.14	4.21	73	89	77	82	84
5	20	82.35	6.13	74	95	76	80	90
6	57	79.86	5.24	71	100	75	78	85
7	103	81.5	6.48	68	115	75	80	88
8	180	80.87	4.91	71	95	76	80	87
9	345	80.91	4.74	67	101	77	80	86
10	463	81.03	4.45	68	97	77	80	86
11	447	80.31	4.19	68	95	77	80	84
12	443	80.72	4.74	65	101	76	80	86
13	439	81.39	4.47	67	97	77	82	86
14	459	81.64	4.91	65	101	77	82	86
15	445	81.61	5.23	68	100	77	80	88
16	374	80.84	4.73	67	97	76	80	86
17	299	81.64	5.94	65	111	77	81	86
18	266	81.46	5.51	69	101	76	80	88
19	189	80.98	4.93	68	95	76	80	86
20	162	79.59	5.05	68	98	75	80	84
21	104	79.75	4.73	63	92	75	80	86
22	113	79.84	5.63	68	104	74	80	84
23	94	80.55	5.44	71	98	75	80	86
24	40	81.43	7.16	71	107	75	81	88

Table C-4: Speed statistics for site 320-Northbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	24	77	5.1	68	89	72	76	83
2	27	78.04	4.62	68	94	75	77	82
3	20	79.3	5.11	72	89	75	79	86
4	17	75.88	4.68	68	84	70	76	83
5	24	77.42	5.11	71	89	73	77	85
6	21	79.24	6.02	69	92	74	78	85
7	46	80.37	5.49	66	94	76	81	85
8	79	78.9	3.92	72	89	75	78	84
9	146	78.24	4.84	65	94	73	78	83
10	186	79.35	4.64	67	97	75	80	84
11	282	77.9	3.63	66	89	75	77	82
12	275	78.6	3.94	66	91	75	78	83
13	276	78.88	4.3	69	94	75	78	83
14	310	79.69	4.53	69	100	75	80	85
15	389	79.29	4.32	67	97	75	80	83
16	338	79.19	4.05	66	92	75	80	83
17	320	78.8	4.2	69	94	75	79	83
18	222	79.92	4.08	69	94	76	80	83
19	173	79.4	5.14	67	97	75	80	85
20	144	80.88	5.96	70	107	76	80	87
21	136	78.81	4.72	68	94	74	78	84
22	104	78.61	5.05	64	100	74	78	83
23	104	80.49	6.86	63	115	75	80	87
24	44	77.18	5.67	65	87	72	76	85

Table C-5: Speed statistics for site 320-Northbound middle lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	159	72.76	4.34	62	84	68	72	79
2	159	72.44	5.34	55	87	67	72	79
3	153	72.39	4.5	59	86	67	72	77
4	144	72.16	4.4	60	82	67	72	77
5	140	73.61	5.23	62	94	69	74	79
6	198	73.48	5.21	58	94	68	74	79
7	226	74.83	5.02	62	91	70	75	79
8	375	74	4.01	62	89	70	74	78
9	472	73.71	4.66	32	87	70	74	79
10	594	74.15	4.5	60	103	70	74	79
11	648	73.19	3.87	61	89	69	74	77
12	630	73.3	4.34	61	94	69	74	78
13	683	73.15	4.72	57	92	69	74	77
14	709	74.21	4.25	61	94	70	74	79
15	761	73.79	3.94	61	92	70	74	78
16	773	73.87	4.3	61	94	70	74	79
17	687	73.51	4.42	54	89	69	74	79
18	596	74.2	4.35	55	94	70	74	79
19	505	73.95	4.41	57	91	70	74	79
20	451	73.25	4.84	31	89	69	74	79
21	391	72.26	5.54	20	111	68	72	77
22	403	72.97	4.7	58	87	68	73	77
23	319	73.56	4.92	57	92	68	74	79
24	199	71.71	4.9	61	91	67	71	77

Table C-6: Speed statistics for site 320-Northbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	188	69.29	5.93	48	86	63	69	76
2	202	69.91	5.93	29	89	64	70	75
3	199	69.43	6.57	17	84	64	69	76
4	195	69.75	5.79	53	107	65	69	75
5	206	70.15	5.22	58	84	65	69	76
6	223	70.38	5.11	55	83	65	70	76
7	281	71.14	4.7	56	86	66	71	76
8	307	70.72	4.98	55	88	65	70	76
9	366	70.19	5.66	53	100	64	70	76
10	427	70.65	5.25	54	86	64	72	76
11	404	70.02	5.33	48	88	64	70	75
12	421	69.85	5.47	50	86	64	70	76
13	424	69.63	6.16	45	89	63	70	76
14	453	70.86	5.9	51	97	66	70	76
15	458	70.74	5.45	46	91	66	70	76
16	474	70.41	5.77	46	91	65	70	76
17	471	70.18	5.84	29	87	64	70	76
18	446	70.66	5.66	49	97	64	70	76
19	419	69.83	6.04	24	83	64	70	76
20	370	70.43	5.62	51	94	65	70	76
21	310	69.67	6.2	50	89	63	70.5	76
22	320	70.84	6.2	48	89	64	71	77
23	305	71.04	6.23	51	97	65	71	77
24	211	69.48	5.69	44	87	64	70	75

Table C-7: Speed statistics for site 9904 Southbound shoulder lane

				Percentiles		
Hour	N	Mean	Std Dev	15th Pctl	50th Pctl	85th Pctl
1	127	69.84	6.52	65	69	76
2	145	69.73	4.82	65	69	75
3	128	68.69	5.67	63	69	75
4	133	68.45	5.49	64	68	75
5	197	68.55	6.64	64	69	75
6	277	68.82	6.28	63	69	75
7	370	68.89	6.14	64	68	76
8	403	68.43	6.06	64	69	74
9	459	68.68	6.23	64	68	75
10	458	68.32	6.46	63	68	75
11	490	68.56	7.26	63	69	76
12	456	69.57	5.92	64	70	76
13	460	70.37	6.3	65	71	77
14	445	71.48	7.15	66	72	78
15	461	72	6.42	67	73	78
16	476	71.81	6.02	66	73	78
17	432	72.32	5.29	68	73	78
18	414	72.31	5.61	68	73	78
19	350	72.55	5.81	68	73	78
20	336	72.88	6.41	68	73	79
21	306	72.86	6.6	69	73	78
22	262	73.4	5.8	68	74	79
23	237	71.79	8.15	67	72	79
24	186	69.34	6.63	65	69	76

Table C-8: Speed statistics for site 9904 Southbound middle lane

				Percentile		
Hour	N	Mean	Std Dev	15th	50th Pctl	85th
1	91	72.99	5.47	68	73	78
2	74	73.84	5.75	70	74	80
3	79	72.97	5.62	67	73	79
4	97	71.97	6.45	66	72	78
5	138	71.26	5.51	67	71	77
6	334	72.17	5.88	67	73	78
7	537	73.2	6.26	68	74	79
8	646	72.83	5.88	68	73	78
9	687	72.53	6.36	68	73	78
10	720	72.55	5.87	68	73	78
11	732	72.63	6.03	67	73	78
12	716	72.8	6.02	68	73	79
13	710	71.9	6.2	67	73	77
14	669	72.45	6.04	67	73	78
15	711	72.6	5.9	68	73	78
16	715	72.33	5.72	68	73	78
17	690	71.83	6.4	67	72	78
18	612	72.3	5.92	67	73	78
19	550	71.99	6.6	67	72	79
20	472	72.83	5.83	68	73	79
21	363	72	7.03	67	73	78
22	291	72.96	5.54	68	73	78
23	204	72.64	6.31	67	73	80
24	125	71.23	8.35	66	72	78

Table C-9: Speed statistics for site 9904-Southbound median lane

Hour	N	Mean	Std Dev	Percentiles 15th	50th Pctl	85th
1	23	73.13	7.03	68	74	78
2	9	72.33	6.89	66	72	80
3	12	73.08	6.19	68	74	79
4	19	69.16	7.88	59	70	78
5	28	72.79	5.11	68	73.5	78
6	92	72.1	5.99	67	72	78
7	211	72.09	7.02	67	73	79
8	278	73.33	6.36	68	74	79
9	296	72.33	5.59	67	73	77
10	307	71.6	6.69	66	72	78
11	376	72.76	5.47	68	73	78
12	297	72.37	6.18	67	73	77
13	339	72.43	6.34	68	73	78
14	334	72.69	5.89	67	73	79
15	323	73.07	5.51	68	73	78
16	376	72.24	5.29	68	73	77
17	361	72.43	5.56	67	73	78
18	305	72.35	5.76	67	73	78
19	262	72.48	6.13	67	73	78
20	169	73.76	6.16	70	74	79
21	142	73.16	5.68	69	74	78
22	98	74.03	6.66	68	75	81
23	56	71.59	5.37	66	72	77
24	25	70.8	4.56	66	71	76

Table C-10: Speed statistics for site 9904-Northbound shoulder lane

Hour	N	*Mean*	Std Dev	Percentiles 15th	50th Pctl	85th
1	30	73.13	4.67	70	73.5	78
2	19	73.16	5.12	68	74	78
3	13	73.85	5.11	70	75	78
4	33	73.64	3.86	70	74	78
5	46	73.5	6.58	68	73	81
6	84	74.88	5.73	70	75	80
7	178	73.34	6.12	68	73	80
8	254	73.68	5.89	69	74	80
9	276	73.09	5	69	74	78
10	361	72.76	6.16	68	73	79
11	435	73.27	6.4	68	74	79
12	469	72.66	6.03	68	73	78
13	443	72.74	6.27	68	73	78
14	591	73.58	5.79	69	74	80
15	682	72.7	6.23	68	73	79
16	669	72.83	6.02	68	73	78
17	586	72.89	5.87	68	73.5	78
18	446	72.85	6.8	69	73	79
19	323	72.79	5.46	68	74	78
20	257	73.35	5.89	68	73	80
21	200	73.05	7.07	70	73	79
22	111	73.77	6.33	68	75	80
23	85	72.05	9.38	68	73	78
24	31	73.61	5.57	68	73	80

Table C-11: Speed statistics for site 9904-Northbound middle lane

Hour	N	Mean	Std Dev	Percentiles 15th	50th Pctl	85th
1	135	74.39	6.15	69	75	80
2	90	73.94	9.7	70	75	80
3	109	73.48	5.33	69	73	79
4	168	73.04	5.61	68	74	78
5	194	72.96	5.53	68	73	79
6	302	73.7	5.25	70	74	79
7	468	73.31	5.64	69	74	79
8	539	73.1	5.78	68	74	79
9	630	73.06	5.65	68	73	78
10	746	73.16	6.82	68	74	79
11	829	73.2	6.26	68	74	79
12	833	73.13	6.02	68	73	79
13	842	73.47	6.36	69	74	79
14	913	72.6	5.65	68	73	79
15	1015	73.69	6.43	68	75	80
16	991	73.45	6.17	69	74	79
17	930	72.85	6.47	68	74	79
18	780	72.64	5.72	68	73	78
19	624	71.82	6.46	68	72	77
20	548	71.47	5.88	66	72	78
21	424	71.67	6.09	67	72	78
22	304	71.66	5.4	67	72	77
23	262	72.3	5.9	67	72	79
24	169	73.76	7.19	69	75	80

Table C-12: Speed statistics for site 9904-Northbound median lane

Hour	N	Mean	Std Dev	Percentile 15th	50th Pctl	85th
1	189	70.78	5.96	66	71	78
2	156	71.25	5.83	66	72	78
3	179	71.39	6.26	66	72	78
4	262	72.24	6.41	67	73	78
5	242	73.4	5.24	69	74	79
6	260	72.02	5.99	67	73	78
7	348	73.2	5.62	69	73	79
8	399	72.63	6.31	67	73	79
9	426	72.34	6.52	66	73	79
10	484	72.44	6.59	67	72	79
11	490	71.36	6.12	67	72	78
12	515	71.66	6.37	67	72	78
13	527	72.03	6.73	66	73	78
14	544	71.88	6.39	67	72	78
15	576	71.84	6.08	66	72	78
16	582	71.32	5.73	67	72	77
17	522	71.62	7.57	66	73	78
18	436	71.32	5.98	67	71	78
19	391	71.53	5.82	66	72	78
20	382	71.28	7.39	66	72	78
21	350	71.25	6.09	66	72	78
22	276	70.21	6.39	65	70	77
23	285	70.23	6.95	65	70	78
24	239	71.95	7.13	68	72	78

Table C-13: Speed statistics for site 9905-Southbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	203	67.77	5.79	24	85	63	69	73
2	152	66.78	5.91	23	77	61	68	72
3	177	67.57	5.58	26	84	62	68	73
4	194	67.55	7.02	16	81	61	68	74
5	273	68.18	5.12	55	86	62	68	73
6	427	68.56	5.7	25	88	63	69	73
7	464	68.32	5.47	25	82	63	69	74
8	499	67.61	5.18	17	84	63	68	72
9	554	67.38	5.38	20	88	62	68	72
10	579	67.17	5.4	47	88	62	67	73
11	613	67.62	5.01	50	87	62	68	73
12	591	67.15	5.4	23	93	62	67	72
13	595	67.8	5.12	54	100	63	67	73
14	583	67.16	6.26	11	105	61	67	73
15	660	67.68	4.75	53	85	63	68	73
16	706	67.78	4.69	50	85	63	68	72
17	756	68.56	5.43	19	89	64	68	74
18	575	69.24	5.38	19	95	65	69	74
19	479	68.32	5.2	34	89	64	68	73
20	429	67.74	5.27	24	84	63	67	73
21	427	66.93	4.81	49	80	62	67	72
22	358	67.47	6.35	24	81	63	68	73
23	277	67.48	6	24	84	62	68	73
24	218	68.73	4.84	50	85	64	69	73

Table C-14: Speed statistics for site 9905-Southbound middle lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	130	72.38	5.43	62	88	66	73	78
2	109	72.07	5.9	59	90	66	72	78
3	97	72.48	4.97	59	85	68	72	78
4	151	73.6	5.7	60	94	68	73	79
5	238	73.51	4.37	58	88	69	73	78
6	454	74.1	4.93	24	88	70	74	79
7	554	74.1	5.5	3	98	70	74	79
8	631	72.99	4.18	60	98	69	73	77
9	654	72.89	4.22	61	87	68	73	78
10	684	72.1	5.18	4	88	68	72	77
11	718	73.11	4.45	62	100	69	73	78
12	763	72.62	4.49	24	88	69	73	77
13	841	73.16	4.05	57	85	69	73	77
14	829	73.01	4.13	60	89	69	73	77
15	942	72.63	4.26	57	92	69	73	77
16	1089	73.23	3.9	57	89	70	73	77
17	1234	73.72	4.07	49	93	70	74	78
18	858	74.73	4.16	60	93	71	75	79
19	580	73.98	5.5	1	92	70	74	78
20	485	73.09	4.33	60	89	69	73	78
21	480	72.21	4.6	56	106	68	72	77
22	353	72.26	6.23	27	90	68	73	77
23	244	72.82	4.05	62	85	69	73	77
24	160	72.42	5.35	60	86	66	72	79

Table C-15: Speed statistics for site 9905-Southbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	13	74	3.98	67	78	69	74	78
2	11	73.36	5.7	67	82	68	71	81
3	6	73.5	3.51	71	80	71	72	78
4	12	77.75	4.99	71	89	74	75.5	82
5	39	75.77	4.98	62	88	72	76	81
6	110	79.8	4.58	66	92	76	79.5	84
7	157	77.95	4.17	69	89	74	78	83
8	167	75.8	5.03	62	93	71	75	81
9	198	76.11	4.45	64	89	72	76	81
10	249	75.33	5.03	59	90	71	75	81
11	265	76	5.82	30	91	72	76	81
12	283	75.77	4.58	53	94	72	76	80
13	306	76.78	3.57	67	96	74	77	80
14	323	76.82	5.03	46	96	73	76	81
15	409	76.52	4.35	58	91	73	76	81
16	604	76.87	4.4	30	95	73	77	81
17	682	76.92	4.2	63	95	73	77	81
18	363	78.47	3.91	58	93	75	78	82
19	189	77.54	3.68	69	89	73	78	81
20	107	76.5	4.43	63	90	72	77	81
21	132	75.48	4.79	58	93	71	75	80
22	74	77.22	4.11	68	94	73	77	81
23	36	77.83	6.41	64	93	72	76	86
24	15	73.27	3.63	68	80	70	72	78

Table C-16: Speed statistics for site 9905-Northbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentile 15th	50th	85th
1	19	75.63	6.04	64	86	68	77	83
2	12	75.08	5.68	66	81	68	76	81
3	16	69.69	5.04	62	78	63	70	75
4	23	77.65	6.87	68	88	69	78	86
5	70	76.53	6.68	59	92	69	77.5	83
6	353	78.31	4.34	65	92	74	78	83
7	634	78.42	4.23	60	94	75	78	82
8	550	77.51	4.6	42	94	73	78	82
9	385	77.58	4.85	62	96	72	78	82
10	397	77.82	4.84	57	101	74	78	83
11	350	74.55	6.99	44	89	70	75	80
12	395	76.49	5.7	54	96	71	77	82
13	371	77.03	5.39	59	101	72	77	82
14	377	77.34	5.68	57	92	71	77	83
15	471	77.83	5.28	59	100	72	78	83
16	384	77.43	5.18	54	98	72	78	83
17	394	77.55	6.07	53	118	72	78	83
18	266	78.31	6.51	30	92	74	78	84
19	167	78.56	6.57	50	103	72	78	85
20	143	76.69	5.27	57	99	72	76	81
21	108	74.87	6.15	60	89	68	75	81
22	86	75.43	7.07	50	98	69	76	80
23	41	75.93	11.54	48	118	67	74	82
24	14	76.71	4.79	66	82	73	76	82

Table C-17: Speed statistics for site 9905-Northbound middle lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles		
						15th	50th	85th
1	115	71.96	5.95	58	92	66	72	78
2	101	71.56	5.2	54	86	66	72	76
3	106	70.71	6.76	30	92	65	71	76
4	181	69.78	5.49	53	84	64	70	76
5	342	71.2	5.06	54	92	66	72	76
6	838	72.94	4.67	56	95	68	73	77
7	1257	73.05	4.47	57	113	68	73	77
8	1191	72.9	4.63	46	106	68	73	77
9	915	73.17	4.7	58	94	69	73	78
10	869	72.95	4.75	46	92	68	73	77
11	953	71.13	6.05	41	86	66	72	76
12	899	72.79	5	30	99	68	73	78
13	921	73.09	4.62	57	89	69	73	78
14	892	72.83	5.02	56	91	67	73	77
15	988	72.77	4.78	54	93	68	73	78
16	899	73.14	5.08	56	94	68	73	78
17	904	73.54	5	57	97	68	73	79
18	738	73.87	4.95	60	91	69	74	79
19	544	73.75	5.25	57	110	69	73	79
20	518	72.94	5.2	48	91	68	73	78
21	419	73.36	4.54	63	92	68	74	79
22	350	72.44	4.89	57	91	68	72	78
23	253	72.45	6.49	32	100	67	72	79
24	166	72.76	6.03	57	88	66	73	79

Table C-18: Speed statistics for site 9905-Northbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentile s		
						15th	50th	85th
1	119	68.67	5.27	56	82	62	69	74
2	162	67.85	5.78	52	87	62	68	74
3	120	66.94	6.61	46	88	62	67.5	73
4	141	67.6	5.06	55	82	63	68	72
5	254	67.34	5.38	35	81	62	68	73
6	462	68.17	5.08	50	84	63	68	73
7	647	69.65	5.61	38	93	65	69	75
8	601	68.93	5.53	50	89	63	69	75
9	461	68.08	5.96	30	87	63	69	74
10	456	68.42	5.36	46	86	64	69	74
11	515	66.53	6.41	37	87	61	67	72
12	495	68.18	5.5	47	88	62	68	74
13	471	68.05	5.54	49	90	63	68	74
14	497	68.18	5.73	52	96	62	68	74
15	501	67.85	5.45	51	89	62	68	74
16	459	68.09	6.05	49	88	62	68	74
17	472	68.56	5.72	33	86	63	69	74
18	434	69.67	5.64	55	110	64	69	75
19	344	69.04	5.93	46	91	64	69	75
20	319	68.32	6.43	31	87	62	69	74
21	305	68.81	4.61	58	81	64	69	74
22	274	67.79	5.45	51	96	62	68	73
23	214	67.95	5.23	39	80	63	69	73
24	170	68.18	5.37	54	91	63	68	73

Table C-19: Speed statistics for site 9901-Westbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles		
						15th	50th	85th
1	123	72.31	6.14	58	100	66	72	78
2	120	71.99	5.9	55	85	66	73	78
3	119	72.13	6.48	38	90	67	73	78
4	117	71.95	5.21	57	83	66	72	77
5	135	71.9	5.68	51	89	66	72	78
6	208	72.29	5.6	48	88	66	73	77
7	281	73.31	5.46	57	87	67	74	79
8	353	72.84	5.02	50	95	68	73	78
9	396	71.95	5.76	54	90	66	72	78
10	413	71.05	7.55	20	95	65	72	77
11	459	72.81	6.41	26	87	68	73	79
12	591	67.15	5.4	23	93	62	67	72
13	595	67.8	5.12	54	100	63	67	73
14	583	67.16	6.26	11	105	61	67	73
15	660	67.68	4.75	53	85	63	68	73
16	706	67.78	4.69	50	85	63	68	72
17	756	68.56	5.43	19	89	64	68	74
18	575	69.24	5.38	19	95	65	69	74
19	479	68.32	5.2	34	89	64	68	73
20	429	67.74	5.27	24	84	63	67	73
21	427	66.93	4.81	49	80	62	67	72
22	358	67.47	6.35	24	81	63	68	73
23	277	67.48	6	24	84	62	68	73
24	218	68.73	4.84	50	85	64	69	73

Table C-20: Speed statistics for site 9901-Westbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles		
						15th	50th	85th
1	15	80	5.25	72	88	75	80	87
2	12	79.92	7.67	66	90	71	81.5	88
3	17	75.82	3.3	70	81	73	74	80
4	23	75.3	5.71	64	85	69	75	82
5	27	77.26	3.17	70	83	74	78	81
6	36	76.69	3.82	67	85	73	78	81
7	79	77.35	3.99	65	88	73	78	81
8	97	76.92	8.28	7	94	74	77	82
9	130	76.69	4.51	64	92	72	76.5	82
10	166	75.45	4.57	57	86	71	76	80
11	167	78.05	4.4	68	92	74	78	82
12	180	77.91	4.13	61	91	74	77	82
13	233	78.18	4.88	63	101	74	78	83
14	228	78.27	4.77	39	100	75	78	82
15	262	78.53	5.09	31	99	74	79	83
16	270	78.75	4.9	42	93	74	79	84
17	224	77.16	4.95	41	91	73	77	81
18	159	77.6	4.05	68	87	73	77	83
19	138	75.34	6.59	40	91	71	76	79
20	76	76.32	4.52	66	91	72	76	80
21	71	76.69	4.37	66	92	73	77	80
22	45	75.64	5.62	51	87	72	76	80
23	46	77.04	5.62	66	90	72	77.5	84
24	22	75.91	4.12	69	86	71	77	79

Table C-21: Speed statistics for site 9901-Eeastbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	20	79.3	4.92	70	86	74	79	85
2	21	78.38	6.92	65	95	72	78	85
3	16	74.88	4.46	67	85	71	74.5	80
4	15	78.6	8.37	65	96	68	78	89
5	20	76	3.83	68	85	72	76	79
6	58	75.66	7.54	30	89	71	77	80
7	81	76.7	5.4	61	94	72	76	81
8	92	78.1	4.37	69	91	73	78	83
9	129	77.14	3.8	67	88	73	77	80
10	168	77.63	7.72	1	102	73	78	84
11	221	77.23	5.98	12	90	74	77	81
12	193	76.94	8.32	1	93	74	78	81
13	198	77.46	5.1	49	91	73	78	82
14	201	77.98	4.3	65	91	74	78	82
15	234	77.72	5.48	30	94	74	78	82
16	218	77.82	5.25	23	90	75	78	82
17	202	77.43	4.88	54	96	73	78	81
18	155	77.97	5.16	40	90	75	78	82
19	100	77.32	6.38	43	88	73	78	82
20	107	77.33	4.91	61	91	72	78	82
21	71	75.54	3.9	66	84	72	75	80
22	59	76.71	3.8	69	88	73	76	81
23	52	76.4	3.68	7	84	73	77	80
24	34	76.32	4.52	64	82	71	77.5	81

Table C-22: Speed statistics for site 9901- Eastbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	135	71.93	5.69	59	92	66	72	78
2	111	71.07	7.02	55	89	63	72	78
3	109	70.52	6.23	33	85	66	71	76
4	115	70.9	5.71	51	85	66	71	76
5	131	71.74	4.89	58	88	66	72	76
6	240	72.04	6.51	17	89	66	72.5	78
7	314	72.62	5.46	42	90	67	73	78
8	329	73	5.57	51	85	67	73	79
9	393	72.88	5.55	55	104	67	73	78
10	466	72.52	5.99	30	89	66	73	78
11	449	71.96	5.3	50	85	66	73	77
12	458	72.43	5.23	45	87	67	73	78
13	453	72.53	5.82	19	97	67	73	77
14	487	73.12	5.63	56	97	67	74	79
15	523	72.87	5.31	49	90	67	73	78
16	498	73.16	5.08	52	89	67	74	78
17	465	72.82	5.37	52	88	67	74	78
18	403	72.99	5.51	36	89	68	73	79
19	369	73.25	4.8	56	88	68	74	78
20	336	71.93	5.45	37	88	66	72	77
21	264	71.29	5.83	45	86	65	72	76
22	253	72.11	5.74	35	84	67	73	77
23	209	72.56	6.35	54	92	66	73	79
24	178	71.2	5.95	50	84	75	72	77

Table C-23: Speed statistics for site 9928- Westbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	100	66.92	6.52	46	94	61	67.5	73
2	73	67.66	6.1	54	82	62	68	75
3	90	66.99	5.53	56	84	61	66	73
4	91	66.6	5.18	53	79	60	68	71
5	131	66.88	5.63	54	88	60	67	72
6	202	67.5	6.07	53	81	61	68	74
7	258	67.35	5.23	52	79	61	68	72
8	306	67.53	4.99	54	80	62	68	73
9	376	67.24	5.56	48	80	61	68	73
10	390	68.33	5.59	42	83	63	69	73
11	405	67.99	5.59	30	87	62	68	73
12	418	67.67	5.77	36	81	61	69	73
13	442	68.5	6.06	31	84	62	69	74
14	453	67.95	5.05	47	82	63	68	73
15	479	68.4	6.43	34	91	62	70	74
16	462	69.44	5.07	46	86	64	70	74
17	431	68.6	5.42	54	86	62	68	74
18	356	69.15	5.31	51	81	63	69	75
19	308	68.44	5.88	32	86	63	69	74
20	256	66.54	6.48	43	83	60	67	72
21	230	66.77	6.31	45	83	61	68	73
22	161	67.32	6.51	30	81	61	68	74
23	142	66.01	6.19	46	78	59	66	73
24	112	65.83	5.16	49	78	60	66	71

Table C-24: Speed statistics for site 9928- Westbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	12	76.67	12.74	69	104	69	71.5	94
2	9	70.44	6.89	58	81	60	71	79
3	15	68.73	5.06	62	77	62	68	74
4	15	74.27	7.2	66	96	69	72	80
5	26	71.38	5.24	62	85	67	71	77
6	48	73.13	5.18	66	98	68	72	78
7	71	72.32	4.36	62	82	67	72	76
8	90	71.47	3.66	61	80	68	72	75
9	129	72.64	4.14	61	83	68	73	77
10	144	73.13	3.99	61	83	69	73	77
11	162	72.35	4.28	63	87	69	72	77
12	183	72.69	4.92	61	86	67	72	78
13	176	73.65	4.07	61	83	70	73	78
14	203	73.35	3.95	62	93	69	73	77
15	224	73.87	4.93	63	94	70	73	78
16	192	74.26	4.01	64	91	70	74	78
17	198	73.45	4.33	64	90	69	73	78
18	130	73.72	4.72	62	102	69	74	78
19	115	73.41	4.64	62	85	69	73	79
20	67	70	4.3	60	78	65	70	74
21	52	71.75	4.39	61	82	67	72	75
22	37	72.51	5.22	62	83	67	72	79
23	34	72.03	6.53	49	83	67	72	79
24	14	70.07	5.36	64	85	66	69	75

Table C-25: Speed statistics for site 9928- Eastbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	10	72.2	6.32	65	83	66	71.5	80
2	8	71.88	4.79	69	83	69	70	80
3	9	75.56	12.04	68	97	68	70	89
4	11	69.91	4.28	63	76	65	71	75
5	23	71.13	4.51	59	81	67	72	75
6	69	72.7	4.2	65	82	68	73	78
7	94	72.05	4.68	61	83	67	72	76
8	104	72.8	4.77	66	99	68	72	78
9	165	71.23	3.78	60	84	68	71	75
10	181	72.2	4.26	63	91	68	71	76
11	169	72.37	4.6	61	89	68	72	78
12	140	71.3	4.57	62	87	67	71	75
13	184	72.97	4.75	63	89	68	74	78
14	183	72.75	4.39	64	93	69	72	77
15	168	72.36	4.01	64	87	68	72	76
16	136	72.96	5.31	61	93	68	72	78
17	151	71.4	5.31	39	86	67	71	77
18	105	72.74	4.18	62	84	69	73	77
19	65	72.4	4.84	66	87	67	72	77
20	43	70.88	3.22	62	80	68	71	74
21	51	70.8	5.2	61	90	66	71	75
22	29	71.07	4.46	61	79	66	70	77
23	15	71.33	4.55	64	80	66	71	77
24	11	71.45	6.46	62	85	65	72	77

Table C-26: Speed statistics for site 9928- Eastbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	94	69.21	6.38	53	89	64	69	76
2	82	70.17	5.17	60	87	66	69	75
3	81	70.73	5.73	49	89	67	71	75
4	107	70.46	4.68	59	85	65	71	75
5	149	69.91	5.09	54	84	65	71	75
6	271	70.6	5.57	55	97	65	71	76
7	348	70.52	5.38	46	89	65	71	76
8	427	71.23	4.72	57	94	67	71	76
9	453	70.49	4.88	56	88	65	71	75
10	463	70.06	5.24	46	86	65	71	75
11	460	70.68	5.41	50	93	65	71	76
12	425	69.93	5.26	54	85	64	70	75
13	468	70.78	4.93	52	89	66	71	75
14	450	70.57	5.41	53	89	65	71	76
15	454	70.44	5.22	53	89	64	71	76
16	423	70.63	5.19	54	87	65	71	76
17	376	70.41	4.91	55	86	65	71	75
18	317	70.24	5.2	53	86	64	71	76
19	299	70.19	5.77	52	91	64	70	77
20	217	70.11	5.31	52	90	65	70	76
21	204	69.71	5.92	45	89	65	70	76
22	182	70.45	5.49	50	89	65	71	75
23	132	69.71	4.75	57	82	65	70	74
24	118	69.66	5.87	37	86	64	69.5	75

Table C-27: Speed statistics for site 351- Westbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	36	70.61	5.2	56	83	65	70	75
2	36	72.31	5.4	61	85	67	73	77
3	55	70.33	5.76	54	83	65	70	76
4	75	70.96	6.45	54	90	64	71	77
5	113	72.46	6.5	56	98	66	72	79
6	168	73.8	7.17	43	101	67	75	80
7	218	73.86	6.01	53	90	68	74	80
8	307	73.39	5.97	55	90	67	73	80
9	303	73.28	6.07	51	95	66	73	80
10	315	73.53	6.26	30	90	69	75	80
11	424	73.66	5.61	55	97	68	73	79
12	419	73.39	6.38	45	96	67	73	80
13	397	71.95	5.63	53	92	66	72	77
14	370	71.44	6.2	51	87	65	71	77
15	409	73.25	6.38	51	92	68	73	80
16	395	72.05	6.29	49	87	65	73	77
17	364	64.35	6.79	44	85	57	64	72
18	318	71.28	6.98	47	97	64	71	77
19	266	72.48	6.78	55	92	65	73	80
20	204	72.76	6.98	51	92	66	73	80
21	161	73.39	6.8	51	96	66	73	80
22	117	71.68	7.35	56	87	62	73	79
23	85	72.39	7.06	51	85	65	72	81
24	63	73.52	6.74	60	89	67	73	81

Table C-28: Speed statistics for site 351-Westbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	6	74.33	8.66	65	87	65	74	85
2	5	75.8	7.05	64	83	68	77	81
3	3	77	1	76	78	76	77	78
4	10	76.5	4.09	71	85	72	77	81
5	18	78.83	5.67	70	87	72	78	86
6	33	77.94	5.62	61	95	74	78	82
7	40	80.15	5.43	68	92	74	80	86
8	84	75.88	5.04	65	92	71	76	81
9	97	78.51	6.07	68	105	74	78	84
10	108	78.56	7.45	36	95	74	78	84
11	165	79.67	6.09	60	101	74	78	86
12	163	76.63	10.54	35	102	71	78	86
13	143	76.04	6.04	45	97	71	75	82
14	174	77.2	5.86	65	97	71	76	83
15	167	78.05	6.98	42	95	71	78	85
16	232	76.36	6.7	37	92	70	76	83
17	215	68.2	6.42	49	87	61	68	75
18	199	76.93	7.33	36	104	70	77	83
19	126	77.5	5.32	60	92	72	78	83
20	76	78.21	6.17	62	95	72	78	85
21	60	76.47	7.05	51	92	69	77	84
22	43	76.86	6.48	65	92	70	76	84
23	32	82.34	8.65	69	101	74	80	94
24	9	79.44	8.88	69	98	70	78	93

Table C-29: Speed statistics for site 351-Eastbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	16	86.56	10.86	71	111	76	85	102
2	8	80.25	9.72	65	92	67	83	91
3	2	72	5.66	68	76	68	72	76
4	8	80.25	7.4	69	92	71	79	90
5	22	81.77	14.99	38	116	72	80	96
6	50	87.34	9.51	69	120	77	87	97
7	94	87.67	8.81	64	120	79	87	96
8	90	88.98	13.01	3	116	79	89	101
9	113	86.34	9.95	65	120	77	87	95
10	159	86.16	9.93	34	108	78	87	96
11	149	88	8.19	69	120	80	87	98
12	168	87.47	8.66	39	112	80	87	96
13	145	86.43	9.83	33	120	78	86	96
14	180	84.51	9.04	41	112	77	85	94
15	180	86.88	10.04	40	116	78	87	96
16	213	82.92	10.23	17	105	76	83	91
17	193	80.05	7.76	53	112	72	80	88
18	168	82.11	6.44	64	98	75	82	89
19	173	83.66	9.55	18	111	76	83	93
20	119	84.78	7.89	67	108	77	85	94
21	66	86.59	8.8	69	108	78	87	96
22	47	86.23	9.51	70	108	76	85	98
23	46	84.7	11.06	64	112	74	83	98
24	24	80.83	9.1	68	104	73	78	90

Table C-30: Speed statistics for site 351- Eastbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	65	74.57	8.61	33	90	68	75	84
2	60	71.47	7.71	54	87	63	73	81
3	38	70.55	7.03	58	90	64	70	80
4	46	71.76	7.72	57	89	64	72	82
5	85	71.45	8.96	49	92	62	71	81
6	213	74.69	7.8	55	102	66	75	83
7	249	74.24	7.45	51	92	66	75	83
8	287	76.15	7.87	53	104	68	76	84
9	314	76.17	7.69	45	101	68	76	83
10	332	75.54	6.46	58	95	68	76	82
11	439	76.02	6.94	26	104	70	76	83
12	355	74.64	7.51	33	108	67	75	81
13	374	74.57	6.87	41	92	68	75	81
14	341	73.88	6.57	54	92	68	73	81
15	385	75.74	7.01	24	97	70	76	83
16	342	74.15	6.78	35	108	68	75	80
17	283	69.09	7.42	47	89	61	69	77
18	257	73.24	7.02	32	101	66	73	80
19	254	73.88	6.97	46	95	68	75	81
20	249	74.49	6.91	54	92	67	75	81
21	184	74.96	7.35	50	108	67	75	83
22	144	75.36	7.93	54	101	67	75	83
23	112	74.04	7.73	44	92	66	75	81
24	95	72.91	6.27	56	102	67	73	78

Table C-31: Speed statistics for site 9919-Southbound shoulder lane

Hour	N	Mean	Std Dev	Percentile 15th	50th	85th
1	136	63.96	5.37	60	64	69
2	123	64.07	5.26	59	64	70
3	120	64.53	5.67	59	65	70
4	132	64.13	9.89	60	65.5	71
5	187	65.31	5.58	61	66	70
6	293	65.7	10.92	62	67	72
7	406	67.5	7.74	64	68	73
8	476	65.96	10.08	62	67	72
9	515	66.93	4.93	63	67	72
10	509	65.7	9.23	62	66	72
11	530	66.1	7.52	63	67	72
12	581	65.97	7.29	62	67	72
13	561	66.05	6.43	63	67	71
14	563	66.5	6.75	63	67	72
15	628	66.24	6.16	62	67	72
16	631	66.47	6.5	62	67	72
17	607	66.85	6.82	63	68	72
18	510	66.57	7.47	63	68	71
19	396	66.8	6.52	62	67	73
20	370	65.33	7.65	62	66.5	71
21	312	65.55	6.95	61	66	72
22	238	66.08	7.17	62	66	72
23	212	65.84	5.38	62	66	71
24	177	63.02	6.56	59	64	69

Table C-32: Speed statistics for site 9919- Southbound median lane

Hour	N	Mean	Std Dev	Percentile 15th	50th	85th
1	36	58.86	18.49	58	62.5	69
2	17	59.18	15.44	58	61	67
3	27	59.56	18.17	55	65	71
4	30	66.83	4.08	63	67	71
5	36	64.22	8.71	62	65.5	69
6	114	65.91	11.51	64	68	71
7	184	66.62	8.59	64	68	71
8	218	66.34	9.14	64	68	71
9	267	67.33	4.38	64	67	72
10	301	64.32	10.96	63	66	70
11	334	67.48	5.57	64	68	73
12	384	65.84	7.23	64	66	70
13	368	65.75	7.51	63	66	70
14	350	66.91	8.07	65	67.5	71
15	457	67.17	5.34	64	67	71
16	539	66.82	7.65	64	67	71
17	437	66.32	10.08	64	68	71
18	346	67.38	4.39	64	67.5	72
19	233	66.99	9.25	64	68	73
20	149	65.26	6.82	62	66	70
21	130	65.77	6.51	63	66	70
22	78	64.6	10.18	61	66	69
23	55	64.51	9.8	62	65	71
24	56	62.61	10.08	59	65	68

Table C-33: Speed statistics for site 9919-Northbound median lane

Hour	N	Mean	Std Dev	Percentiles 15th	50th	85th
1	202	58.26	5.75	54	58	64
2	187	61.1	5.74	56	60	67
3	189	59.52	6.02	55	59	66
4	247	60.89	5.66	56	61	68
5	385	61.58	5.96	56	61	68
6	446	67.45	9.26	59	68	78
7	368	77.7	4.88	74	78	83
8	328	76.26	8.08	73	77	81
9	377	76.06	6.32	72	76	81
10	362	75.42	6.22	71	75	80
11	378	75.4	4.6	71	75	80
12	399	73.8	10.12	71	75	80
13	374	75.12	8.7	72	76	80
14	382	76.08	7.11	72	76	81
15	417	75.83	6.76	72	76	81
16	451	75.53	8.37	73	76	80
17	368	76.26	4.28	73	76	80
18	251	75.99	4.35	72	76	80
19	204	75.72	4.94	72	76	80
20	238	69.85	8.11	64	70	77
21	401	57.01	7.33	50	57	65
22	339	54.66	7.59	48	55	63
23	289	54.67	6.72	50	54	62
24	201	59.9	5.8	56	60	66

Table C-34 Speed statistics for site 9932-Southbound shoulder lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	137	69.72	5.59	55	86	64	70	76
2	91	68.07	8.44	44	90	60	68	76
3	79	68.08	6.7	50	86	62	68	74
4	61	66.92	10.09	1	85	62	68	73
5	115	67.92	5.28	53	82	63	68	74
6	160	71.14	7.62	27	91	64	71	79
7	286	71.44	5.91	48	88	65	72	78
8	471	72.23	5.93	50	100	67	72	78
9	533	70.98	5.59	52	94	65	71	76
10	584	71.38	6.28	1	91	65	72	77
11	605	70.13	5.87	47	92	64	70	76
12	584	70.34	5.78	41	90	64	70	76
13	616	70.52	5.7	50	90	65	70	77
14	591	71.09	5.72	55	112	66	71	77
15	586	71.56	5.47	47	92	66	72	77
16	604	72.17	6.54	1	101	66	72	79
17	579	72.7	5.73	46	93	67	73	79
18	492	72.51	6.13	50	92	66	72	79
19	455	71.1	5.64	48	104	66	71	76
20	380	70.44	5.9	48	86	64	71	76
21	377	70.69	5.99	50	93	64	71	77
22	332	69.59	6.11	49	88	63	70	76
23	254	70.81	6.39	56	92	64	70.5	78
24	167	68.87	6.04	54	87	63	69	75

Table C-35: Speed statistics for site 9932-Southbound median lane

Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles		
						15th	50th	85th
1	15	75.07	7.33	63	84	66	75	83
2	10	78.2	3.39	71	82	74	79	81
3	12	68.17	22.99	2	93	63	72	84
4	11	74.09	5.17	63	82	71	73	80
5	12	78.58	8.12	64	93	71	78.5	87
6	28	75.93	6.83	65	87	68	76.5	84
7	93	79.16	5.76	69	101	72	79	86
8	221	78.07	4.89	64	93	74	77	84
9	336	77.8	5.18	65	95	73	77	83
10	366	78.02	4.62	65	100	73	78	83
11	374	77.05	4.94	63	104	73	77	83
12	363	77.7	5.4	30	109	73	77	83
13	399	78.01	5.12	57	99	73	77	84
14	381	78.14	5.85	31	96	72	78	84
15	379	78.75	5.04	65	96	73	78	84
16	325	79.55	5.34	61	96	74	79	86
17	327	78.84	5.21	65	100	74	78	85
18	302	78.98	5.03	63	95	74	78	85
19	262	77.18	6.62	33	96	72	77	83
20	184	77.76	5.57	59	93	72	77	84
21	140	78.09	7.34	35	106	72	77	86
22	128	76.39	7.11	35	92	70	77	83
23	85	77.75	5.95	65	97	72	77	84
24	30	74	5.69	64	87	67	73	80

Table C-36: Speed statistics for site 9932-Northbound median lane

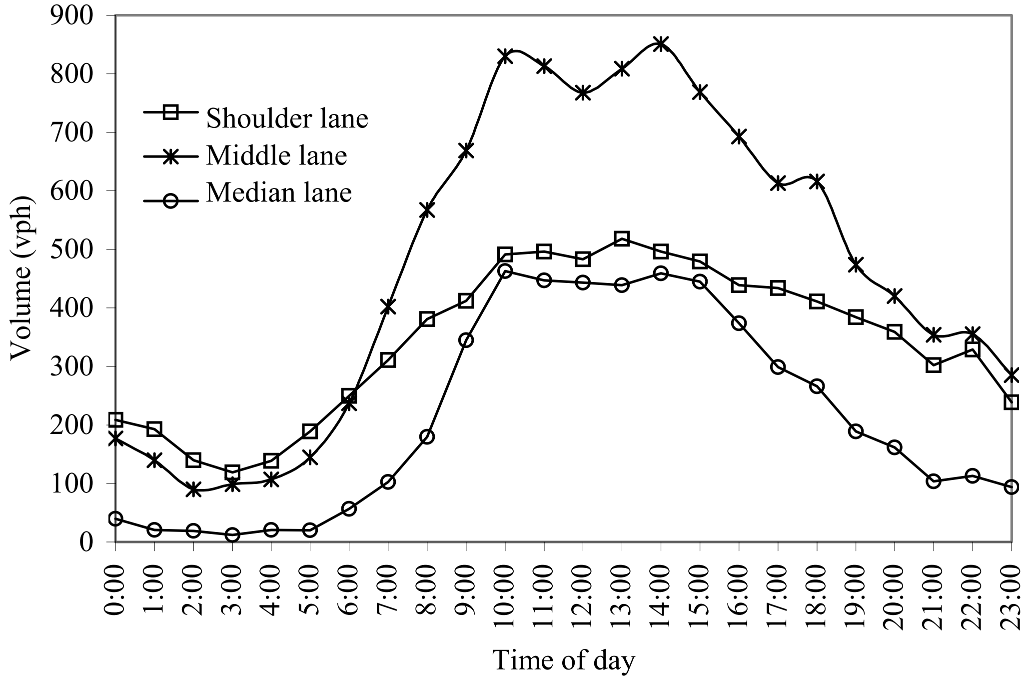
Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentile		
						15th	50th	85th
1	35	75.11	5.92	59	92	69	76	81
2	25	76.24	6.67	69	102	70	75	80
3	20	76.35	4.73	69	88	72	75.5	81
4	25	74.56	5.58	64	86	68	75	81
5	27	78.11	5.45	68	88	72	76	85
6	84	76.37	5.19	62	95	72	75.5	81
7	75	76.35	4.39	65	94	72	76	80
8	94	76.14	6.83	35	92	72	75	83
9	169	77.01	5.09	67	91	72	77	82
10	235	76.41	5.32	61	102	72	75	81
11	262	75.96	4.7	65	91	70	76	81
12	247	76.38	4.59	64	92	72	75	81
13	241	75.95	4.47	62	89	72	76	80
14	207	77.1	5.37	66	94	72	77	82
15	239	77.28	4.76	67	99	73	77	83
16	281	77.09	4.4	61	89	72	77	81
17	200	77.34	4.78	62	89	72	77	82
18	201	75.83	5.16	41	87	71	75	81
19	149	76.73	5.19	65	94	71	76	82
20	147	77.9	6.01	64	94	72	77	85
21	112	77.25	5.5	62	100	72	76.5	82
22	91	75.42	4.86	63	87	71	75	81
23	55	75.09	6.27	63	92	68	75	81
24	45	75.62	7.07	62	96	70	75	85

Table C-37: Speed statistics for site 9932-Northbound shoulder lane

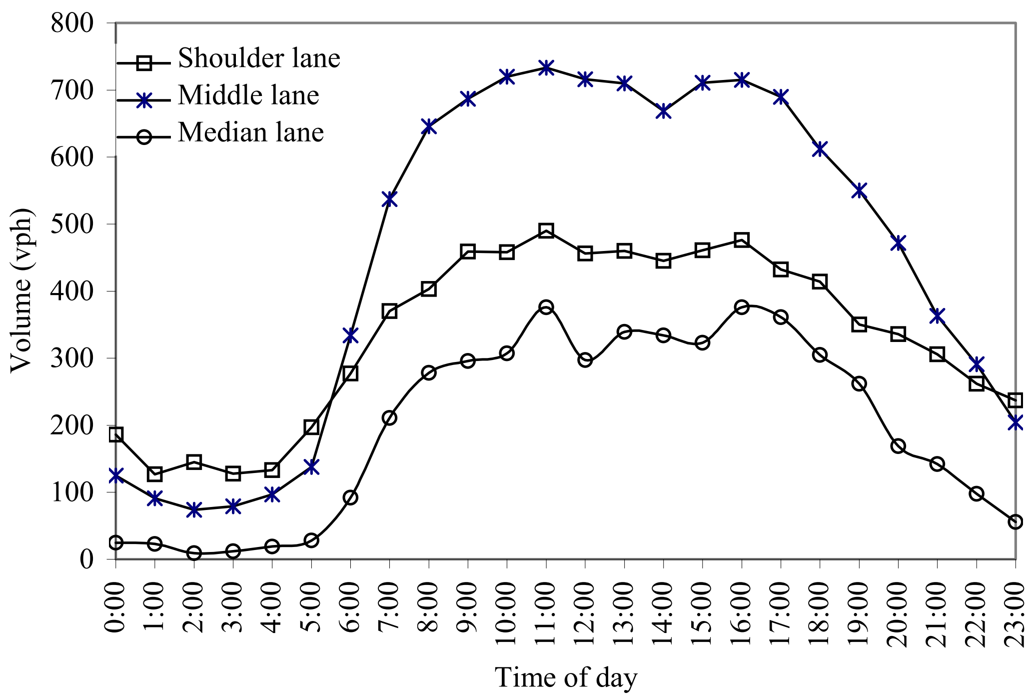
Hour	Volume	Mean	Std Dev	Minimum	Maximum	Percentiles 15th	50th	85th
1	114	68.3	6.98	35	85	62	69	74
2	115	68.64	9.75	35	93	62	69	78
3	119	69.46	7.94	33	86	62	70	77
4	134	69.19	7.63	35	84	62	70	78
5	187	70.38	5.66	56	98	64	71	76
6	248	70.87	6.2	30	94	65	71	77
7	277	71.4	5.3	53	87	66	72	77
8	301	70.33	6.25	40	98	65	70	76
9	437	70.31	5.82	35	100	64	70	76
10	494	69.51	4.85	35	85	65	70	74
11	486	69.9	5.47	52	87	64	70	75
12	489	70.32	5.68	52	90	64	70	77
13	446	69.72	5.75	35	92	64	70	76
14	446	70.36	5.12	55	89	66	70	76
15	443	70.33	4.91	56	87	65	70	75
16	482	71.12	5.21	48	89	66	71	77
17	427	70.78	4.86	55	86	66	71	76
18	416	70.06	5.44	34	96	65	70	75
19	341	69.52	5.82	42	86	63	70	75
20	325	70.4	6.59	34	92	64	71	77
21	291	70.56	6.07	36	103	64	70	77
22	259	69.68	5.32	54	82	63	70	76
23	205	70.4	5.88	49	88	64	70	77
24	139	69.53	8.51	35	92	62	70	77

APPENDIX D--VARIATION OF TRAFFIC VOLUME BY TIME OF THE DAY

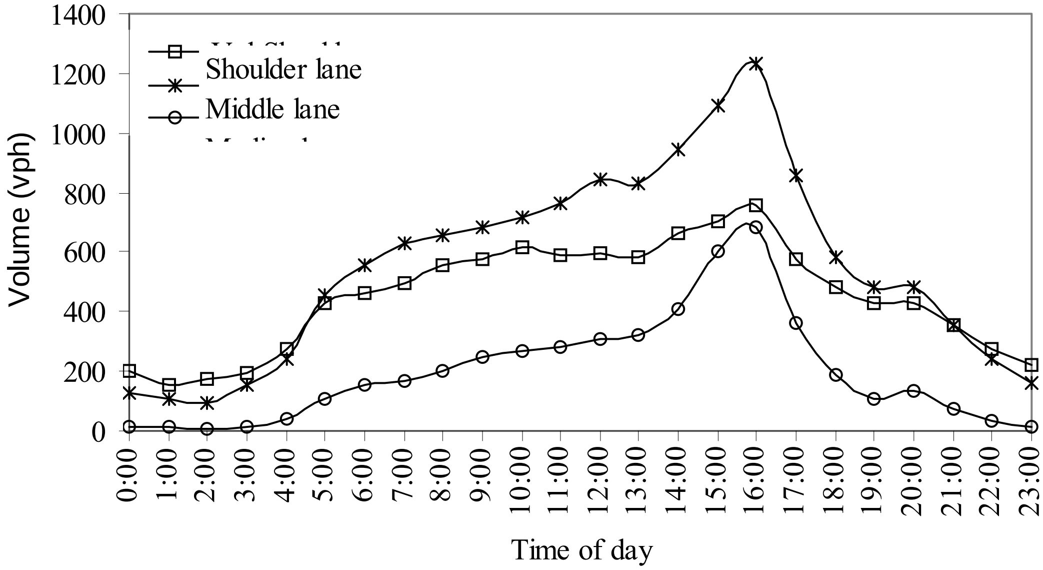
2.3.3



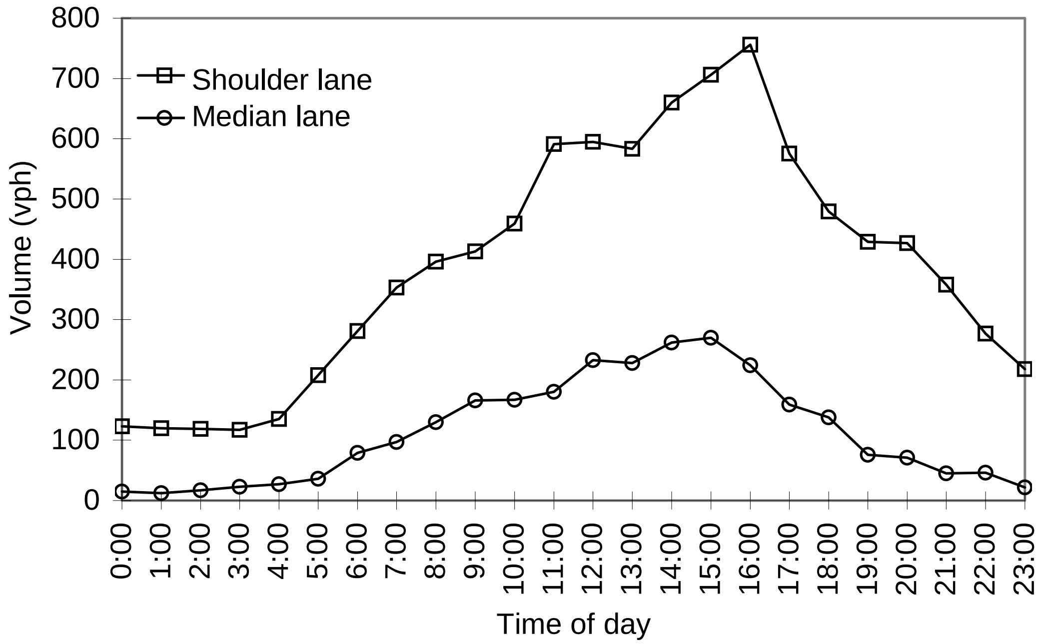
Variation of traffic volume by time of the day on Site 320



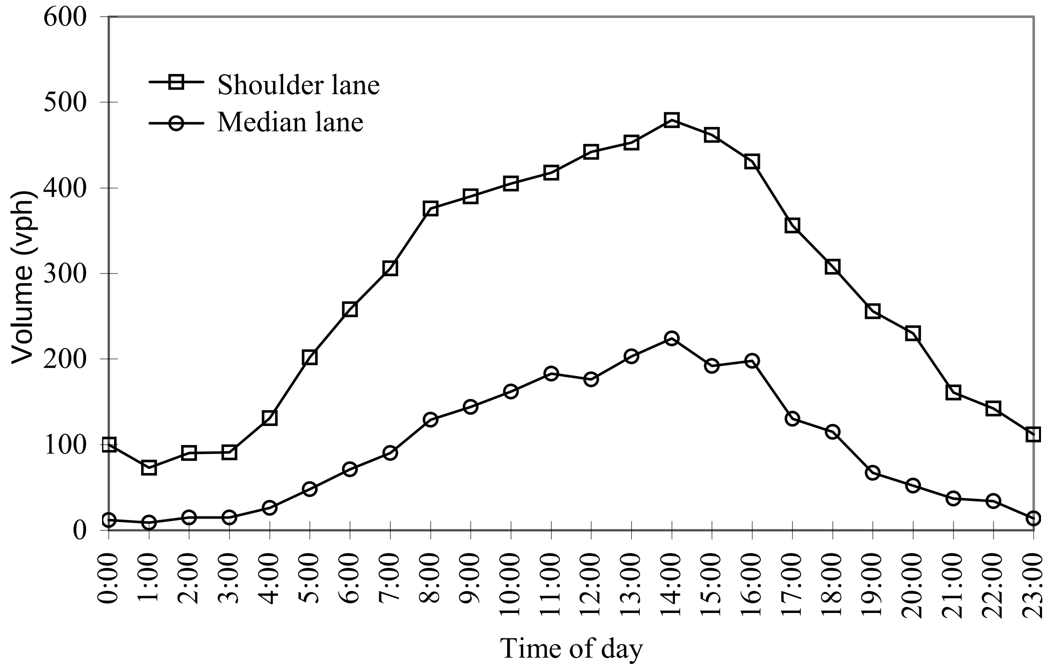
Variation of traffic volume by time of the day on Site 9904



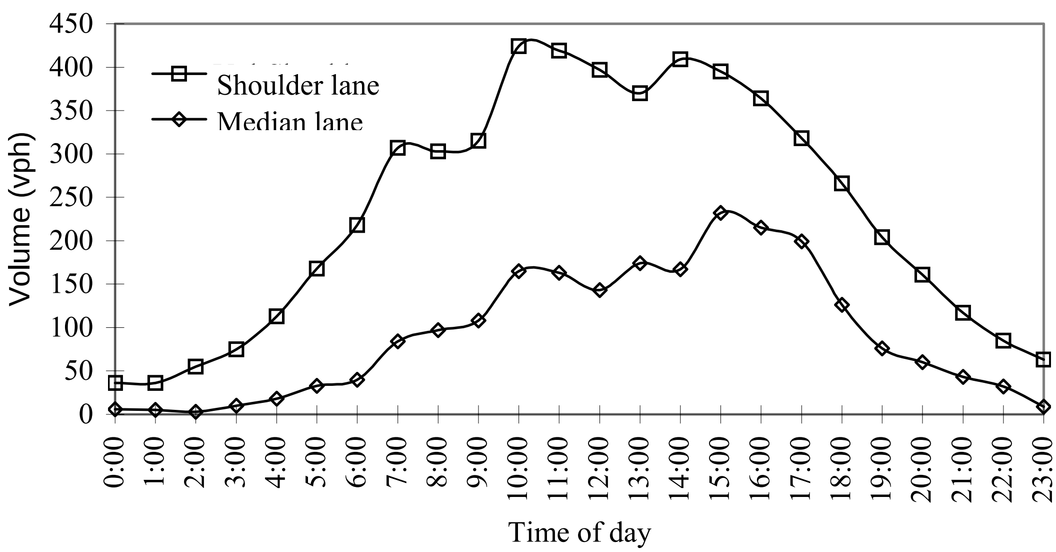
Variation of traffic volume by time of the day on Site 9905



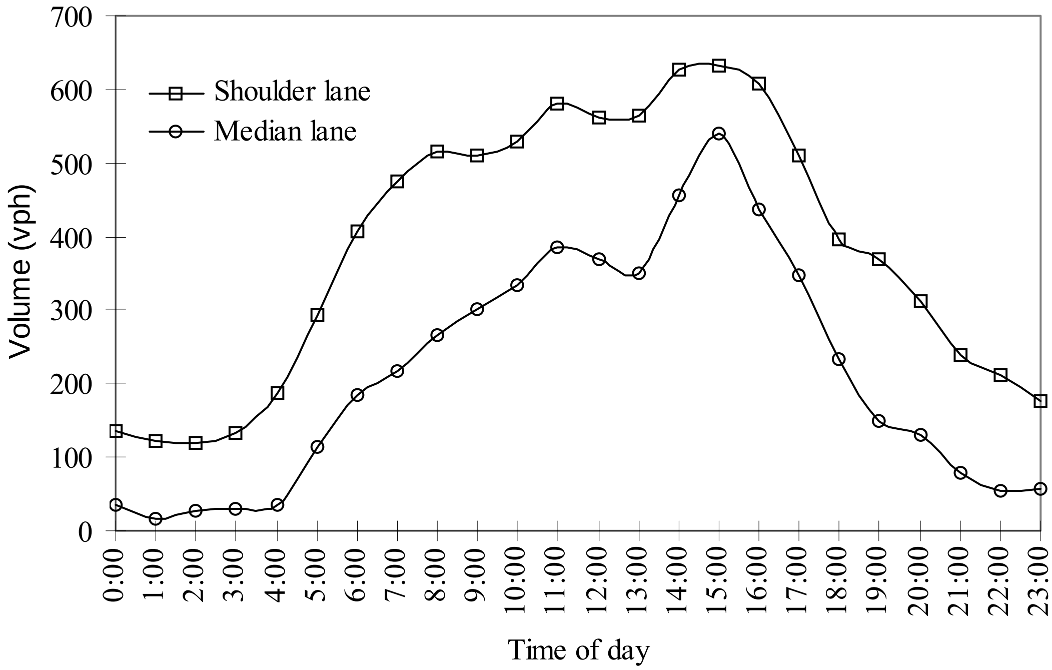
Variation of traffic volume by time of the day on Site 9901



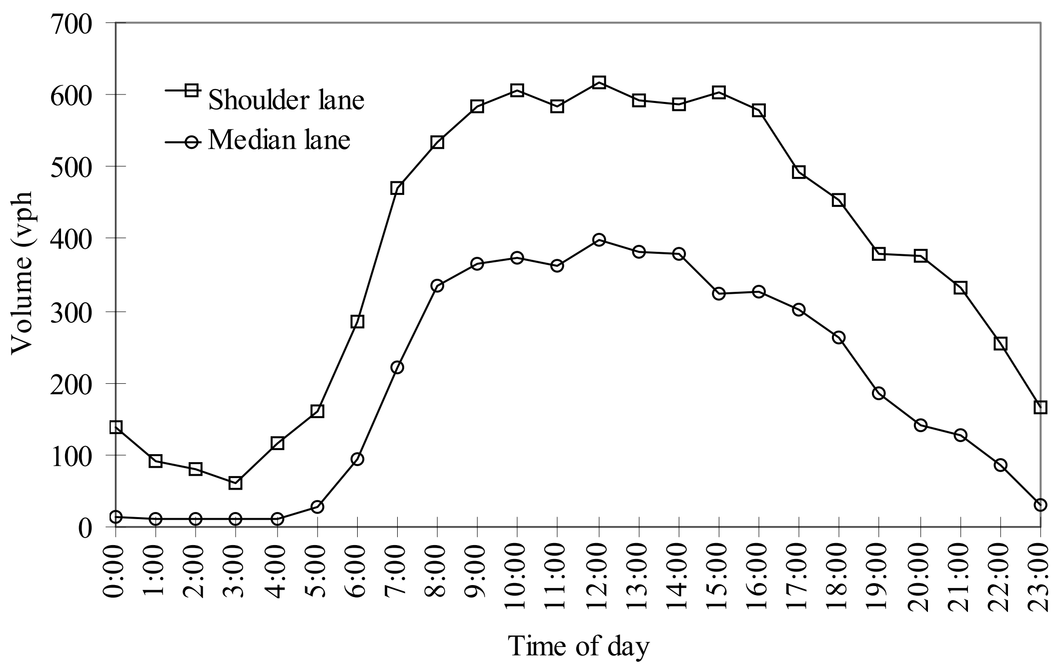
Variation of traffic volume by time of the day on Site 9928



Variation of traffic volume by time of the day on Site 351



Variation of traffic volume by time of the day on site 9919



Variation of traffic volume by time of the day on Site 9932

APPENDIX E --FEDERAL HIGHWAY ADMINISTRATION VEHICLE CLASSIFICATION (CLASS F SCHEME)

FHWA Vehicle Classes with Definitions (FHWA, 2001)

1. ***Motorcycles*** (Optional) -- All two or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles. This vehicle type may be reported at the option of the State.
2. ***Passenger Cars*** -- All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.
3. ***Other Two-Axle, Four-Tire Single Unit Vehicles*** -- All two-axle, four-tire, vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification. *Because automatic vehicle classifiers have difficulty distinguishing class 3 from class 2, these two classes may be combined into class 2.*
4. ***Buses*** -- All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.

   NOTE: In reporting information on trucks the following criteria should be used:

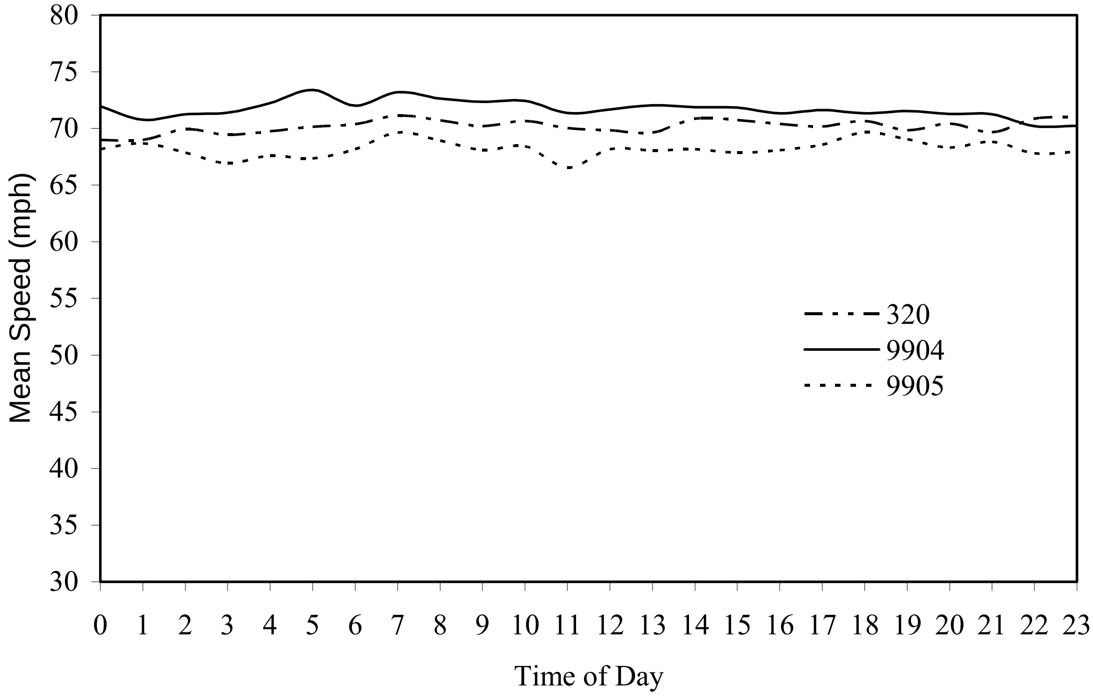
   a. Truck tractor units traveling without a trailer will be considered single-unit trucks.
   b. A truck tractor unit pulling other such units in a "saddle mount" configuration will be considered one single-unit truck and will be defined only by the axles on the pulling unit.
   c. Vehicles are defined by the number of axles in contact with the road. Therefore, "floating" axles are counted only when in the down position.
   d. The term "trailer" includes both semi- and full trailers.

5. ***Two-Axle, Six-Tire, Single-Unit Trucks*** -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.
6. ***Three-Axle Single-Unit Trucks*** -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
7. ***Four or More Axle Single-Unit Trucks*** -- All trucks on a single frame with four or more axles.
8. ***Four or Fewer Axle Single-Trailer Trucks*** -- All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9. ***Five-Axle Single-Trailer Trucks*** -- All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10. ***Six or More Axle Single-Trailer Trucks*** -- All vehicles with six or more axles consisting

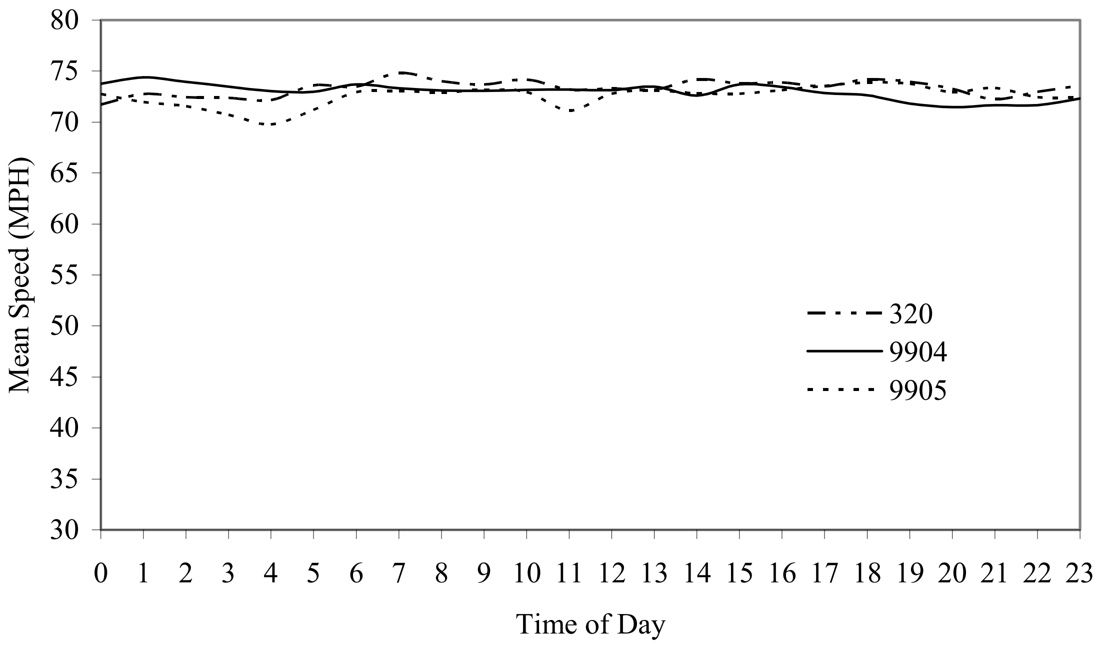
of two units, one of which is a tractor or straight truck power unit.

11. ***Five or fewer Axle Multi-Trailer Trucks*** -- All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12. ***Six-Axle Multi-Trailer Trucks*** -- All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13. ***Seven or More Axle Multi-Trailer Trucks*** -- All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

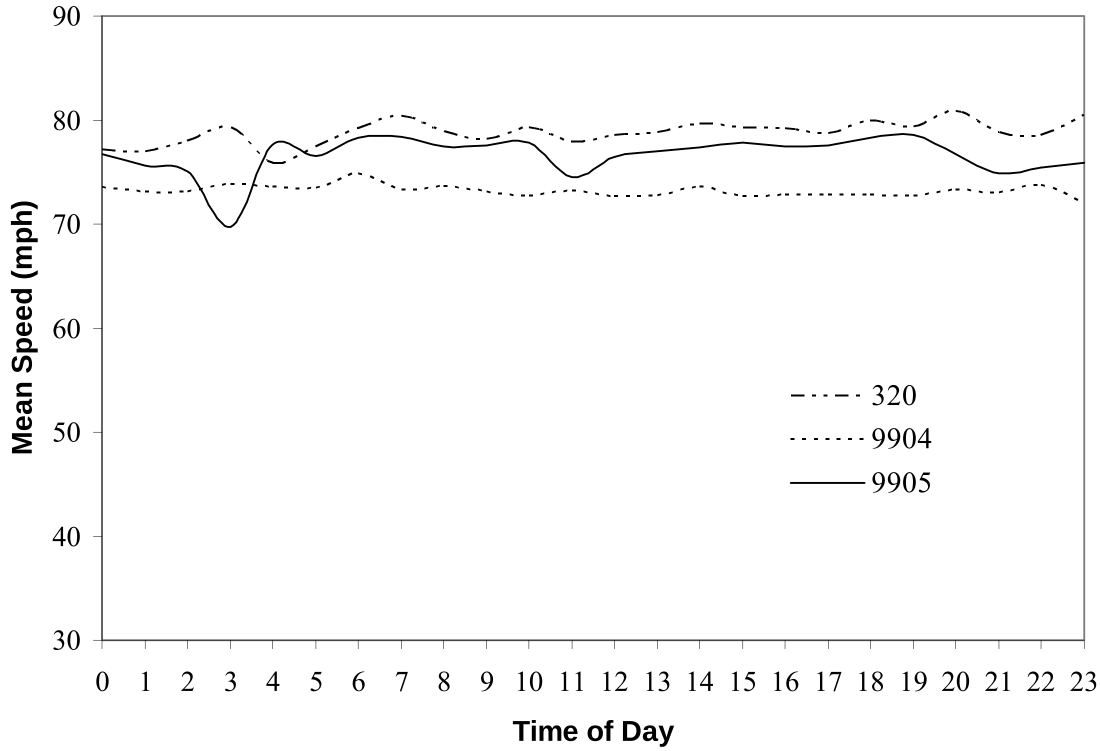
APPENDIX F--VARIATIONS OF 24-HR MEAN SPEEDS OF TRAFFIC IN THE SHOULDER AND MEDIAN LANES



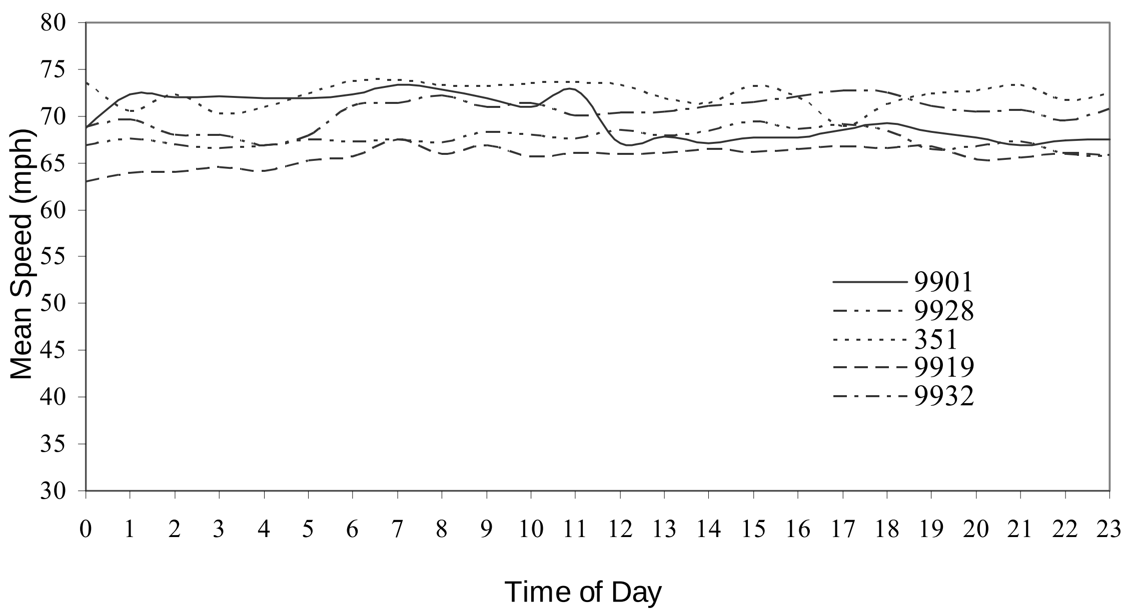
Shoulder lanes of six-lane sections



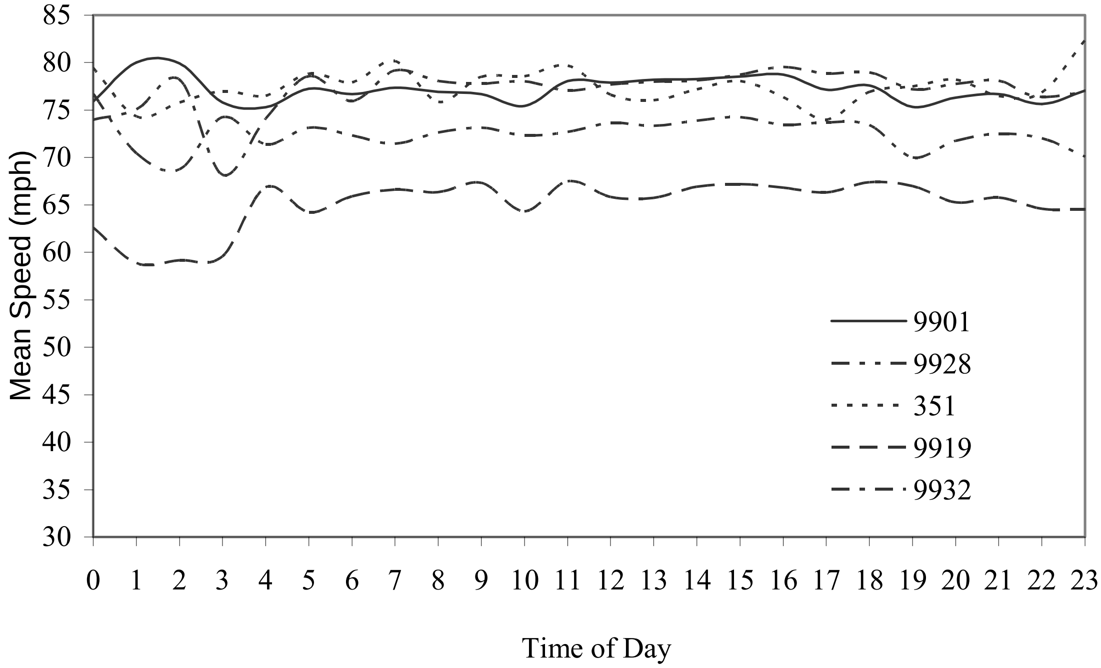
Middle lanes of six-lane section



Median lanes of six-lane sections



Shoulder lanes of four-lane sections



Median lanes of four-lane sections

APPENDIX G--INFERENTIAL STATISTIC RESULTS

G.1 Lane mean speed and lane-based mean speed on six-lane sections

Statistic	Lane mean Speed	Lane-based mean speed
Mean	73	73
Variance	1	1
Observations	6	6
Null hypothesis	0	
Degrees of freedom	10	
t statistic	1.39	
p-value	0.20	
t_{crit}	2.23	

G.2 Lane mean speed and lane-based mean speed on four-lane sections

Statistic	Lane mean Speed	Lane-based mean speed
Mean	73	71
Variance	15	12
Observations	10	10
Null hypothesis	0	
Degrees of freedom	18	
t statistic	0.98	
p-value	0.34	
t_{crit}	2.10	

G.3 Passenger car mean speed and truck mean speed on six-lane sections

Statistic	Passenger car mean speed	Truck mean speed
Mean	73.5	70
Variance	1.9	2
Observations	6	6
Null hypothesis	0	
Degrees of freedom	10	
t statistic	4.34	
p-value	0.0007	
t_{crit}	1.81	

G.4 Passenger car mean speed and truck mean speed on four-lane sections

Statistic	Passenger car mean speed	Truck mean speed
Mean	73	70
Variance	8	17
Observations	10	10
Null hypothesis	0	
Degrees of freedom	16	
t statistic	2.22	
p-value	0.02	
t_{crit}	1.75	

G.5 Trimmed mean speed and average mean speed on six-lane sections

Statistic	Trimmed mean speed	Average mean speed
Mean	73	73
Variance	15	18
Observations	18	18
Null hypothesis	0	
Degrees of freedom	34	
t statistic	0.08	
p-value	0.94	
t_{crit}	2.03	

G.6 Trimmed mean speed and average mean speed on four-lane sections

Statistic	Trimmed mean speed	Average mean speed
Mean	73	73
Variance	17	22
Observations	20	20
Null hypothesis	0	
Degrees of freedom	37	
t statistic	0.21	
p-value	0.83	
t_{crit}	2.03	

G.7 Lane-based mean speed and direction mean speed on six-lane sections

Statistics	Lane-based mean speed	Direction mean speed
Mean	72.5	73
Variance	1.1	1.067
Observations	6	6
Null hypothesis	0	
Degrees of freedom	5	
t statistic	-0.289	
p-value	0.789	
t_{crit}	2.570	

G.8 Lane-based mean speed and direction mean speed on four-lane sections

Statistic	Lane-based mean speed	Direction mean speed
Mean	71.8	73.4
Variance	11.51	14.93
Observations	10	10
Null hypothesis	0	
Degrees of freedom	9	
t statistic	-7.23	
p-value	<0.0001	
t_{crit}	2.262	

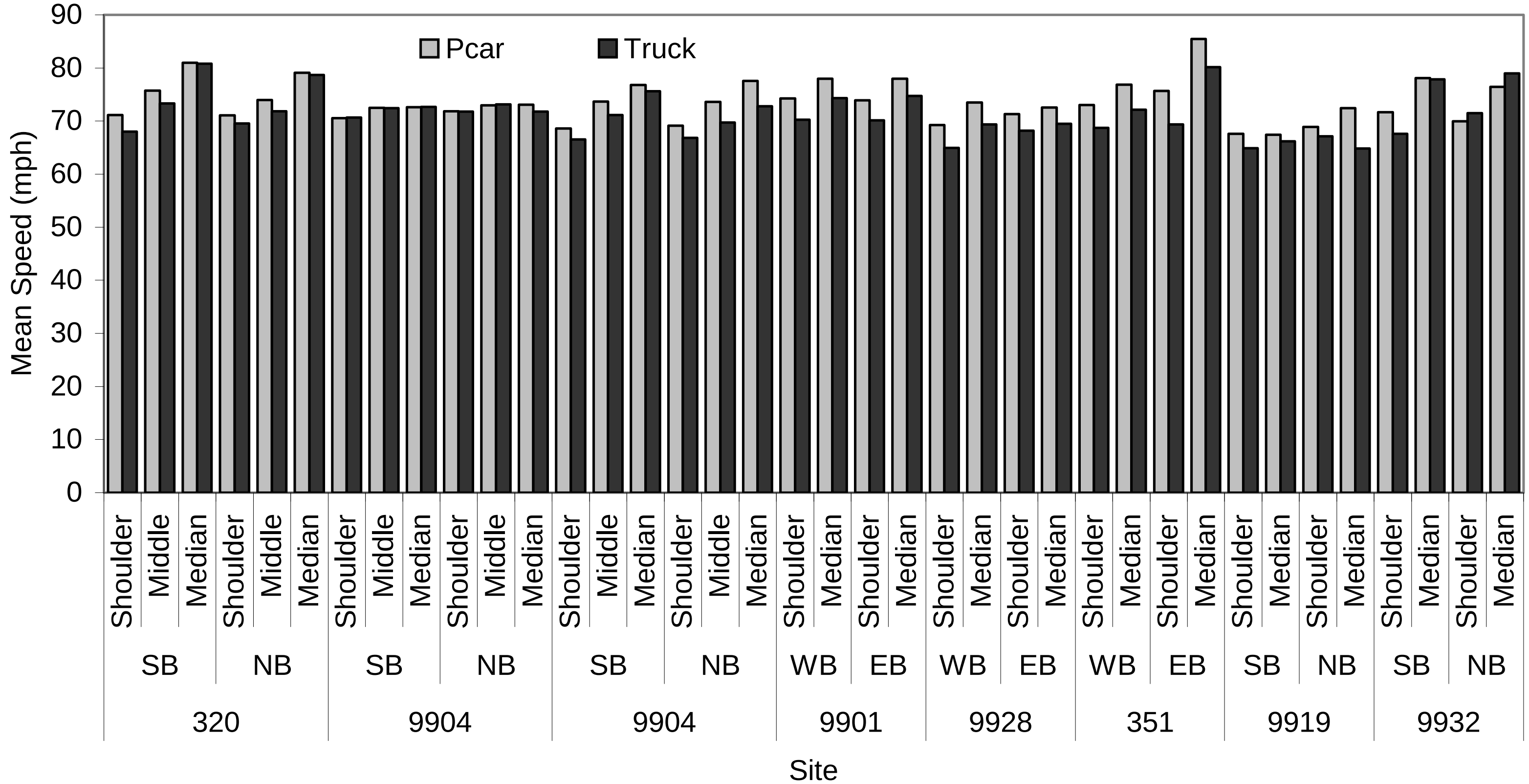
G.9 Vehicle type-based mean speed and direction mean speed on six-lane sections

Statistic	Vehicle type-based mean speed	Direction mean speed
Mean	73	73
Variance	0.67	1.06
Observations	6	6
Null hypothesis	0	
Degrees of freedom	5	
t statistic	-2	
p-value	0.10	
t_{crit}	2.57	

G.10 Vehicle type-based mean speed and direction mean speed on four-lane sections

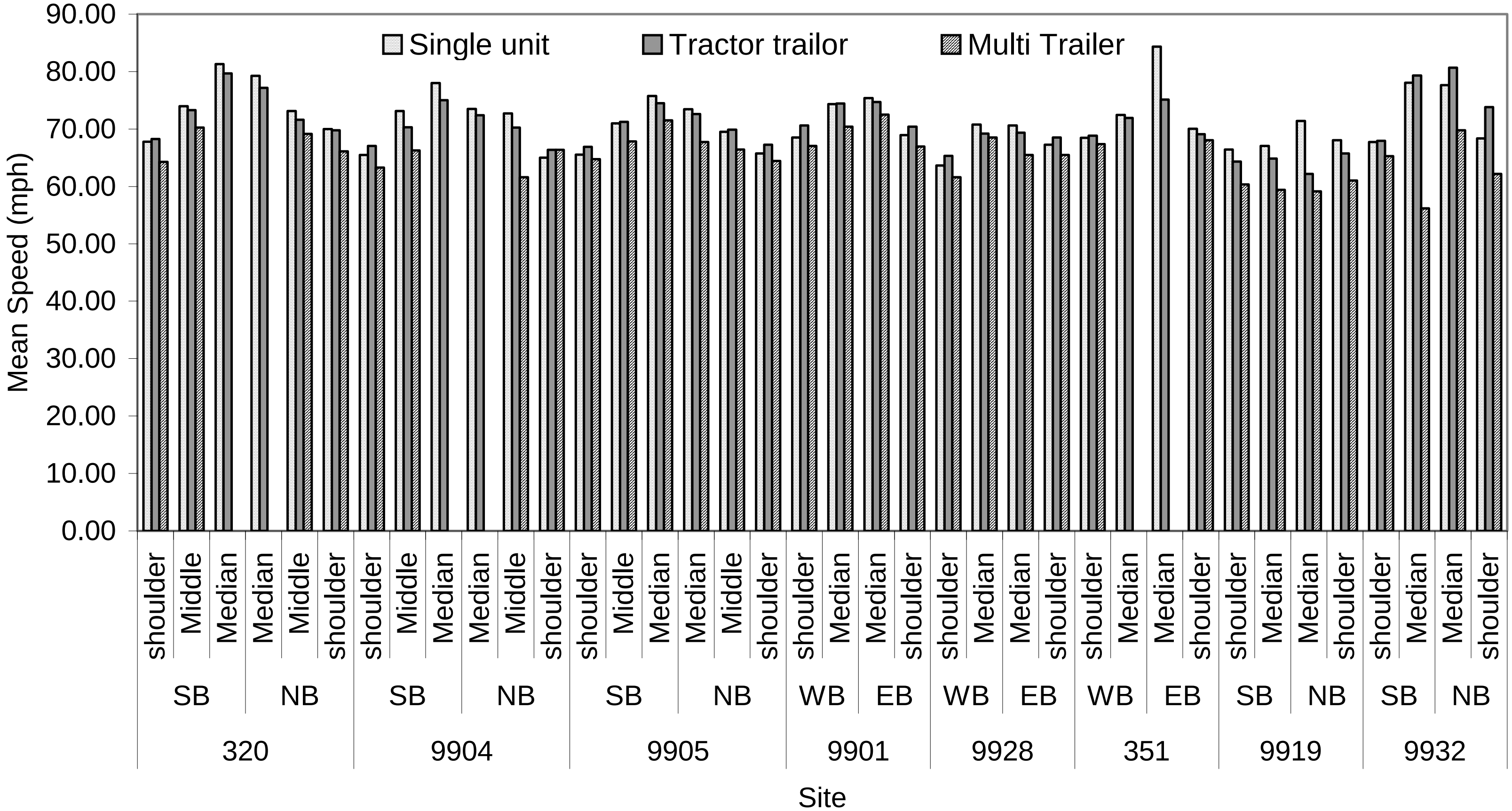
Statistic	Vehicle type-based mean speed	Direction mean speed
Mean	72.1	73.4
Variance	11.43	14.93
Observations	10	10
Null hypothesis	0	
Degrees of freedom	9	
t statistic	-4.33	
p-value	0.0019	
t_{crit}	2.26	

APPENDIX H--VEHICLE TYPE SPEED STATISTICS



SB, NB = Southbound and Northbound direction, respectively.EB, WB= Eastbound and Westbound direction, respectively

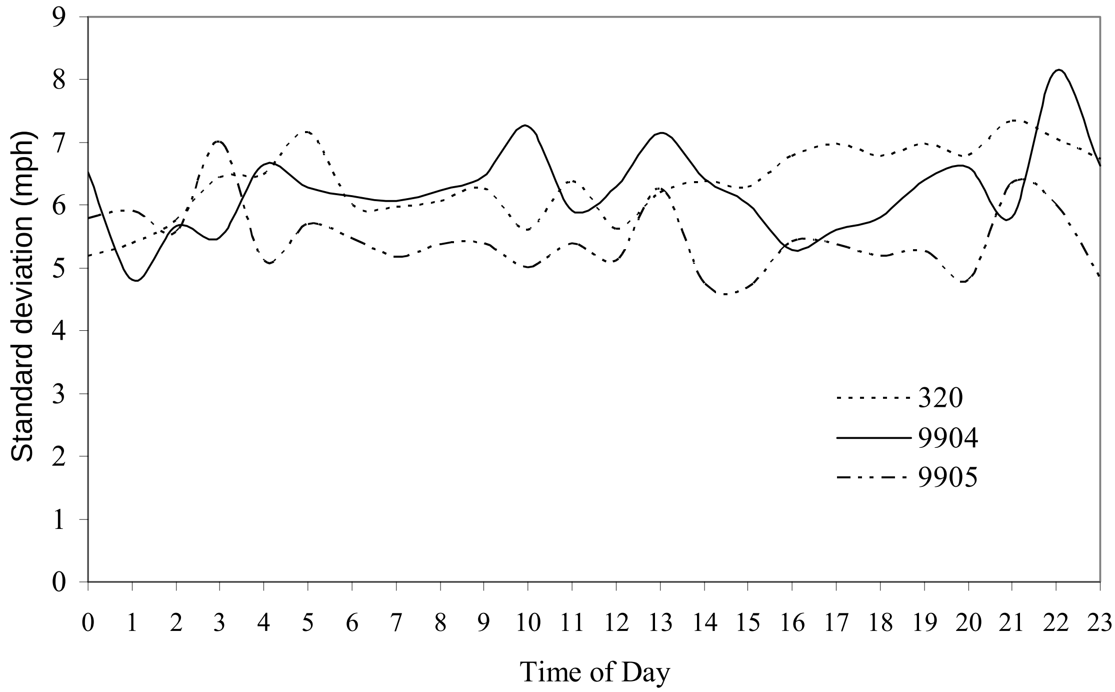
Figure H-1: Passenger cars and truck mean speeds



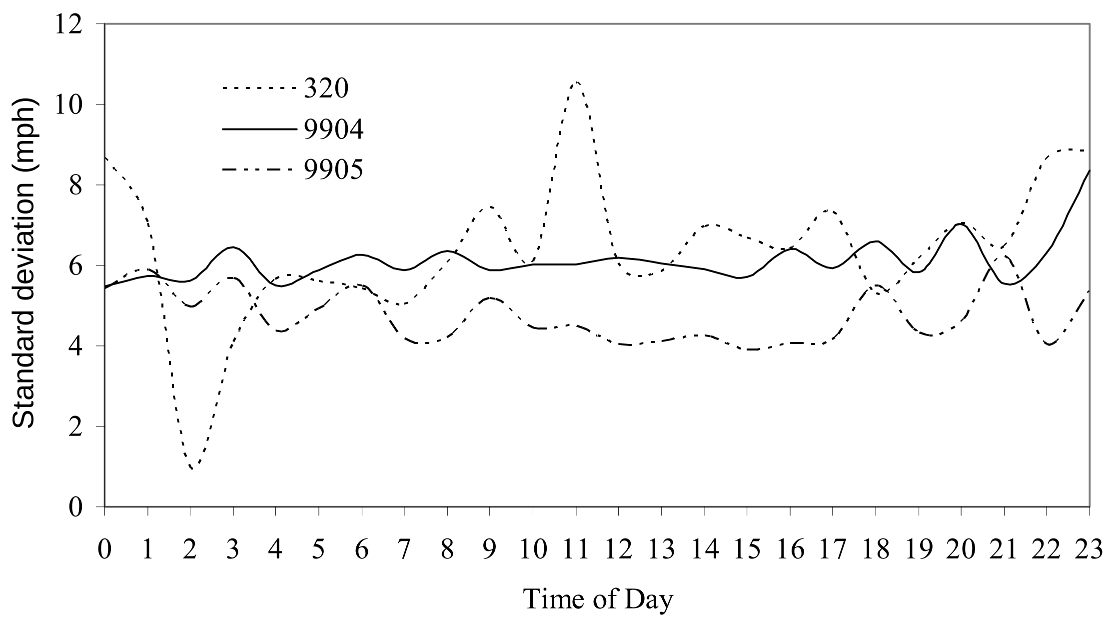
SB, NB = Southbound and Northbound direction, respectively.EB, WB= Eastbound and Westbound direction, respectively

Figure H-2: Truck mean speeds

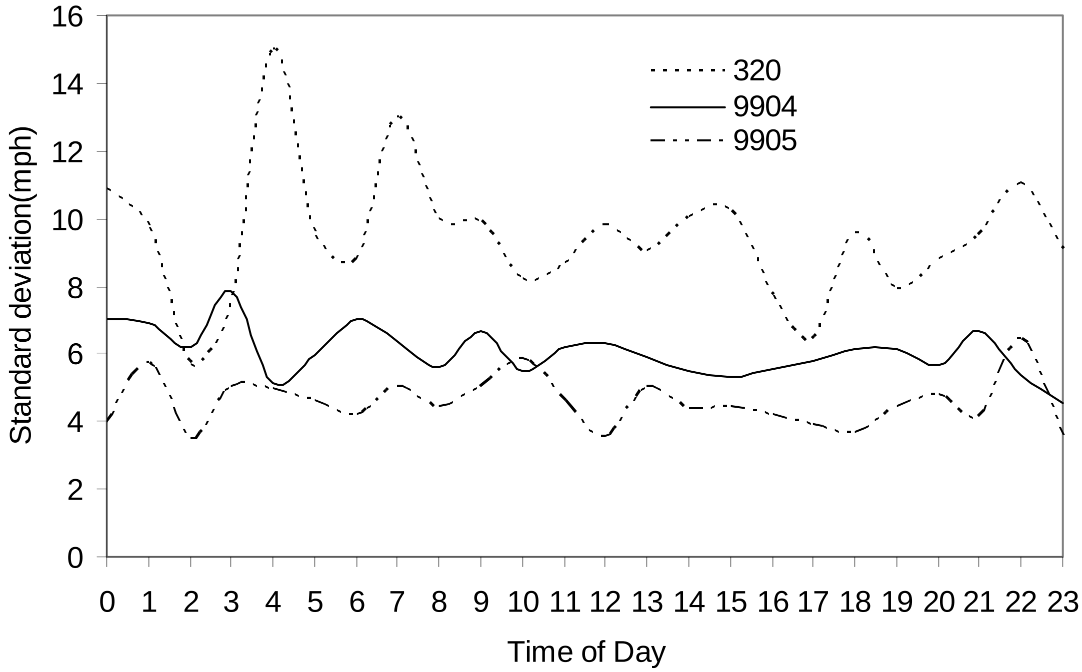
APPENDIX I--HOURLY VARIATIONS OF STANDARD DEVIATIONS



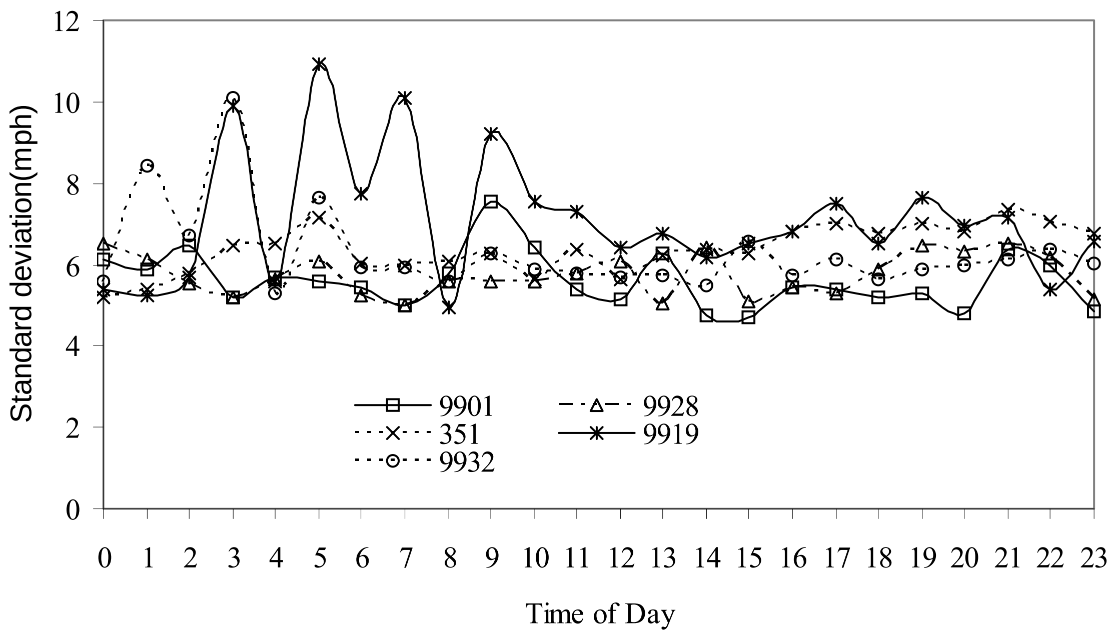
Speed variations on shoulder lanes of six-lane sections



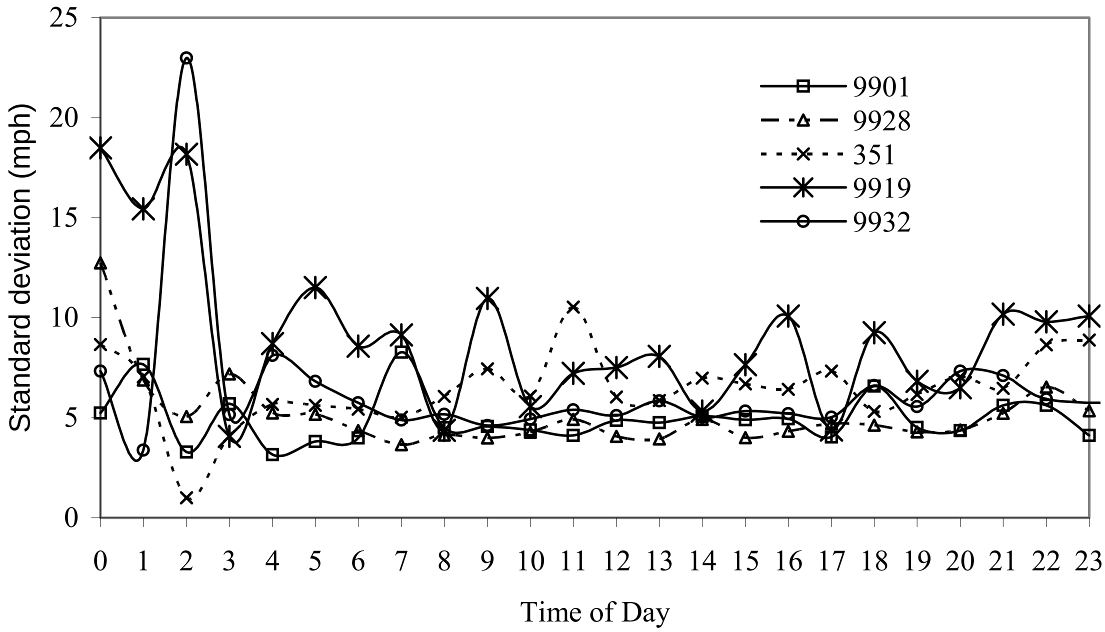
Standard deviations on middle lanes of six-lane sections



Standard deviations on median lanes of six-lane sections



Standard deviations on shoulder lanes of four-lane sections

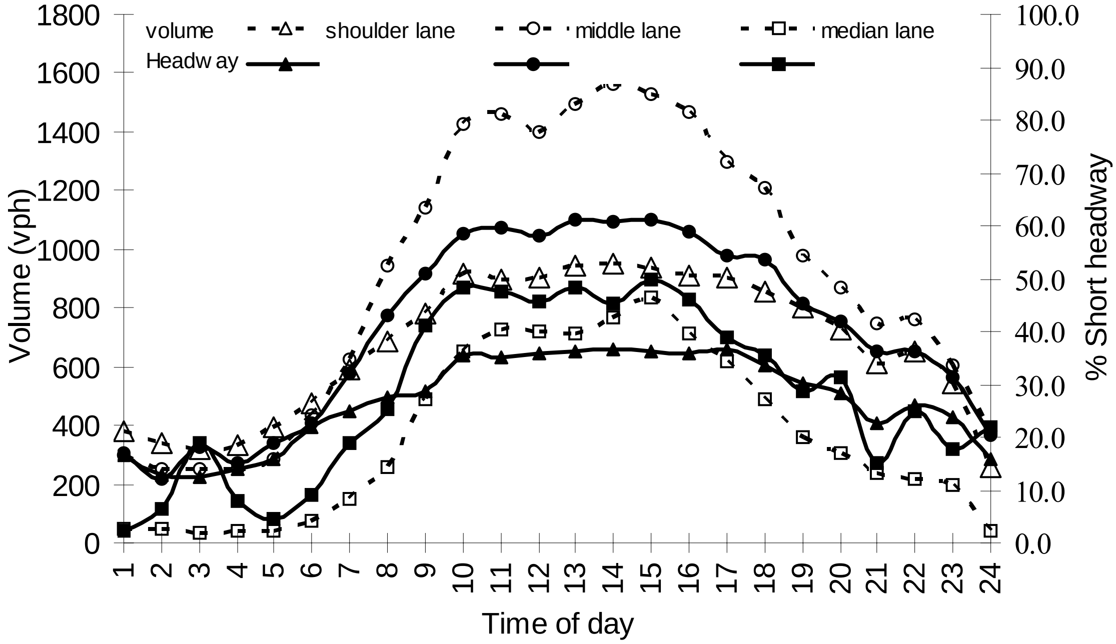


Standard deviations on median lanes of four-lane sections

APPENDIX J --SPEED VARIATIONS IN THE LOWER AND UPPER SIDES OF SPEED DISTRIBUTION

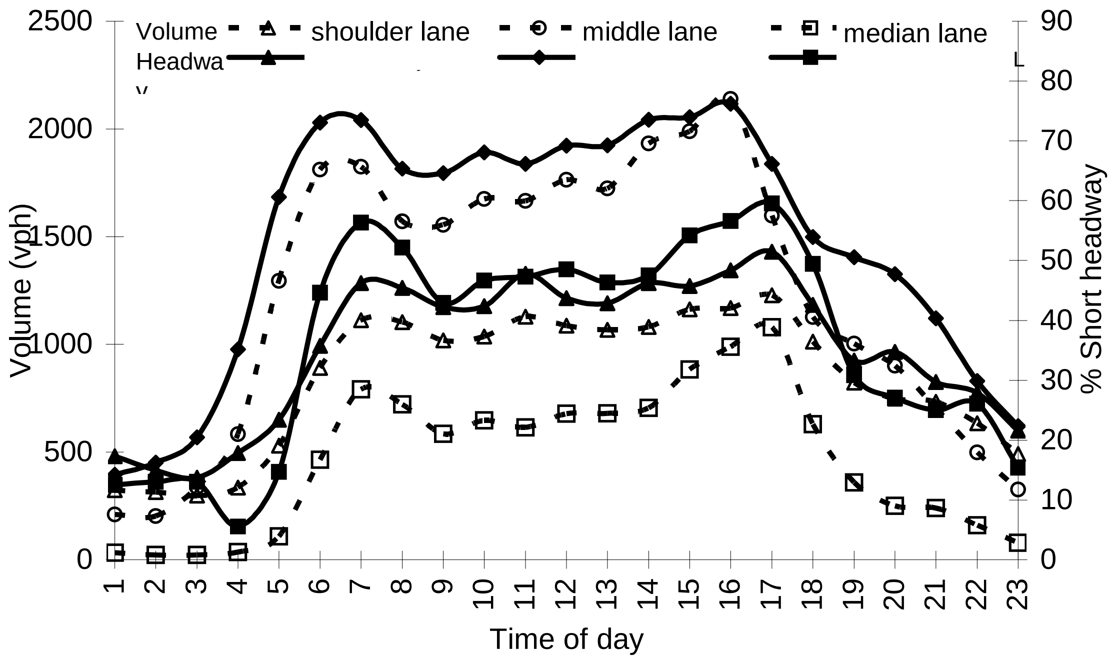
Site (Freeway)	Direction	Lane	85^{th} % speed minus median speed	Median speed minus 15^{th} % speed
320 (I-75)	Northbound	Shoulder	5.71	5.65
		Middle	4.63	4.81
		Median	4.56	5.05
	Southbound	Shoulder	6.09	5.09
		Middle	4.66	4.72
		Median	5.26	5.59
9904 (I-75)	Northbound	Shoulder	6.3	5.2
		Middle	5.85	4.94
		Median	4.75	4.94
	Southbound	Shoulder	6.11	5.72
		Middle	5.86	4.83
		Median	5.78	5.13
9905 (I-95)	Northbound	Shoulder	5.51	5.53
		Middle	5.15	5.14
		Median	5.84	5.48
	Southbound	Shoulder	5.14	5.2
		Middle	4.59	4.76
		Median	4.26	4.69
9901 (I-10)	Westbound	Shoulder	5.31	5.39
		Median	4.54	4.72
	Eastbound	Shoulder	5.73	5.45
		Median	4.56	4.78
9928 (I-10)	Westbound	Shoulder	6.04	5.64
		Median	5	5.39
	Eastbound	Shoulder	5.25	5.28
		Median	4.78	5.17
351 (I-75)	Westbound	Shoulder	6.58	6.23
		Median	6.05	6.79
	Eastbound	Shoulder	7.34	7.65
		Median	8.78	9.77
9919 (I-95)	Northbound	Shoulder	6.29	4.9
		Median	5.94	4.52
	Southbound	Shoulder	5.7	4.14
		Median	5.36	2.72
9932 (TNPK)	Northbound	Shoulder	5.95	6.09
		Median	5.27	5.39
	Southbound	Shoulder	5.98	6.1
		Median	5.63	6.46

APPENDIX K --VARIATIONS OF VOLUMES AND SHORT HEADWAYS WITH TIME OF DAY



Site 320

Site 9904



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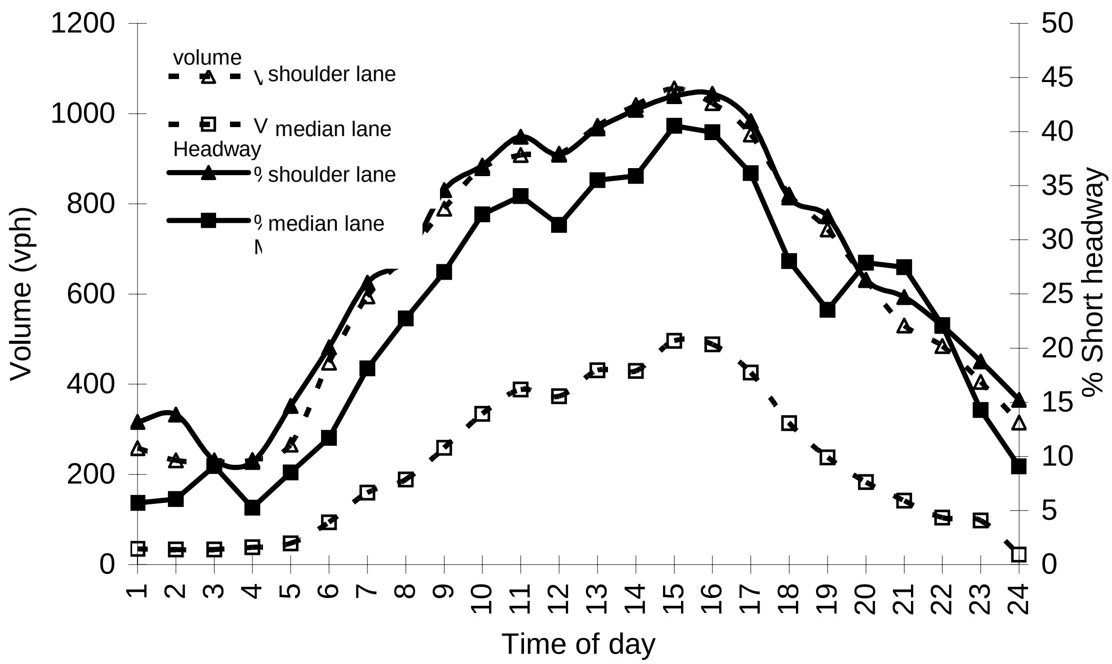

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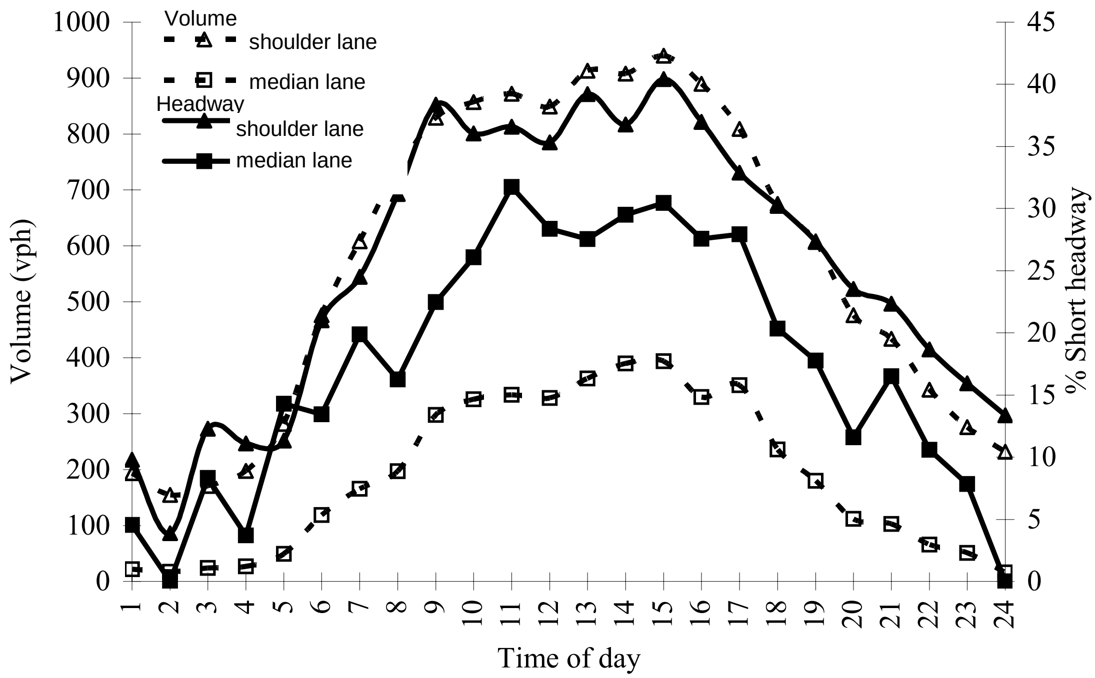

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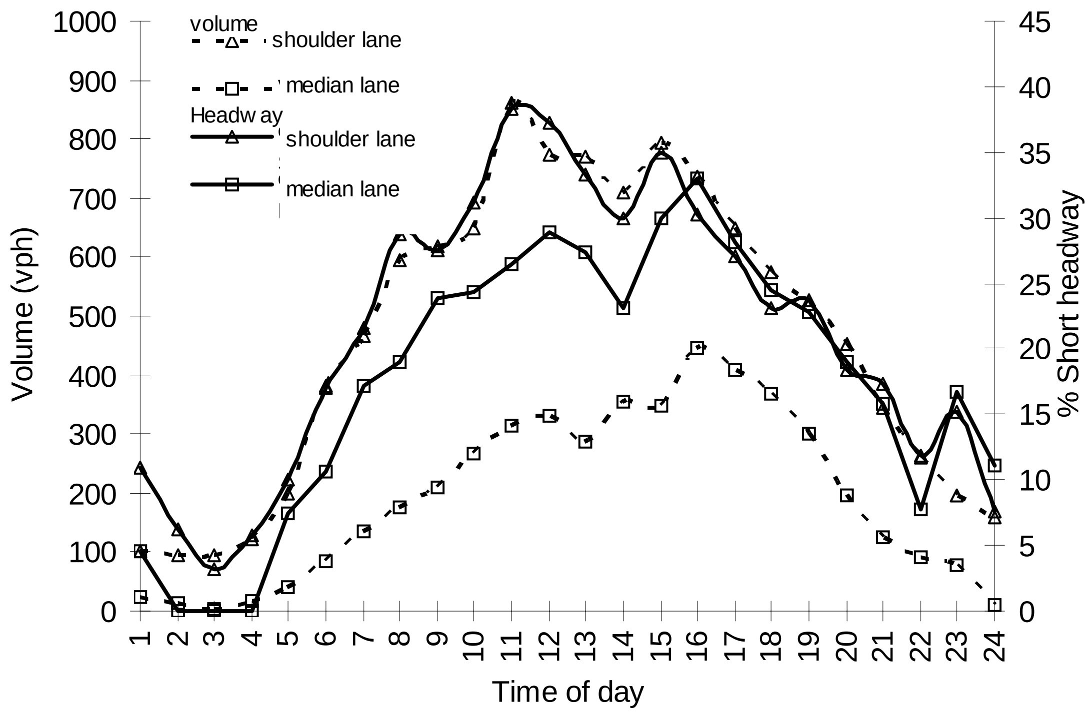

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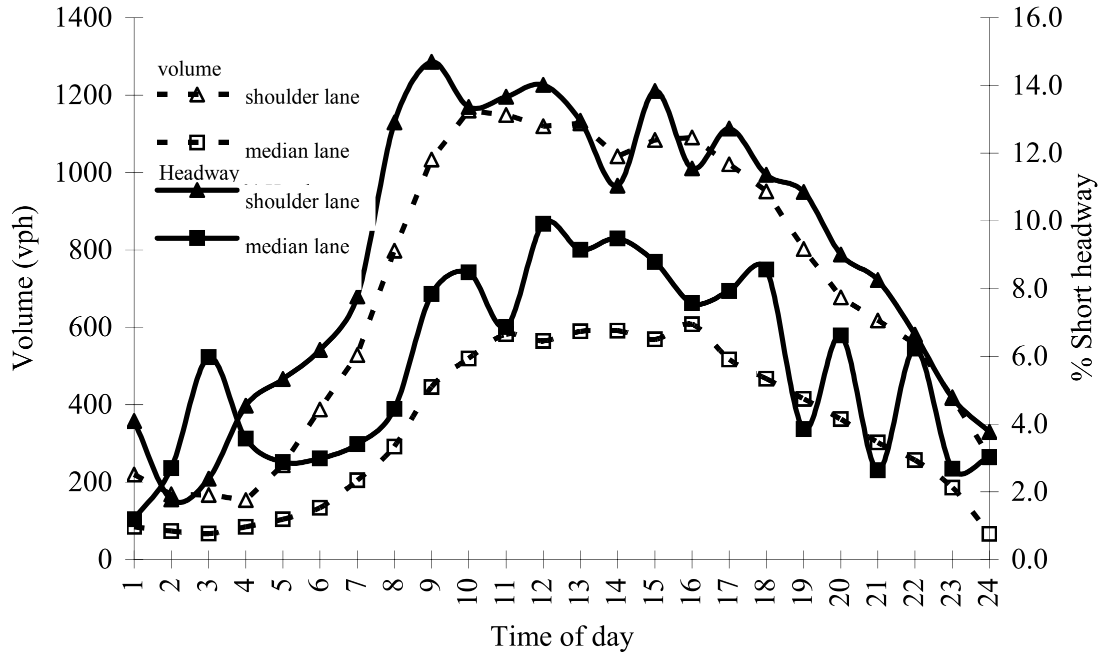
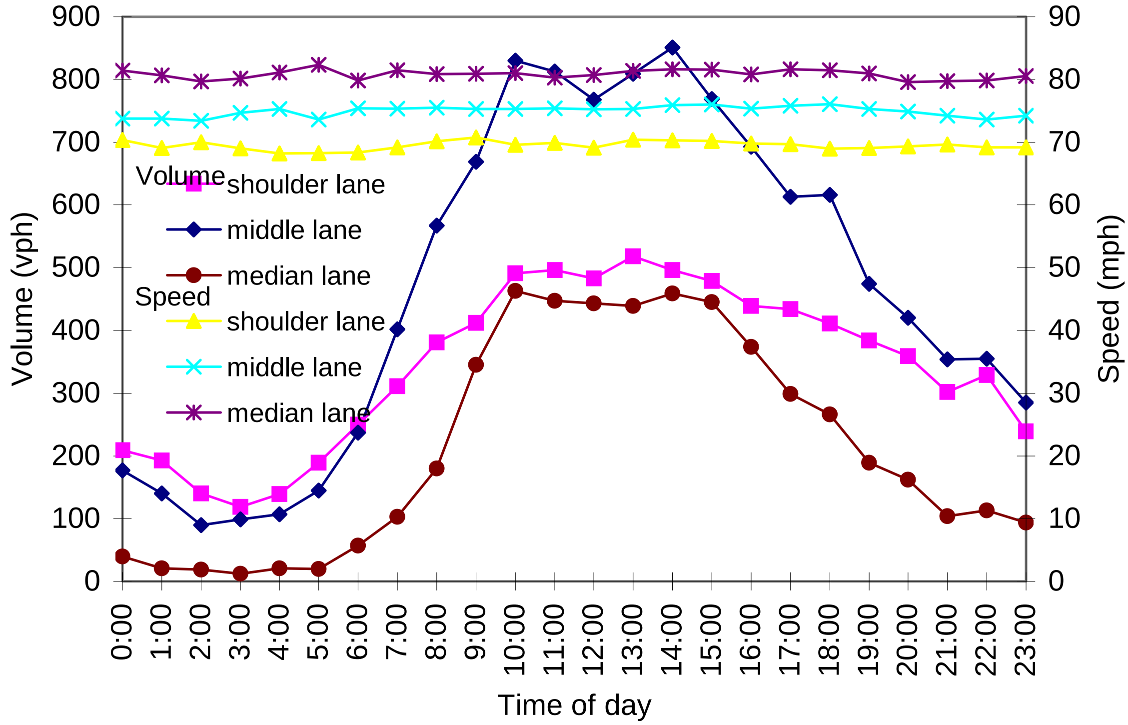


1400
1200
1000
800
600
400
200
0
Volume (vph)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
% Short headway
volume
shoulder lane
median lane
Headway
shoulder lane
median lane
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of day

Site 9932

APPENDIX L--HOURLY VARIATIONS OF SPEED AND VOLUME



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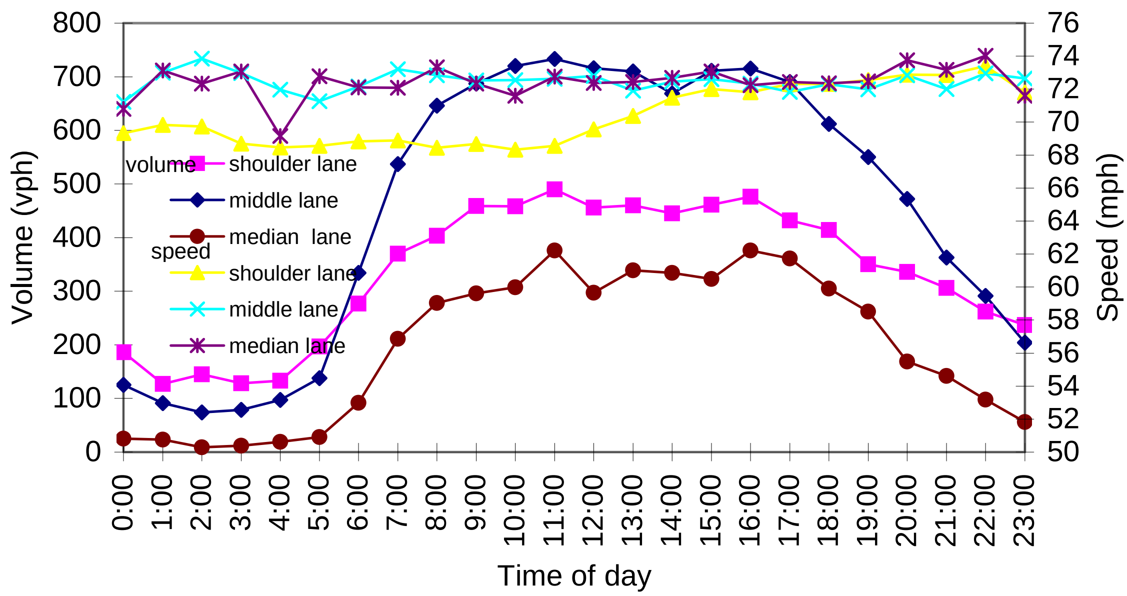

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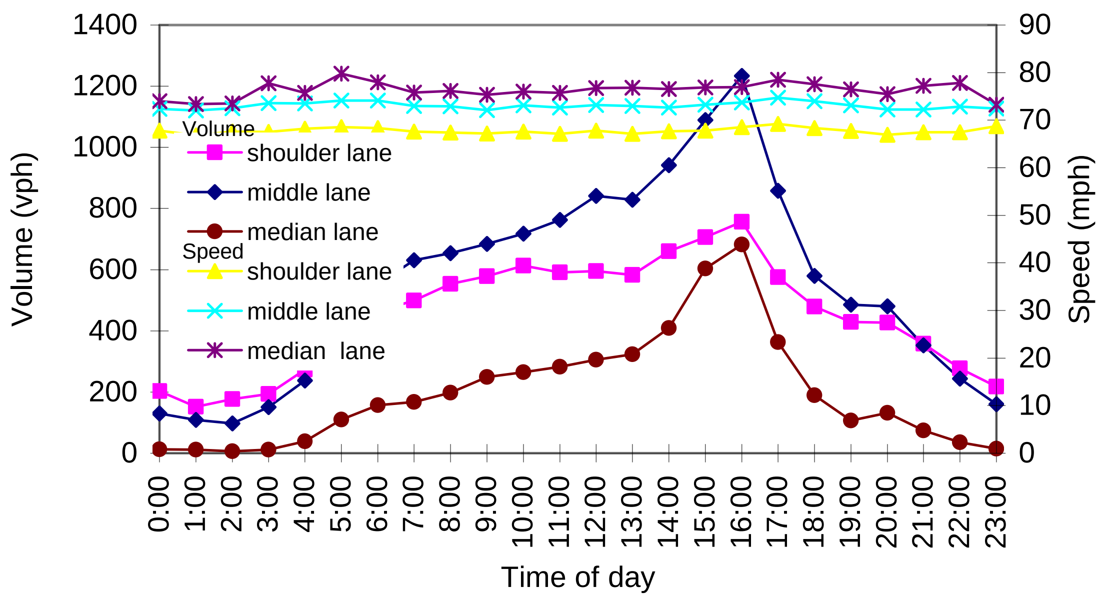

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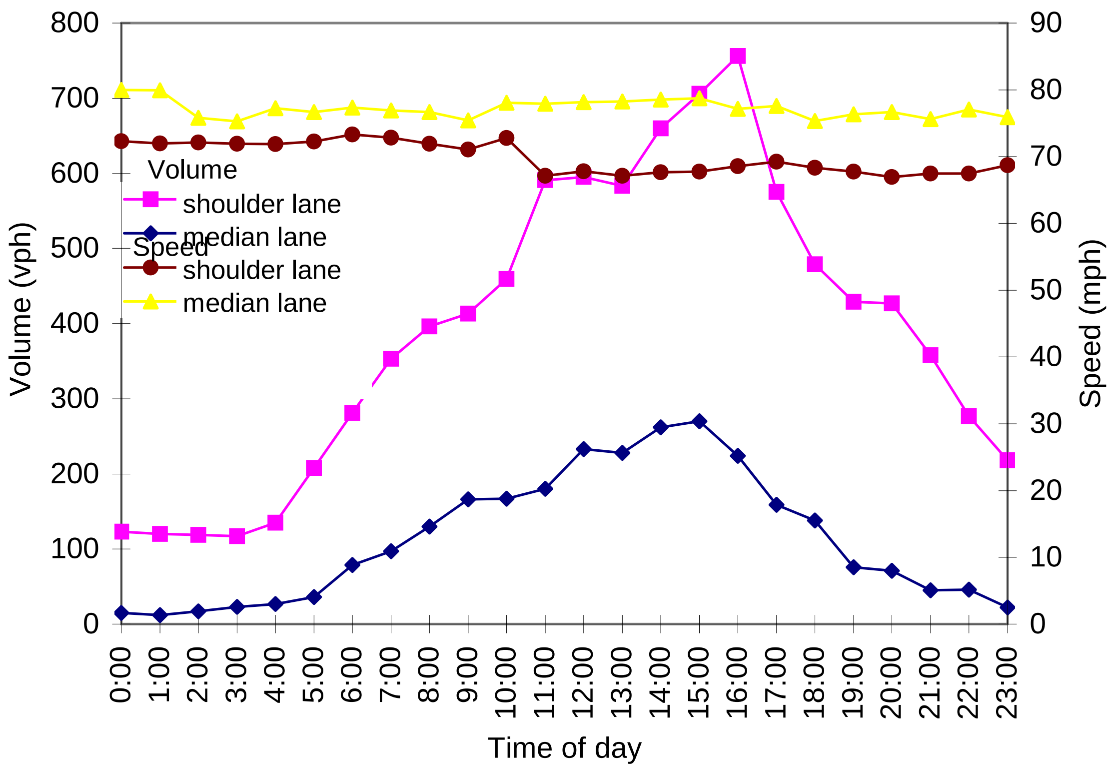

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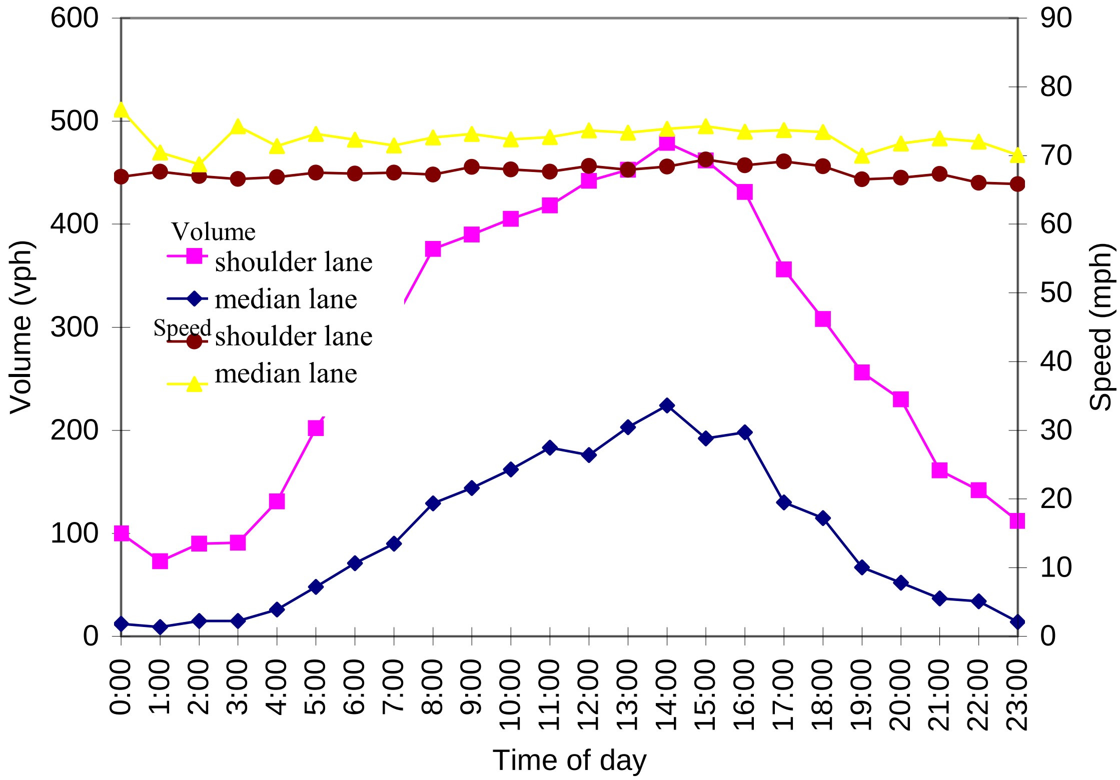
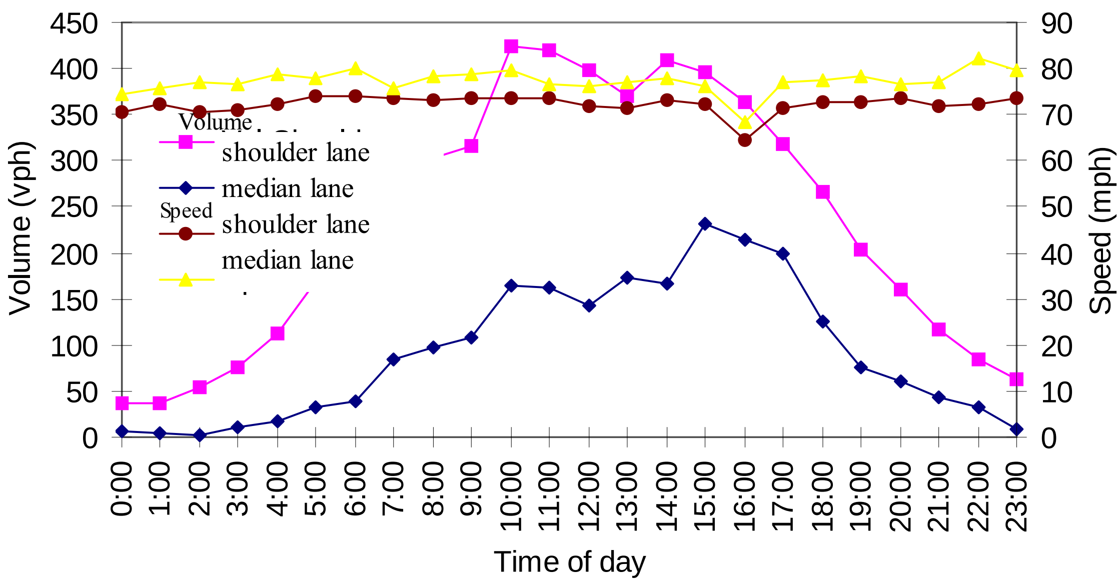


Site 9928



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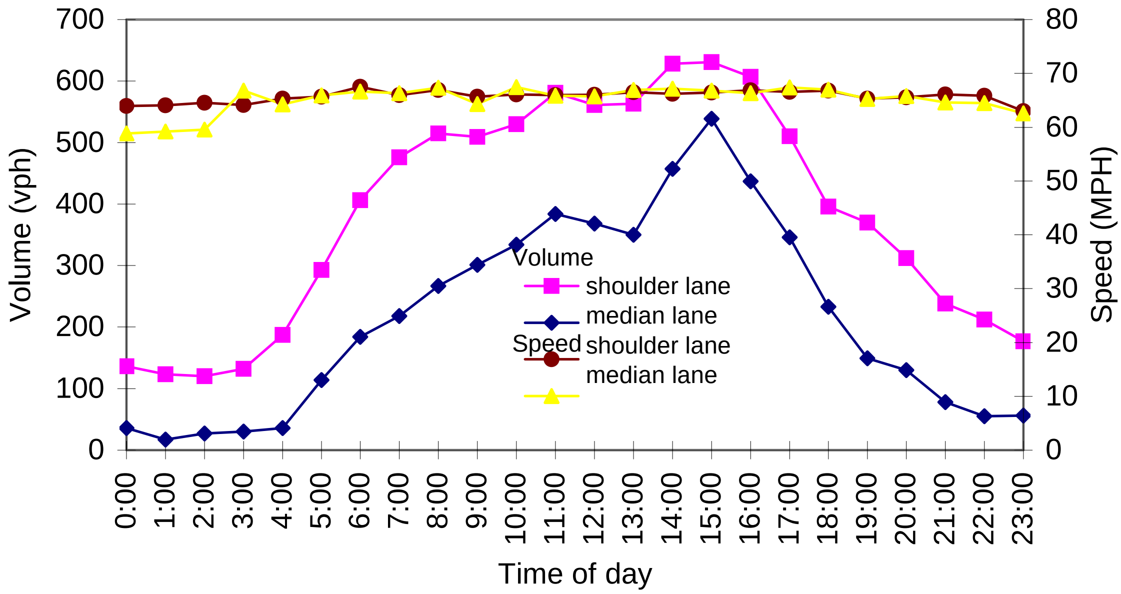

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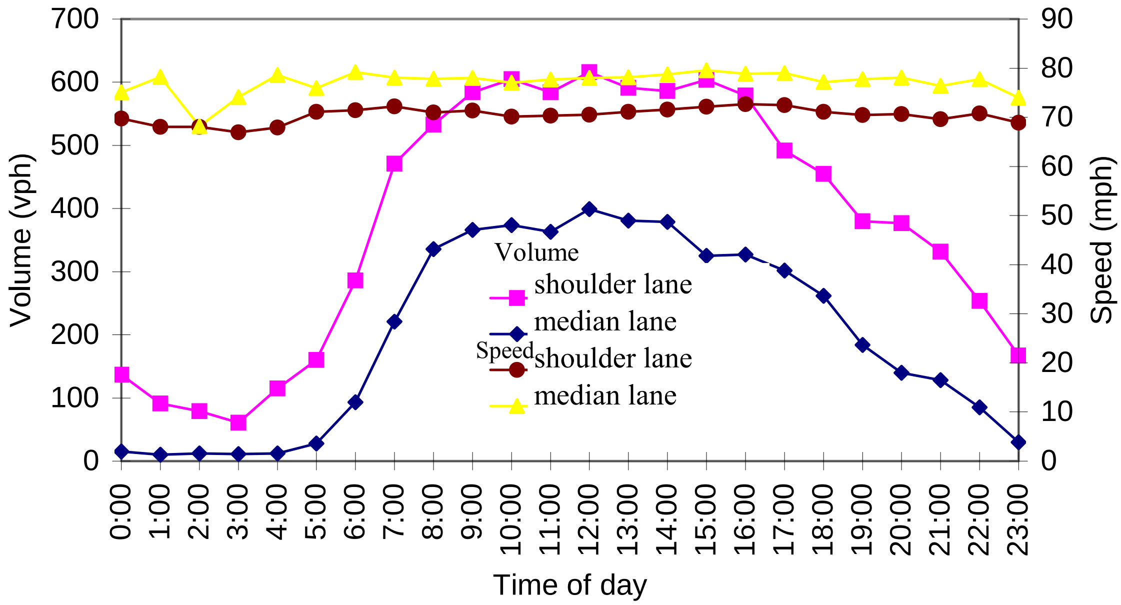
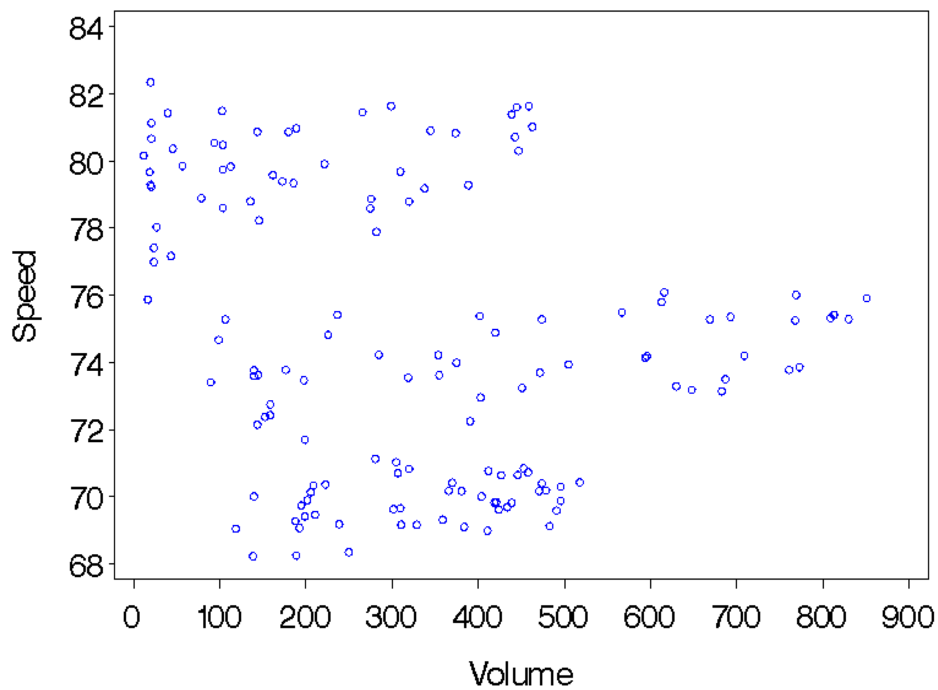


Site 9932

APPENDIX M--SCATTER PLOTS OF SPEED AGAINST VOLUME



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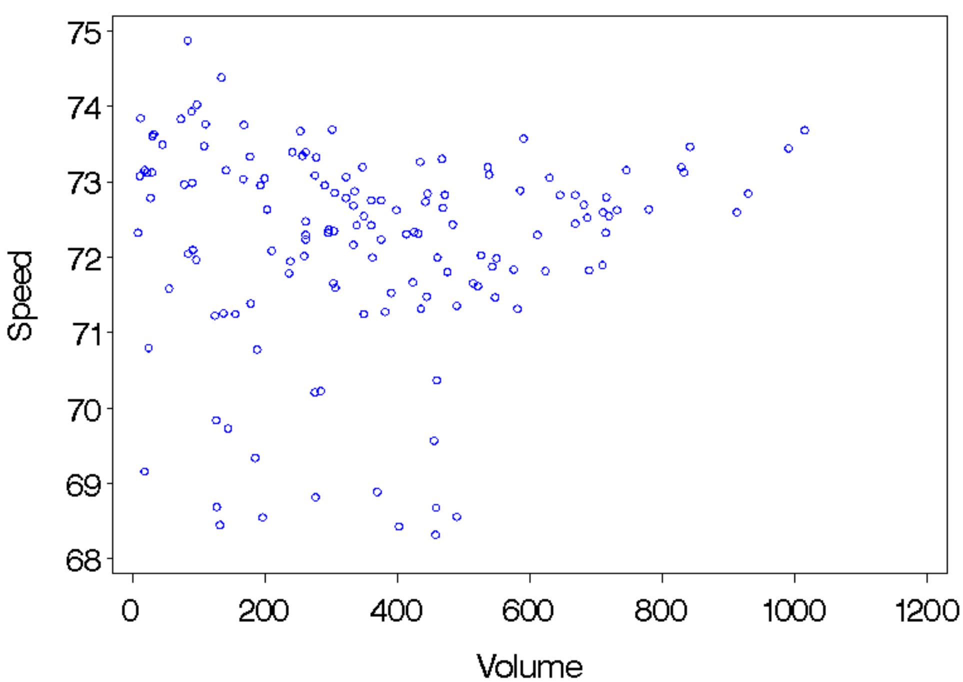

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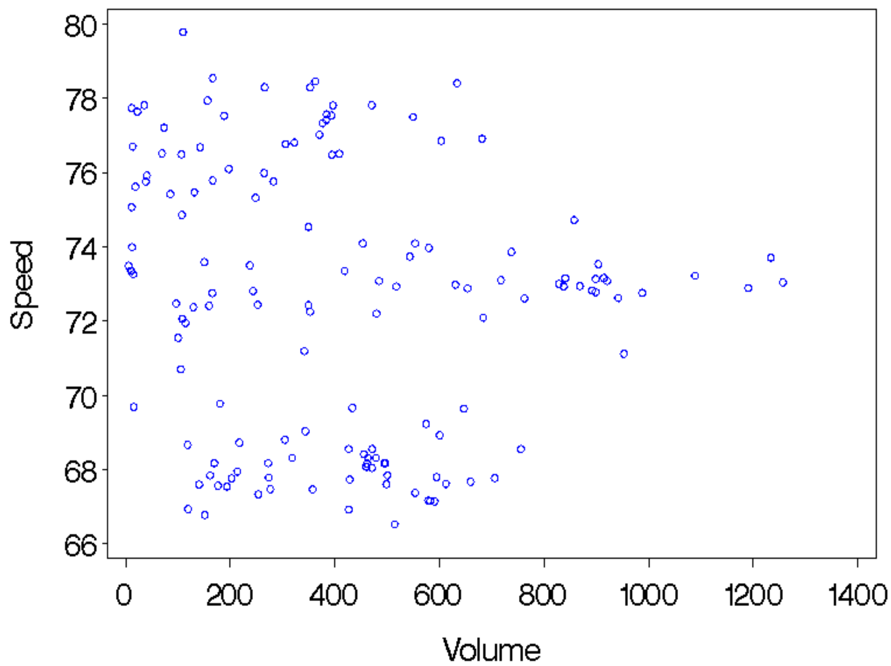

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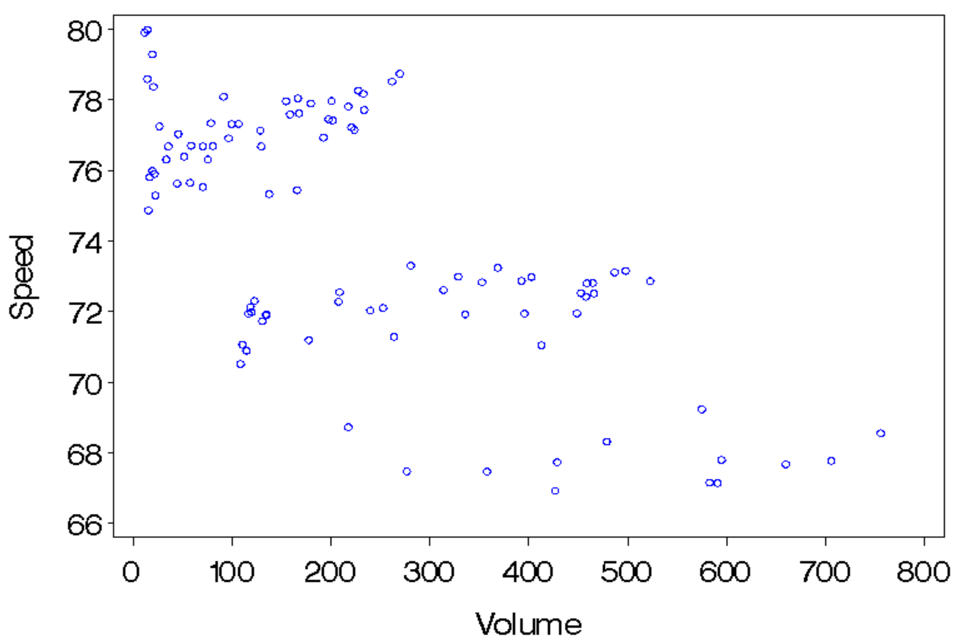

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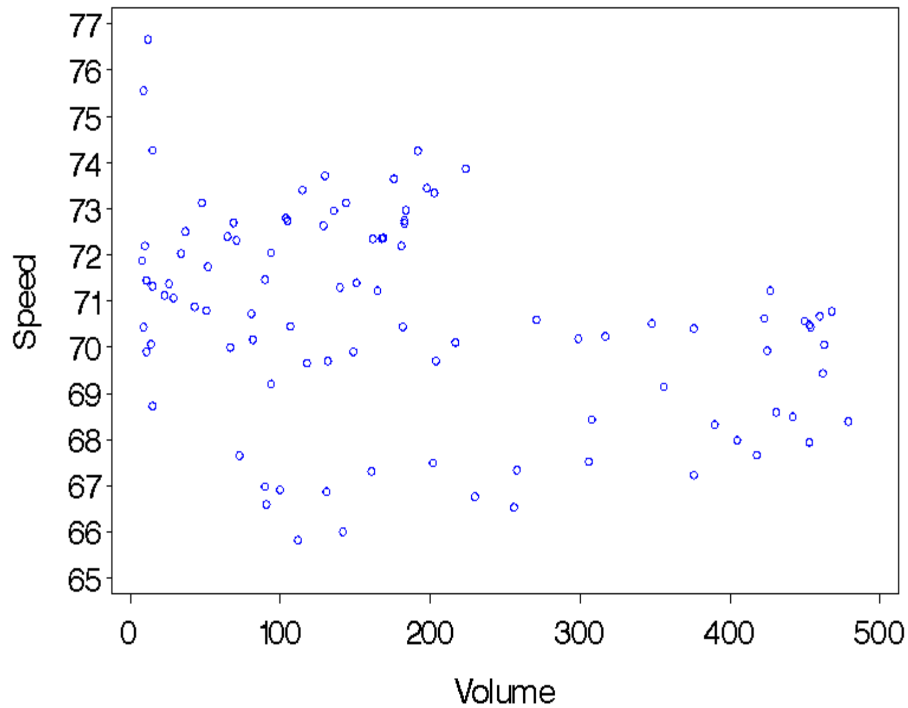

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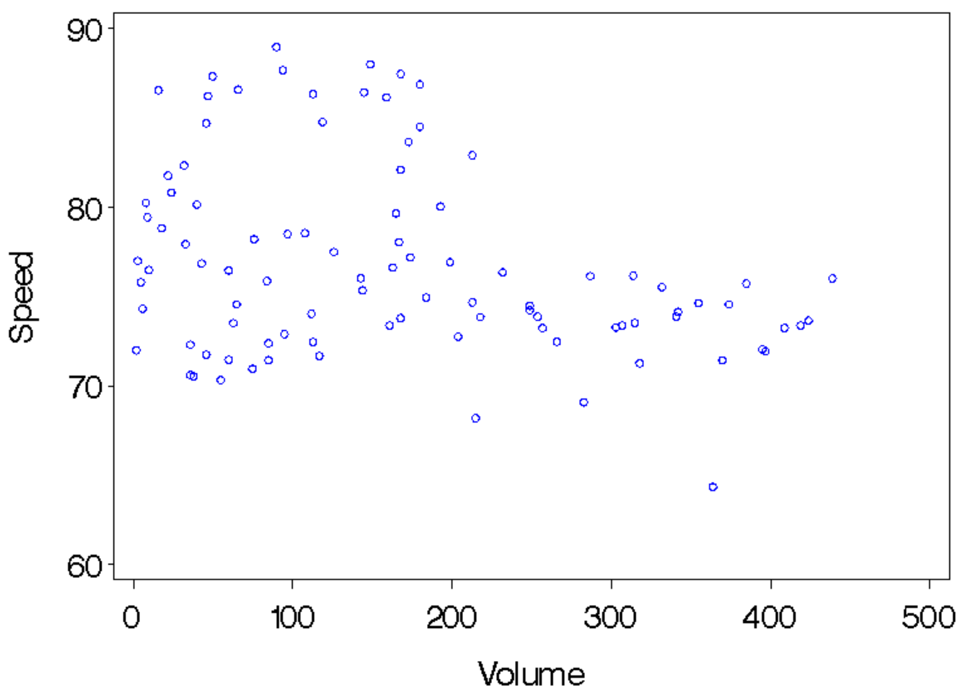

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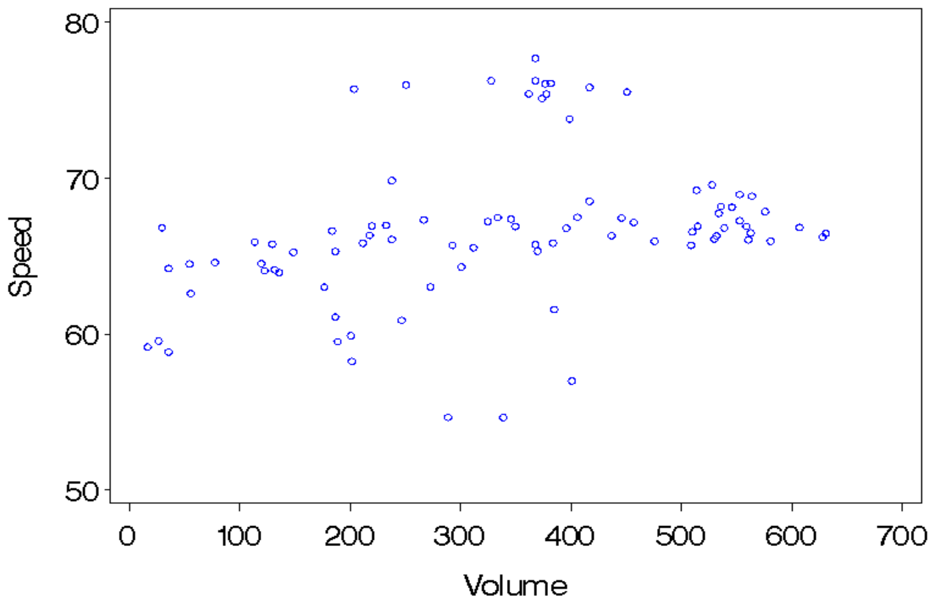

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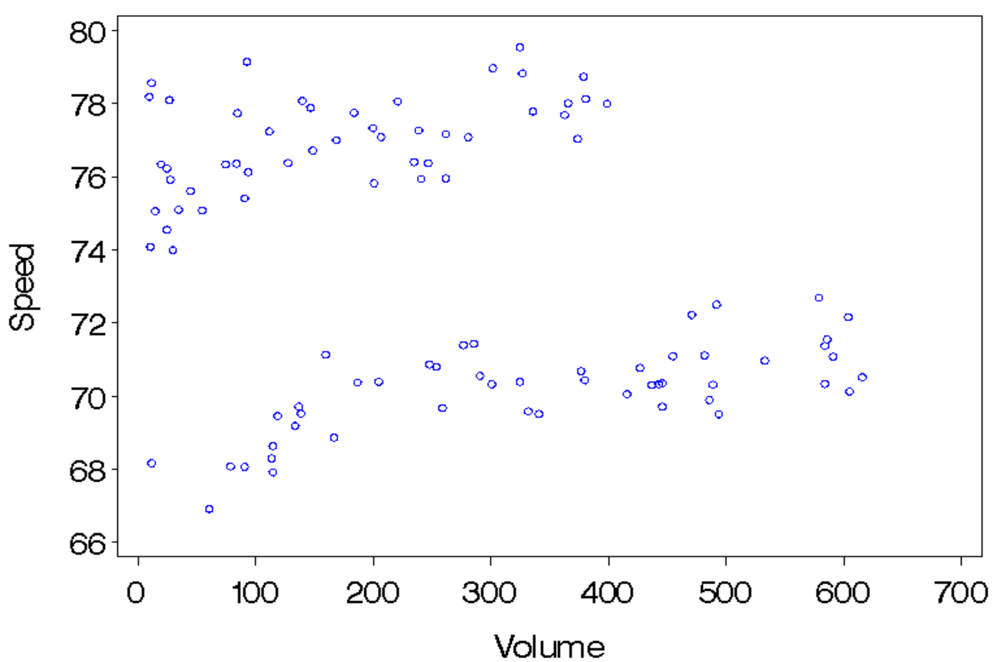
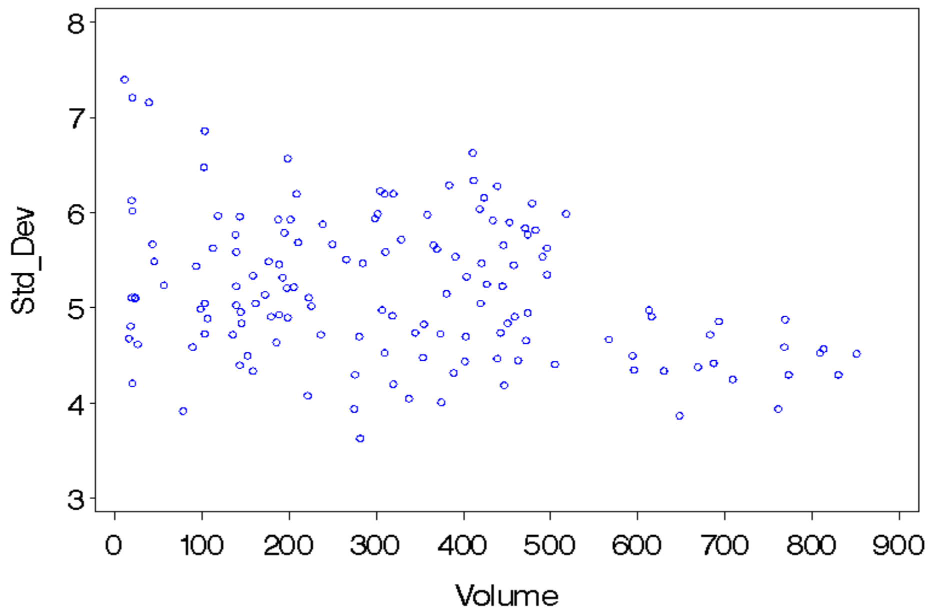


Site 9932

APPENDIX N--SCATTER PLOTS OF VOLUMES AND STANDARD DEVIATIONS



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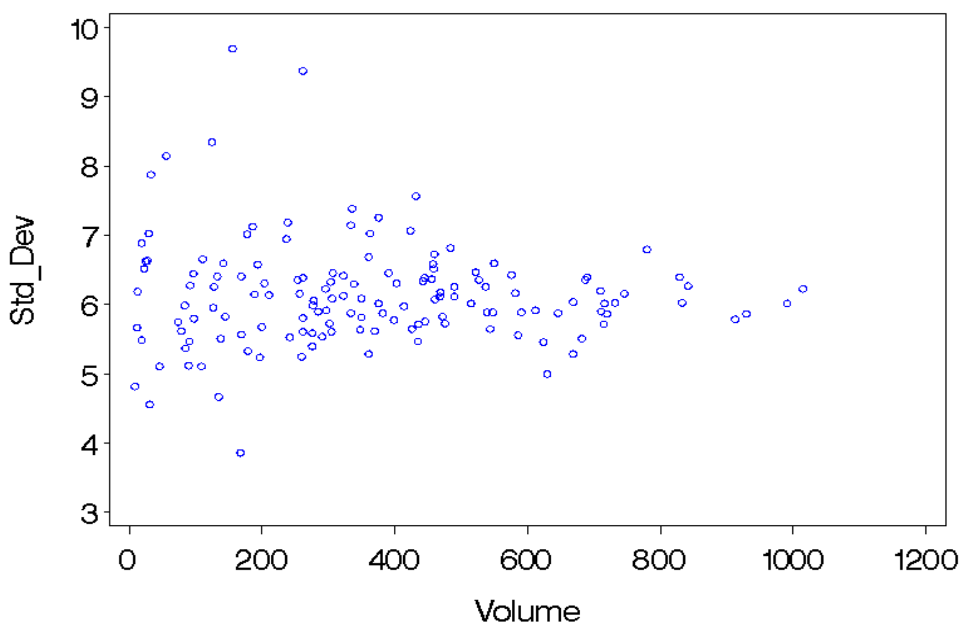

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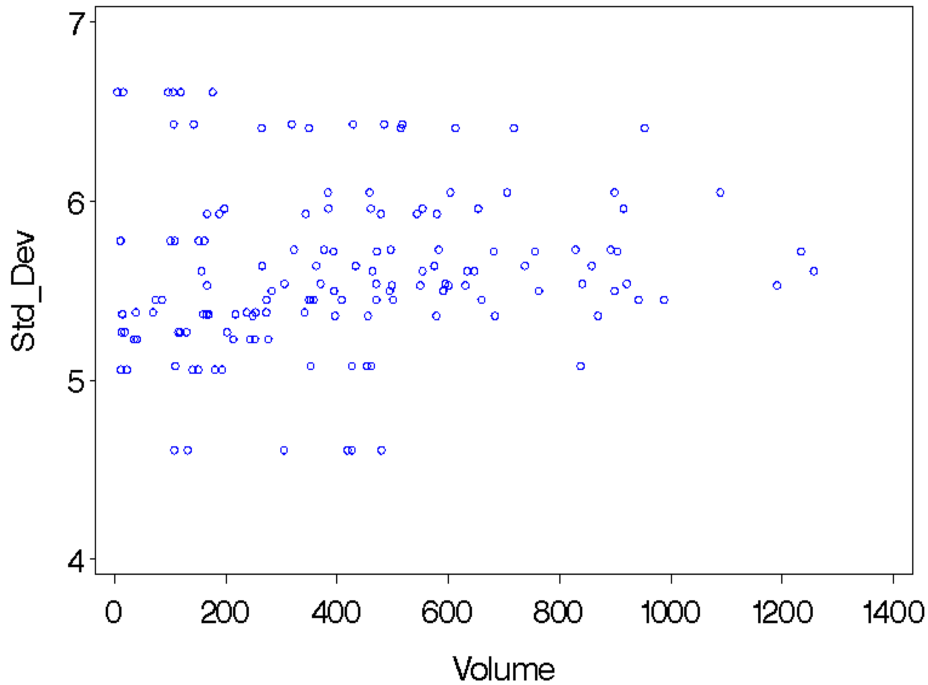

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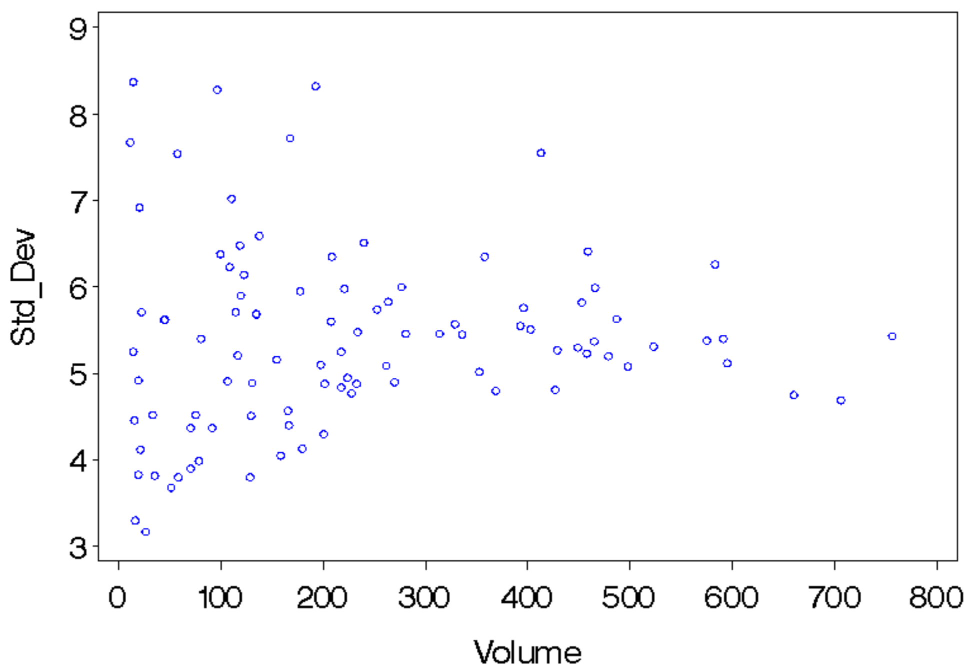

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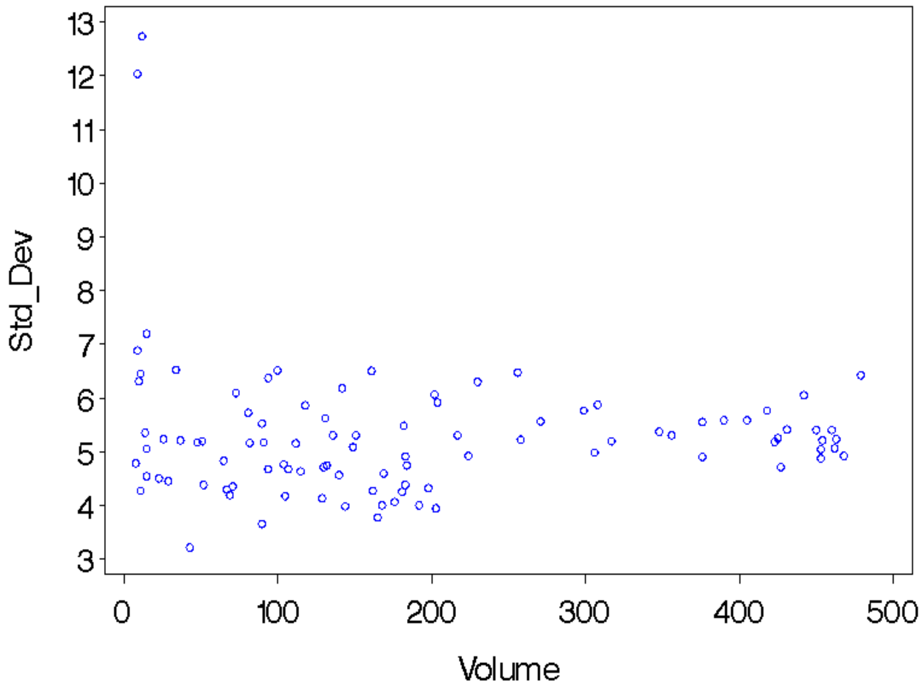

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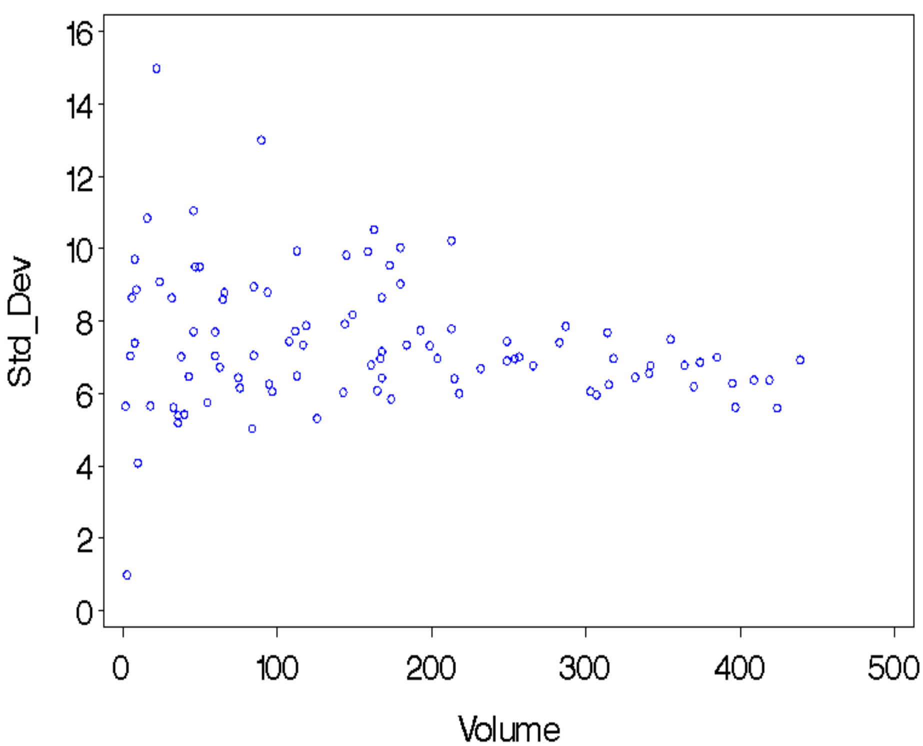

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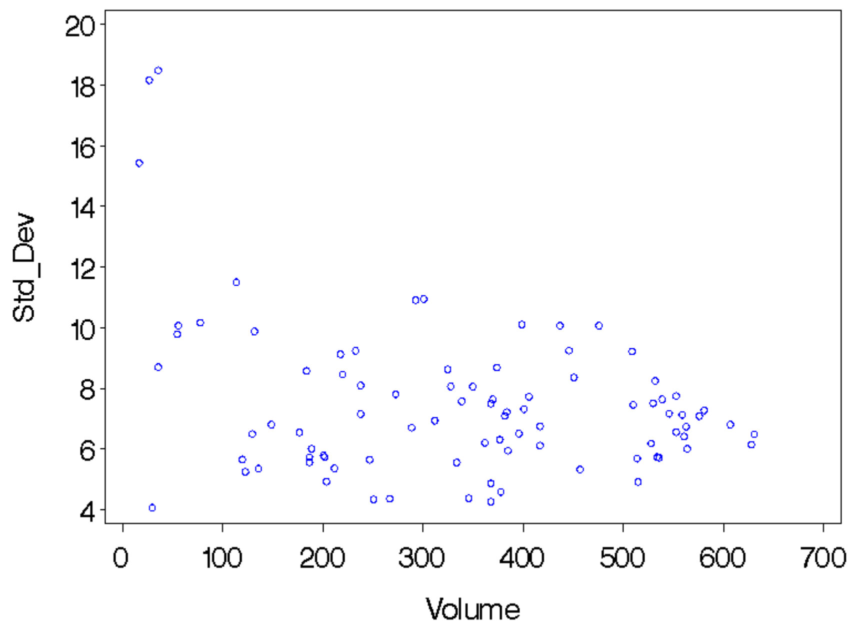

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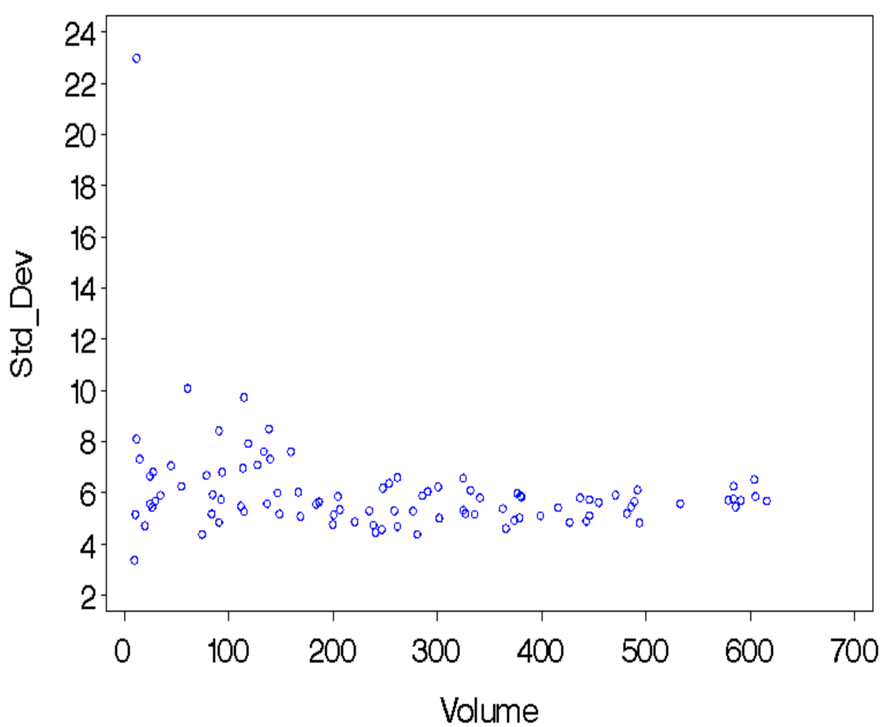

Site 9932