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Understanding Operating Speed Variation of Multilane Highways with New Access Density Definition and Simulation Outputs

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by

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of the requirements for the degree of
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Dedication

I dedicate this dissertation to my dear parents, Weihua Huang and Fang Zheng.

Acknowledgments

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Abstract

Traffic speed is generally considered a core issue in roadway safety. Previous studies show that faster travel is not necessarily associated with an increased risk of being involved in a crash. When vehicles travel at the same speed in the same direction (even high speeds, as on interstates), they are not passing one another and cannot collide as long as they maintain the same speed. Conversely, the frequency of crashes increases when vehicles are traveling at different rates of speed. There is no doubt that the greater speed variation is, the greater the number of interactions among vehicles is, resulting in higher crash potential. This research tries to identify all major factors that are associated with speed variation on multilane highways, including roadway access density, which is considered to be the most obvious contributing factor. In addition, other factors are considered for this purpose, such as configuration of speed limits, characteristics of traffic volume, geometrics of roadways, driver behavior, environmental factors, etc. A microscopic traffic simulation method based on TSIS (Traffic Software Integrated System) is used to develop mathematical models to quantify the impacts of all possible factors on speed variation.

Chapter 1 Introduction

1.1 Background

With the rapid development of roadway traffic and the auto industry, roadway safety has become a global issue. Traffic speed is generally considered a core issue in roadway safety. However, previous studies have shown that faster travel is not necessarily associated with an increased risk of being involved in a crash. When vehicles travel at the same speed in the same direction (even high speeds, as on interstates), they are not passing one another and cannot collide as long as they maintain the same speed. Conversely, when vehicles are traveling at different speeds, crash frequency increases (especially crashes involving more than one vehicle). Speed dispersion can be described as speed variation (or speed deviation). The greater the speed variation is, the greater the number of interactions among vehicles is. Thus, speed variation, not necessarily high speed, is associated with an increase in the frequency of crashes. Some factors, such as configurations of speed limits, characteristics of traffic volume, geometrics of roadways, driver behavior, and environmental factors, may influence speed variation and further affect roadway safety performance. To understand the impacts of contributing factors on speed variation and the relationship between speed variation and safety performance, it is important to develop proper speed control countermeasures for reducing accident risk and improving roadway safety performance. Access density is a widely-used concept that calculates the number of access points within a given distance and has been extensively applied a widely-used concept that calculates the number of access points within a given distance and to studies related to crash modeling, operational impact, and planning. Access density has impacts on transportation safety and transportation operation. Many past studies mention two kinds of relationship: speed variation and crash, and access density and crash.

This research tries to identify possible factors that could influence speed variation on multilane roadways, especially for access design factors. Statistical models are established to summarize relationships between speed variation and these factors. Data collection was performed for modeling, including speed data, geometry data, traffic data, control data, etc. Radar guns were used to collect speed data, and other necessary data came from the Florida Inventory Database. Besides the models basing on the analysis of field data, another method also included using traffic simulation, such as TSIS. The micro-simulation analysis can be further analyzed to obtain the models that specify the impacts of access management treatments and geometric design on traffic operational speed distributions, which could be used to support the findings from the field data analysis.

1.2 Problem Statement

Only a few of studies have focused on the safety impacts of the speed variation or other speed dispersions. Currently, only limited knowledge concerning safety impacts of the speed variation/dispersion, especially on multi-lane highways (arterials and collectors), is available. More particularly, the limitations are as follows:

(1) Past studies focused on the impacts of design speed, which can be used as a surrogate for geometrics design. However, the impacts of access design, such as

the type and density of median openings, access points, and other access control components, on speed variation and roadway safety were not considered.

(2) Safety performance evaluated the impacts of speed variation by focusing on accident rates and/or accident frequency. Other criteria of safety performance, such as accident severity, accident type, and/or traffic conflict, were not considered.

(3) Speed difference (dispersion) can be described as speed variation, speed difference between traffic composition, and speed difference over lanes. Past studies focused on speed variation rather than other criteria.

Because of these limitations, new research is proposed to identify the access design factors that influence speed variation (or other speed dispersions) and evaluate the impacts of contributing factors on safety performance on multilane roadways. This research tries to identify possible factors that could influence speed variation on multilane roadways, especially related to access design factors. Statistical models are established to summarize relationships between speed variation and these factors. Data collection is performed for modeling, including speed data, geometry data, traffic data, control data and etc. Radar guns were used to collect speed data, and other necessary data were obtained from the Florida Inventory Database. Besides the models based on analysis of field data, traffic simulation modeling (TSIS) was used. The micro-simulation analysis can be further analyzed to obtain models that specify the impacts of access management treatments and geometric design on traffic operational speed distributions, which could be used to support the findings from field data analysis.

The meaning of this research is to use micro-traffic flow density to analyze the impact of different access densities on traffic volume and traffic speed variation of arterials. This will fully utilize the characteristics and advantages of the analysis of simulation and calibration, investigate roadway access design factors that could influence speed variation on multilane roadways (arterials and collectors), quantify the impacts of the contributing factors on safety performance, and get a more scientific security check of speed variation between all factors.

1.3 Research Motivation

In 2010, 235, 461 traffic crashes, 2,444 fatalities and 2,261 fatal crashes occurred on Florida roadways. In 2009, 33,808 fatalities and 30,797 fatal crashes occurred on national roadways, and the estimated cost of traffic crashes occurred on national roadways is $230.6 million. Existing studies on traffic safety did not consider the speed variation, which is an important factor towards roadway safety as stated in previous research.

1.4 Research Objectives

The main objective of this research is to fully utilize the characteristics and advantages of analysis of simulation and calibration, investigate roadway access design factors that could influence speed variation on multilane roadways (arterials and collectors), quantify the impacts of the contributing factors on safety performance, and get more scientific security check of speed variation between all factors. More specifically, three major objectives are described as follows:

(1) To identify the factors contributing to speed variation or other speed dispersions on multilane roadways. These factors mainly include roadway access design factors (such as median openings, driveways, intersections, median types, and other access management techniques). Other factors, such as speed limit strategies, geometric design, traffic composition, land use, roadway function classification, and environmental characteristics, could be evaluated.

(2) To quantify the influence of the contributing access design factors on speed variation (or other speed dispersions).

(3) To develop statistical models to describe the relationship between speed variation (or speed dispersions) and roadway access design contributing factors. The models are compatible with the standard protocols in the *Highway Safety Manual* (HSM).

1.5 Organization of the Dissertation

The remainder of the dissertation is organized as follows: Chapter 2 provides a literature review on the impacts of speed limit strategies on roadway safety, safety impacts of speed variation, and access density. Chapter 3 describes the methodologies, including access type definition, speed fluctuation area, simulation parameters, access weight, access density, influence area, developing estimated model, followed by Chapter 4 on data collection. Chapter 5 deals with descriptive statistics of access weight, speed variation analysis, traffic simulation analysis, obtaining extended data from simulation, and statistical modeling. Chapter 6 describes the conclusions and future work.

Chapter 2 Literature Review

2.1 Summary

The relationship between speed variation and accident has been verified by previous researchers. Normally, accident rates increase with increases in speed variation. However, sometimes, speed variation is associated with an unusual crash rate.

One characteristic of access points, that is, significant traffic speed variation is caused by different access points, has not been considered while computing access density. Crash rates have been observed to be highly related to traffic speed variation. Major traffic speed reduction and recovery usually occur at access points. Depending on the types of access points, traffic speed reduction and recovery distributions are different. These distributions are key features of various access types and should be considered in defining access density.

Accident rates increase with the increase of the total number of access points or access point density. In some studies, access density has been defined as the number of access points divided by the length of a roadway segment. Other studies found that driveway density, unsignalized minor street densities and different median types are significantly correlated with crash frequency.

2.2 Past Studies

Past studies and findings are reviewed and summarized in this paper, divided into two main parts: speed variation and crash, and access density and crash.

2.2.1 Speed Variation and Crash

Many previous studies have been performed to investigate the impacts of speed limit strategies on roadway safety, including the criteria of speed limits, uniform/differential speed limits, and variable speed limit strategies. A few previous studies have focused on the safety impacts of speed variation. This section summarizes and reviews all these previous studies.

Garber (1988) explored the traffic engineering factors that influence speed variation and determined to what extent speed variation affects accident rates. The difference between design speed, which was a surrogate of geometrics, and speed limit was considered as the major contributing factor. Accident rates do not necessarily increase with increase in average speed but do increase in speed variation.

Garber and Gadiraju (1989) studied the relationship between speed variation and accident experience. The study examined 36 roadway segments in Virginia, including urban and rural interstates, urban and rural arterials, and rural major collectors. The analysis used accident data from 1983 through 1986 and compared the results with four different speed measures: design speed, posted speed, and the mean and variance of operating speeds. The mean and variance of operating speeds were computed from individual vehicle speeds measured using automatic traffic data recorders for continuous 24-hour weekday periods. They suggest that the difference between these two speeds showed a quadratic relationship against the speed variation, as shown in Figure 1. The conclusions from their research were:

(1) Accident rates increase with increasing speed variation for all classes of roads.

(2) Speed variation on a highway segment tends to be a minimum when the difference between the design speed and the posted speed limit is between 8 and 16 km/h (5 and 10 mph).

(3) For average speeds between 40 and 112.5 km/h (25 and 70 mph), speed variation decreases with increasing average speed.

(4) The difference between the design speed and the posted speed limit has a significant effect on speed variation.

(5) The increasing trend of average speed with respect to the design speed suggests that as the roadway geometric characteristics improve, drivers tend to drive at increasing speeds irrespective of the posted speed limit.

(6) The accident rate on a highway does not necessarily increase with an increase in average speed.

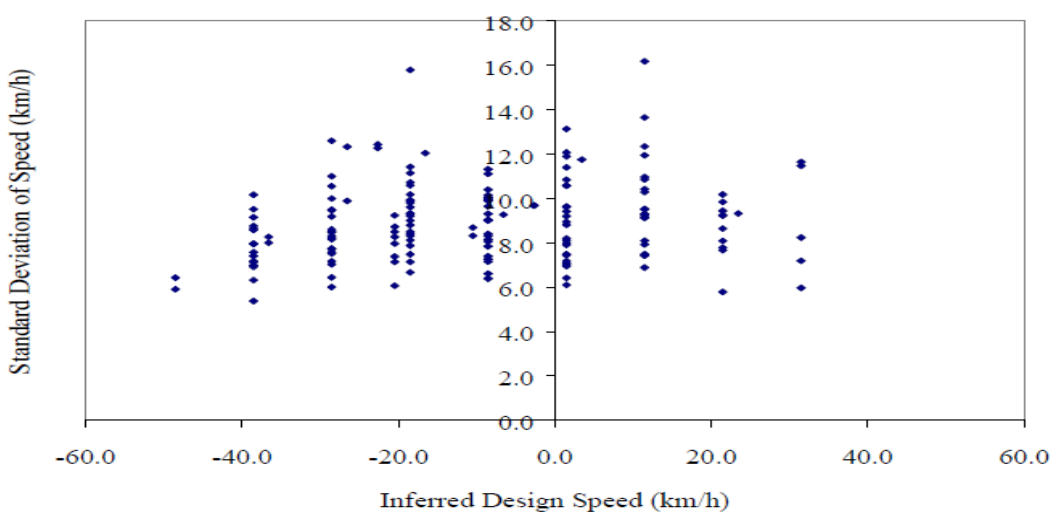


Figure 1 Standard Deviation of Speed vs. Difference between Inferred Design Speed and Posted Speed

Chen (2007) studied the impacts of the difference of average operating speed between large and small vehicles, another criterion to describe speed dispersion, on crash rates based on data collected from an expressway. It was found that a specific traffic composition, which results in a speed difference falling in an interval of 10-15km/h, is associated with an unusual crash rate. Figure 2 illustrates the results in which speed difference is aggregated to eight groups with corresponding aggregated crash rates. Analogical quadratic-shaped curves are manifested for both crash rates versus speed difference. As shown in Figure 2, when the speed difference is less than 5 km/h, crash rates are relatively low. When the speed difference reaches 5 to 10 km/h, average crash rates start increasing and then reach maximum value when the speed difference is at 10 to 15 km/h. Crash rates start to decrease after speed difference surpasses 20 km/h. Therefore, there is one "sensitive speed difference interval," 10 to 15 km/h.

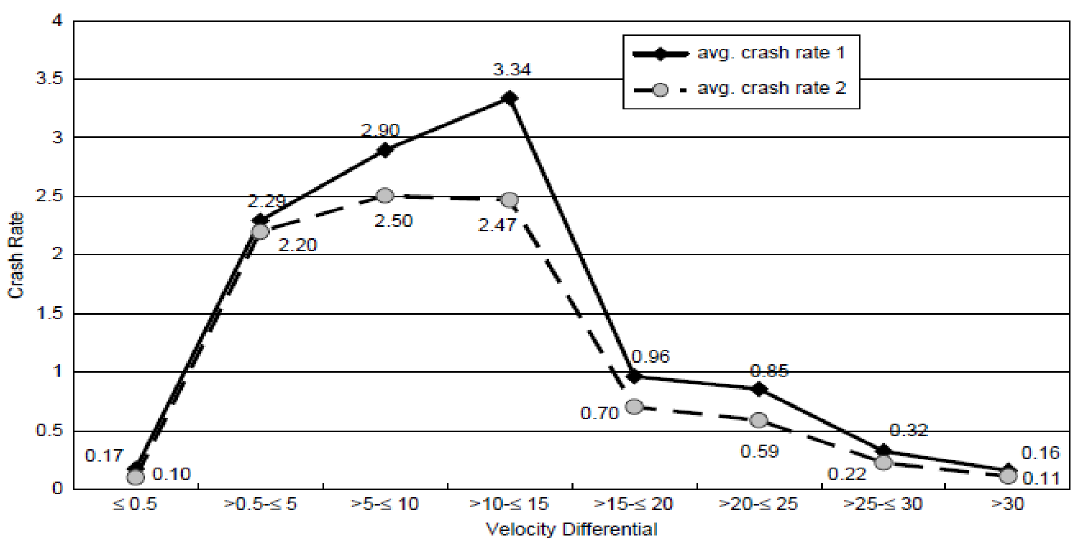


Figure 2 Graphic Illustration of Classification of Speed Difference vs. Crashes

Drummond, Hoel, and Miller (2002) used a simulation-based approach to evaluate safety impacts of increased traffic signal density in suburban corridors. Restricting signal density is becoming one of the most common controversial access management techniques faced by practitioners. Increased signal density can improve access for minor approaches to a corridor, but it can also increase delays and rear-end crashes for vehicles on the mainline approach. Ten years of crash data from two major arterials in Virginia were used in this study, and actual crash rates were compared to operational performance measures simulated by Synchro/SimTraffic model. The results showed that crash rates were positively correlated with stops per vehicle and delay per vehicle and negatively correlated with mainline speed.

Also, three significant findings are extracted from this study. First, the correlation between crash rates and selected mainline performance measures (delay, speed, and stops) was relatively strong despite the inherent variability in crash rates: R^2 (the square of the correlation coefficient), a measure of explained variance in crash rates, yielded values from 0.63 to 0.89. Table 1 shows the correlation of Performance Measures and Crash Rates for 1999–2000: R^2 values.

Second, three distinct regimes relate stops per vehicle to signal density: the installation of the first few signals causes a drastic increase in stops, the addition of the next set of signals causes a moderate increase in stops, and the addition of a third set of signals does not significantly affect the number of stops per vehicle. Figure 3 and Figure 4 show a similar three-regime model with regard to the total stops per vehicle and number of signals.

Third, multiple regime models also relate delay per vehicle to signal density. Figure 5 demonstrates the relationship between delay per vehicle and signal density for Route 17 corridor in York County in Virginia.

Table 1 Correlation of Performance Measures and Crash Rates for 1999-2000: R^2 Values

Simulated Performance Measure	Route 17	Route 250
Delay per mainline vehicle	0.73	0.87
Stops per mainline vehicle	0.63	0.72
Travel time per mainline vehicle	0.78	0.82
Average speed per mainline vehicle	0.87	0.89
Fuel consumption per mainline vehicle	0.54	0.57
Delay per vehicle overall	0.00	0.86
Stops per vehicle overall	0.38	0.83
Travel time per vehicle overall	0.49	0.78
Average speed per vehicle overall	0.00	0.81
Fuel consumption per vehicle overall	0.61	0.57
Queuing penalty overall	0.83	0.71
Range over which model is valid	11–18 signals in corridor	3–10 signals in corridor

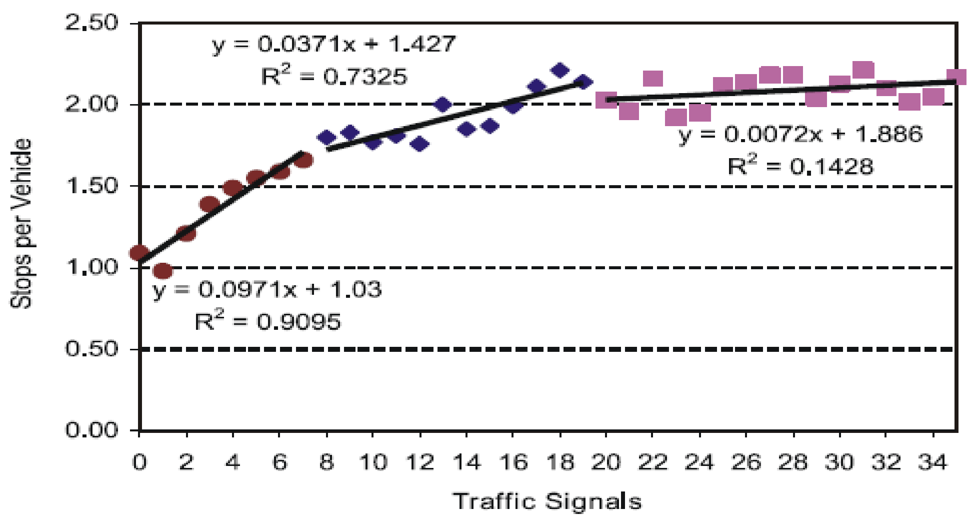


Figure 3 Total Stops Per Vehicle vs. Number of Traffic Signals (Route 17)

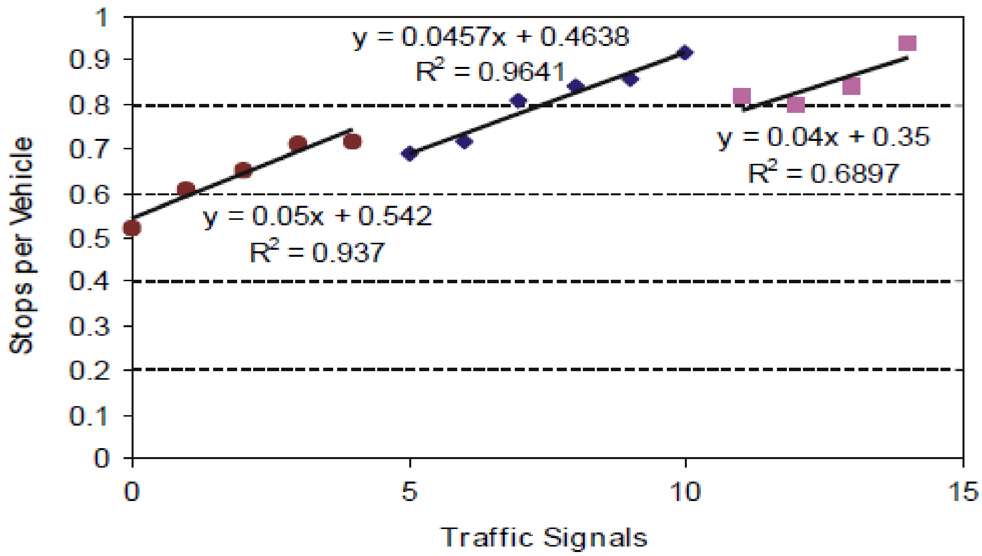
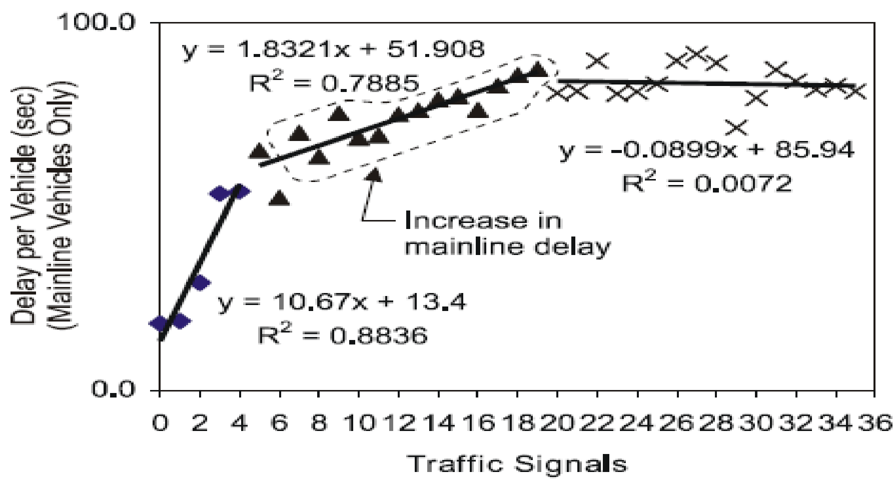
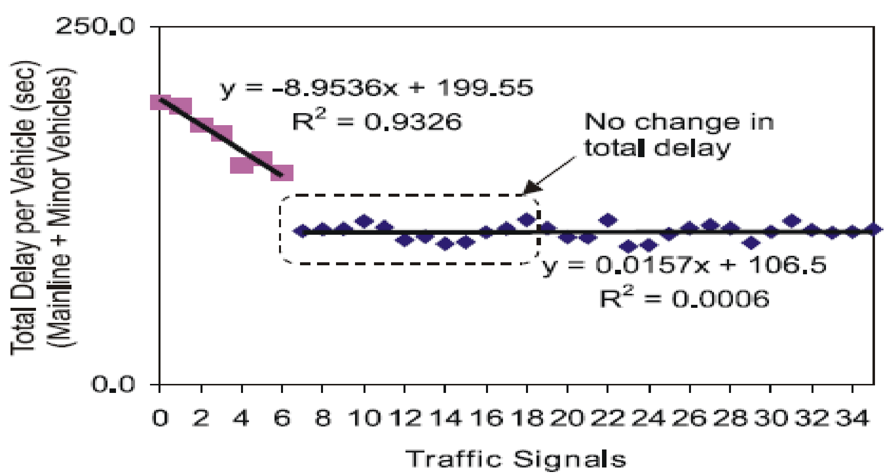


Figure 4 Total Stops Per Vehicle vs. Number of Traffic Signals (Route 250)



(a)



(b)

Figure 5 Route 17: (a) Mainline Delay per Vehicle, (b) Total Delay per Vehicle

2.2.2 Access Density and Crash

Eisele and Frawley (2005) studied the safety and operational impact of raised medians and driveway density by investigating 11 corridors in Texas and Oklahoma. Operational effects (travel time, speed and delay) were investigated through microsimulation on three field test corridors and three theoretical corridors. Table 2 and Table 3 show the characteristics and results for operational microsimulation field case study corridors and operational microsimulation theoretical corridors.

Table 2 Characteristics and Results for Operational Microsimulation Field Case Study Corridors

Case Study	Location	Corridor Length (mi)	Signals per Mile/Access Points per Mile[1]	Median Opening Spacing (ft)[2]	Number of Lanes in Each Direction[3]	Land Uses	Percent Difference in Conflict Points[4]	Estimated Existing ADT[5]	Estimated Future ADT[6]	Future Percentage Difference in Travel Time[4]	Future Actual Difference in Speed (mph)
Texas Avenue	Bryan, Texas	0.66	3.0/91	690 to 1,320	2	Retail, university	−60	18,200	21,800	−11	2 (increase)
									48,000	−38	7 (increase)
31st Street	Temple, Texas	0.71	5.6/66	350 to 850	2	Retail, some residential	−56	13,300	16,000	3	1 (decrease)
Broadway Avenue	Tyler, Texas	1.47	4.1/46	500 to 1,500	3	Commercial, retail	−60	24,400	29,300 48,000	2 57	<1 (decrease) 6 (decrease)

Table 3 Characteristics and Results for Operational Microsimulation Theoretical Corridors

Theoretical Corridor	Median Treatment[1]	Number of Lanes in Each Direction	Percent Difference in Conflict Points[2]	Number of Driveways	Driveway Spacing (ft)	Raised Median Opening Spacing (ft)	Estimated Future ADT[3]	Future Percentage Difference in Travel Time[2]	Future Actual Difference in Speed (mph)
Scenario 1	TWLTL and raised	2	Not applicable	18	660	660	18,000–28,000	Not applicable	Not applicable
Scenario 2	TWLTL	2	−70	42	330	660	18,000 23,000	2 6	<1 (decrease) 2 (decrease)
	Raised						28,000	31	8 (decrease)
	TWLTL	3	−70	42	330	660	18,000 23,000	8 8	2 (decrease) 2 (decrease)
	Raised						28,000 48,000	11 44	3 (decrease) 9 (decrease)
Scenario 3	TWLTL	3	−75	84	165	660	18,000 23,000 28,000	6 1 2	2 (decrease) <1 (decrease) <1 (decrease)
	Raised						33,000 38,000 48,000	7 22 10	2 (decrease) 6 (decrease) 3 (decrease)

The three filed test corridors were all located in Texas: Texas Avenue, Bryan, Texas; 31st Street, Temple, Texas; and Broadway Avenue, Tyler, Texas. Three theoretical corridors are two-way left-turn lanes (TWLTLs), Raised, TWLTLs and Raised. By investigating the case studies, replacing a TWLTL with a raised median resulted in an increase in travel time on two test corridors (31st Street and Broadway Avenue) and a decrease on one test corridor (Texas Avenue). Reversely, replacing a TWLTL with a raised median resulted in an increase in speed on one test corridor (Texas Avenue) and a decrease on two test corridor (31st Street and Broadway Avenue). Detailed crash analysis on 11 test corridors demonstrated that as access point density increases, crash rates increase, as shown in Figure 6.

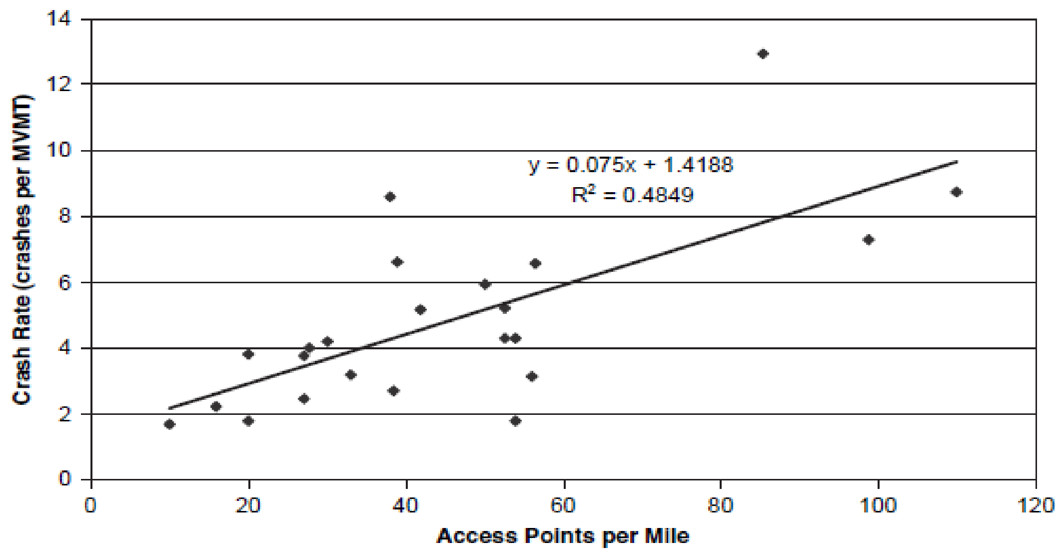
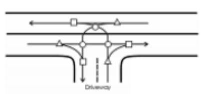
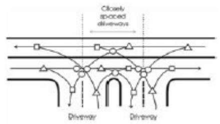
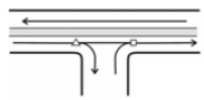
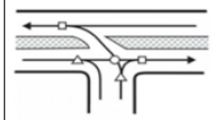
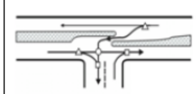


Figure 6 Relationship between Access Point Density and Crash Rates

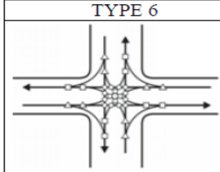
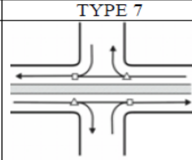
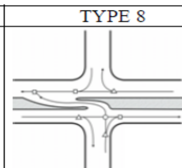
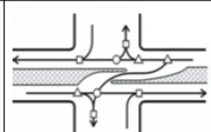
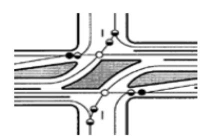
Saxena (2009) compared three distinct methods used to compute access density and provided a comprehensive methodology to enable standardization for research and application in the future. Access density is a widely-used concept that can calculate the number of access points within a given distance and has been extensively applied to studies related to crash modeling, operational impact, and planning. Methods used in previous studies show that access density is computed differently by different studies, and all studies do not include all access points. The proposed weighted methodology takes into account all access points, including driveways, intersections, and median openings, and categorizes them into geometric combinations. Each geometric combination has a potential number of conflict points, which include diverging, weaving, merging, and crossing movements, depending on the type of access point. Weights were assigned to each geometry type based on these conflict point ratio. Table 4 describes basic five types of three-way geometric types, and Table 5 describes basic five types of four way geometric types. The equivalent weights of all other types are calculated with type 1 as base and are summarized in Table 6.

Table 4 Three-Way Geometry Types in Proposed Weighted Methodology

TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5
				
Number of lanes = 2 Median type = Undivided Access = single entrance	Number of lanes = 2 Median type = Undivided Access = closely spaced entrance	Number of lanes = 2 Median type = Raised Access = single entrance	Number of lanes = 2 Median type = Raised Access = left turn egress only from intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn ingress only into driveway or driveway
Conflict Points = 9	Conflict Points = 20	Conflict Points = 2	Conflict Points = 5	Conflict Points = 5
Weighted Access Equivalent = 1	Weighted Access Equivalent = 2.2	Weighted Access Equivalent = 0.2	Weighted Access Equivalent = 0.6	Weighted Access Equivalent = 0.6

Source: "Comparison of Various Methods to Compute Access Density and Proposing a Weighted Methodology," M.S. thesis, University of South Florida, Tampa, p. 28.

Table 5 Four-Way Geometric Types in Proposed Weighted Methodology

TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10
				
Number of lanes = 2 Median type = Undivided Access = typical four-way intersection or driveway	Number of lanes = 2 Median type = Raised Access = typical four-way intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn egress only from intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn ingress only into driveway	Number of lanes = 2 Median type = Raised Access = left turn into driveways from both direction lanes
Conflict Points = 32	Conflict Points = 4	Conflict Points = 7	Conflict Points = 7	Conflict Points = 10
Weighted Access Equivalent = 3.6	Weighted Access Equivalent = 0.4	Weighted Access Equivalent = 0.8	Weighted Access Equivalent = 0.8	Weighted Access Equivalent = 1.1

Source: "Comparison of Various Methods to Compute Access Density and Proposing a Weighted Methodology," M.S. thesis, University of South Florida, Tampa, p. 29.

Table 6 Summary of Equivalent Weights in Proposed Weight Methodology

Category of "Types" Defined Above	Equivalent Weight
*Type 1	1
*Type 2	2.2
*Type 3	0.2
*Type 4	0.6
*Type 5	0.6
*Type 6	3.6
*Type 7	0.4
*Type 8	0.8
*Type 9	0.8
*Type 10	1.1

The author used non-parametric statistical tests to test if the improvement between the existing and proposed methodologies is significantly different. The results show it was not evident that three existing methods of defining access density are different. However, the proposed weighted methodology was found to be significantly different, and correlation values indicate an improvement with reference to explaining the crashes on the selected urban arterial. Also, assigning subjective weights to various access types improves the correlation of access density value with crash rates. This study identifies and compares methods previously used to compute access density and recommends a weighted methodology that includes all access points, which can be used as a standard, universal measure for all access density-related studies including but not limited to safety impacts, operational impacts and planning guidelines.

Although the previous researchers achieved some great results before, there were several gaps existed in previous studies:

(1) There is no quantitative analysis for understanding better about the relationship between crash rates and speed variation.

(2) The format of models between crash rates and speed variation, crash rates and speed, access density and speed are not clear.

(3) There are no study identifying access density considering the Speed Standard Deviation of traffic in close-by areas caused by the access points.

Chapter 3 Research Approach

To achieve the objectives of this research, a set of analyses were performed based on data collected on multi-lane roadways. The data required was divided into several categories, including speed data, inventory data, and traffic/environmental data. Operational speed of individual vehicles was collected in several ways: (a) radar guns to collect operational speed data; (b) potable traffic detectors installed on pavement surfaces to collect individual vehicle speed data; (c) roadway video log surveillance system (RVLS), developed by the transportation group at the University of South Florida, to collect operational speed data; this equipment was installed on a vehicle and recorded the operational speed of adjacent vehicles automatically. After collecting the operational speed data, average speed, speed variation, and speed difference over lanes/traffic composition were calculated.

Data related to roadway access design, geometric design, and speed limit strategies were collected from the Florida Inventory Database. Additionally, the RVLS was used to record more detailed design data on test roadway segments, for example, traffic signs, roadway geometrics, access design, pavement markings, land use, traffic signals, vehicle types, traffic volume, surrounding environmental conditions, etc. All these data were used for modeling the relationships between roadway design access and speed variation. Speed data and other field data were collected from Florida multi-lane highways. More than 15 sites were selected for field data collections with the consideration of access management treatments, geometric design characteristics, land use, area type, number of lanes, and posted speed limits. Google Map functions were used for field site selections.

The main objective of the speed variation analysis was to investigate the influence of contributing factors on speed variation. The contributing factors may include geometric design, access management treatments, speed limit, traffic composition, and/or environmental factors. However, this research focuses more on access management treatments and geometric design factors. Other factors were considered as control factors. Statistic tests were performed to compare speed variation between different sites to identify the factors that statistically significantly contribute to speed variation. Moreover, regression models were developed to describe the relationships between speed variation and the contributing factors, and to obtain the range of the contributing factors that minimizes speed variation. Conceptually, access management treatments should have certain effects on traffic operational speed and speed variation. By optimizing access management treatments and geometric design, it is probable to minimize speed variation, which may result in the improvement of traffic safety performance.

In addition to speed variation, other criteria to describe speed dispersion were examined based on the methods mentioned above—for instance, speed differences between automobiles and heavy vehicles or speed difference over different lane groups.

Besides field data analysis, simulation analysis was performed to analyze the impacts of geometric design and access management treatments on traffic speed variations. In this research, some micro-simulation packages, such as TSIS, were used for the simulation analysis. By adjusting access management treatments and geometric design, the traffic operational speed of each individual vehicle was simulated. The data to be obtained from micro-simulation analysis were further analyzed to obtain the models that specify the impacts of access management treatments and geometric design on traffic operational speed distributions, which was used to support the findings from field data analysis.

The results of speed variation analysis and the results from simulation analysis were consolidated to get the relationship between contributing factors and speed variation. Specific access designs were identified, which may result in minimized speed variation, Regression models, conforming to the protocols used for the development of the proposed AASHTO *Highway Safety Manual*, were developed to predict crash frequency, speed variation, speed limit, access design factors, geometric design, and/or other factors. Figure 7 shows the research approach of this dissertation study. The procedure of proposing a new access density concept is shown in Figure 8. Figure 9 displays the data collection plan of this dissertation study.

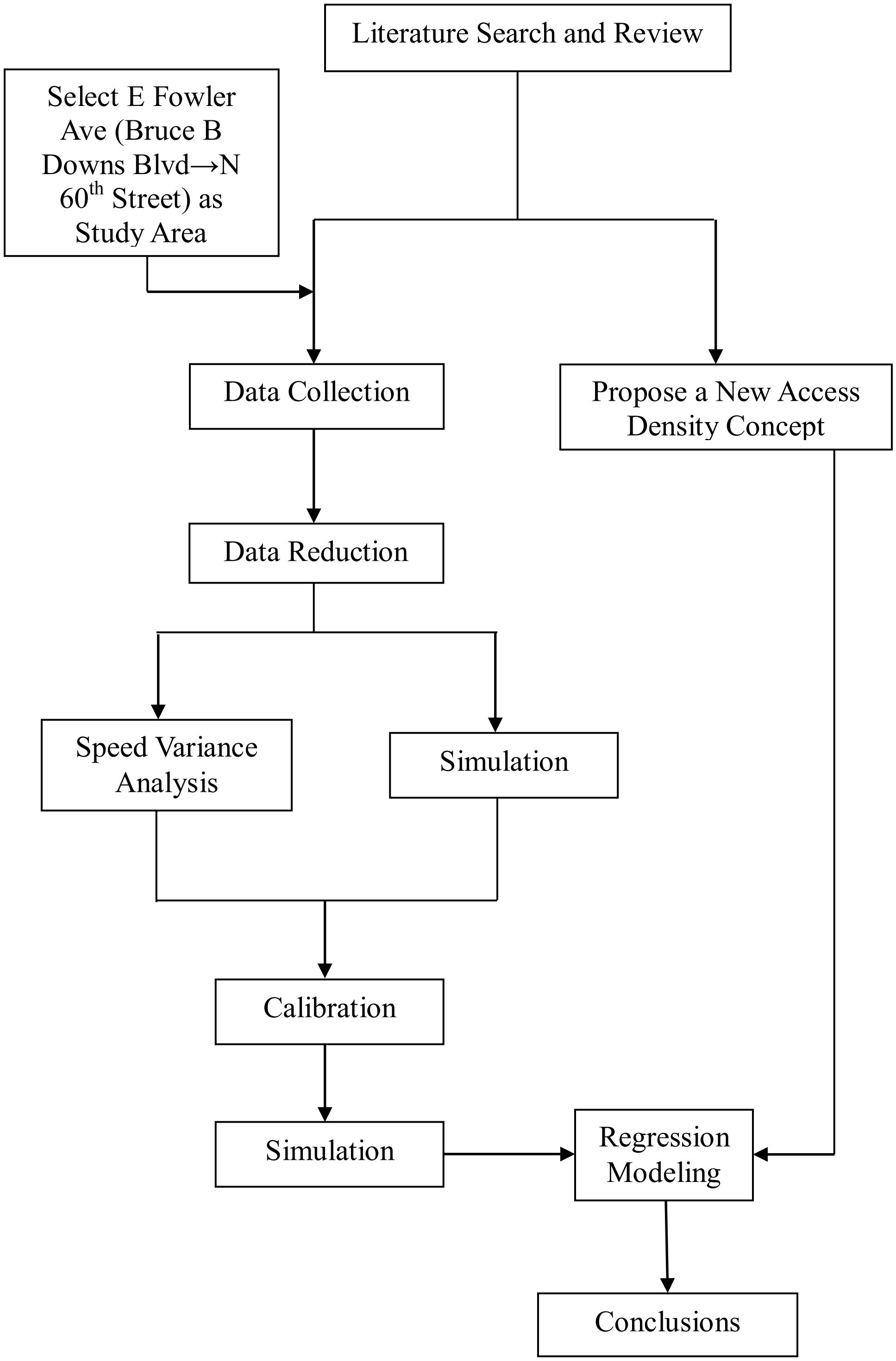


Figure 7 Research Approach

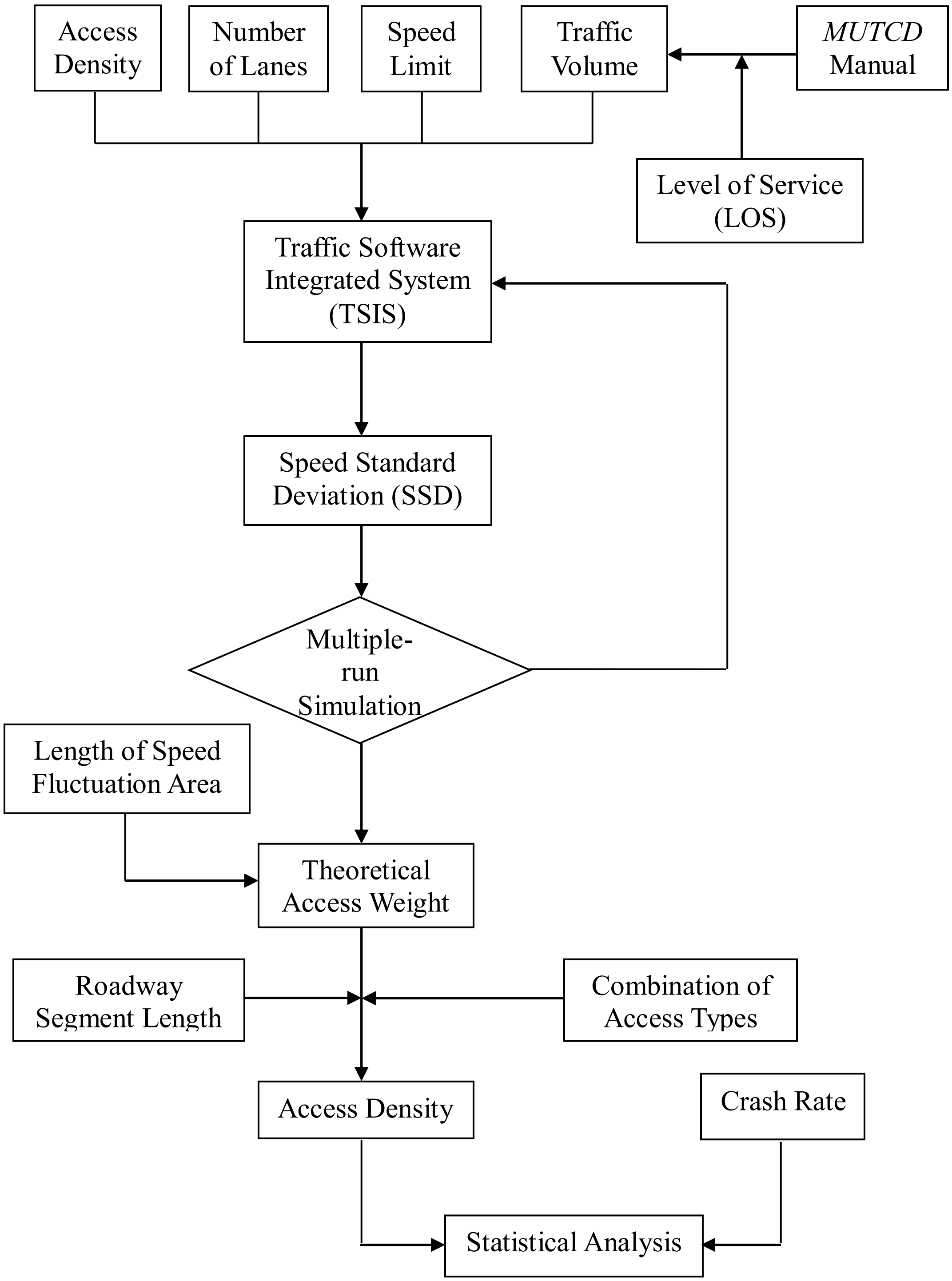


Figure 8 Proposal for a New Access Density Concept

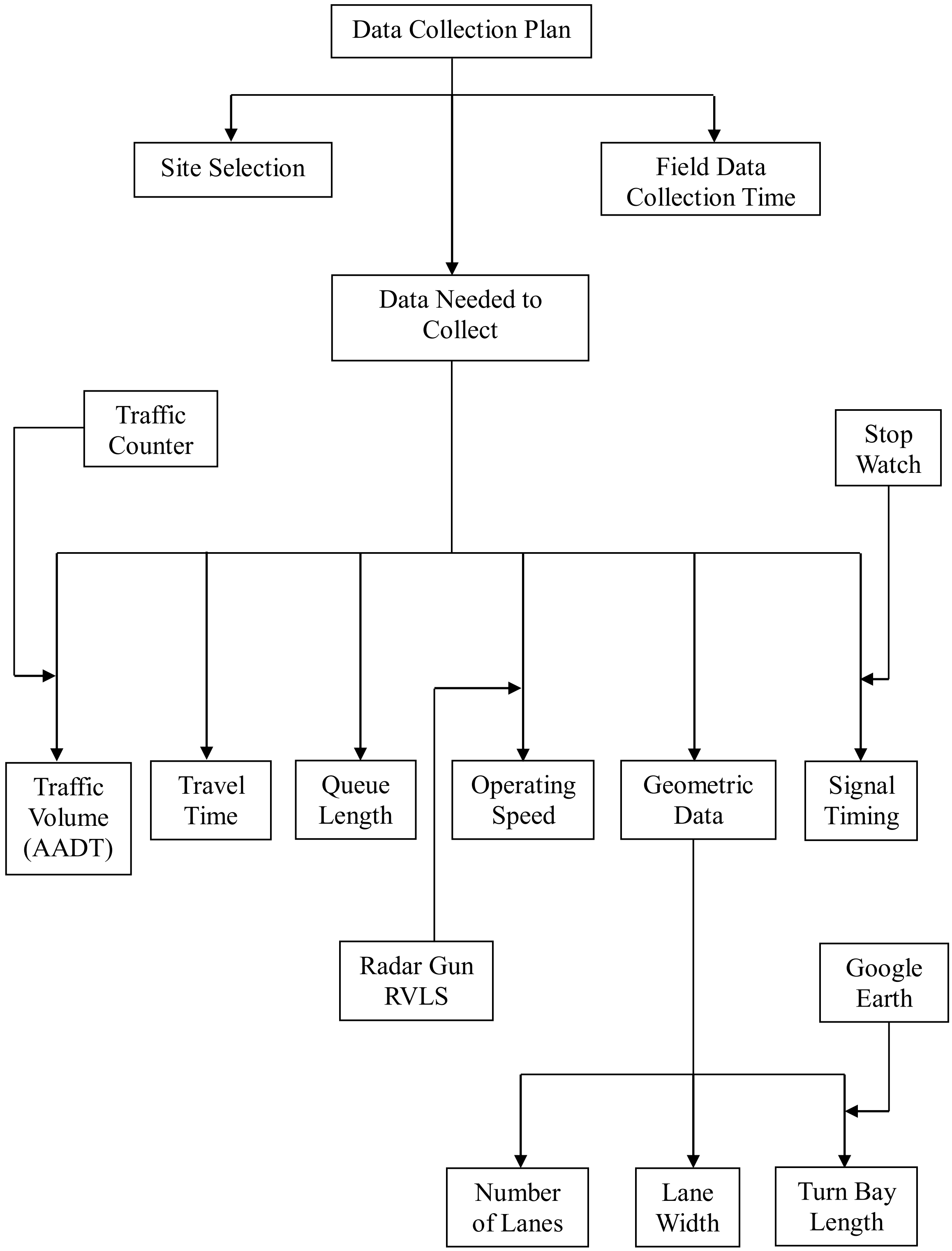


Figure 9 Data Collection Plan

Chapter 4 Introduction of New Definition of Access Density

4.1 Access Type Definition

Driveways and access roads are the physical interface between a site and the abutting roadway. Therefore, it is necessary that access connections be located and designed to ensure safe ingress and egress for the development and to minimize adverse impacts on the roadway.

As shown in Table 7, nine access types in the *Access Management Manual* (Schneider et al. 2003) are considered in this study. These nine access types are commonly used in access management study, which includes midblock median opening, three-leg intersection, and four-leg intersection. Some unusual access types listed in the *Access Management Manual* are not considered this paper, such as Michigan shoulder bypass, continuous two-way left-turn lane, indirect left turn, etc., because they are not easily to find in the field for simulation calibration purposes. Table 8 shows several unusual access types. All these access types are considered as administrative and design techniques, which can be applied to preserve and enhance the safety and operational character of a roadway segment and to mitigate the traffic problems at many types of locations. For example, in the nine access types, a directional median opening for left turns and U-turns limits movements at median openings to specific turns only; the physical design actively prevents all other movements. The technique of the directional median opening for left-turns and U-turns can be applied to unsignalized median openings on multilane, divided urban, and suburban streets. The directional median opening for left turns and U-turns has three advantages:

Table 7 Nine Access Types Used for Obtaining Theoretical Access Weight

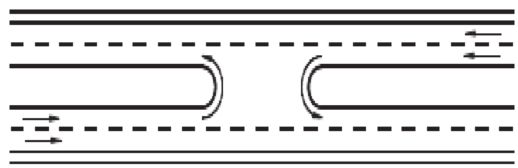
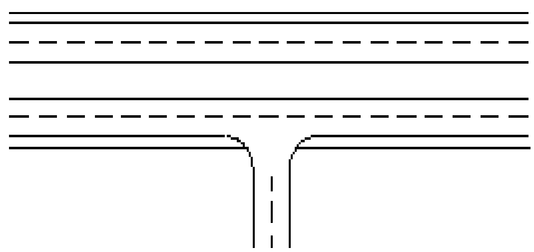
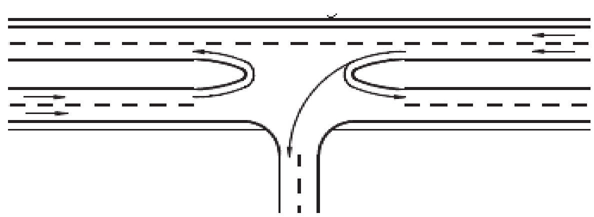
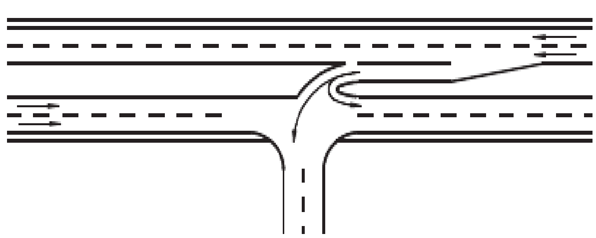
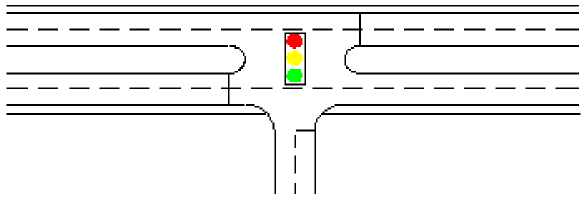
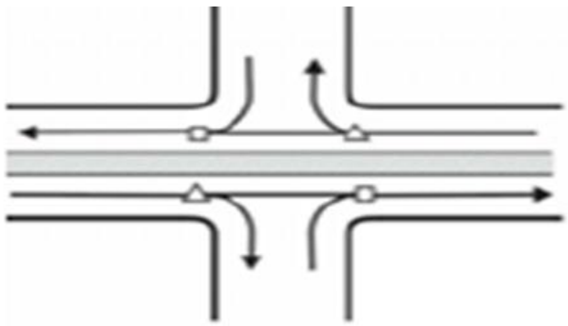
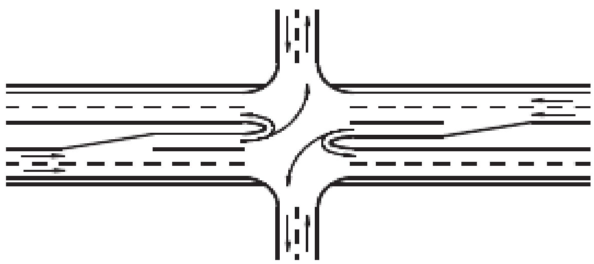
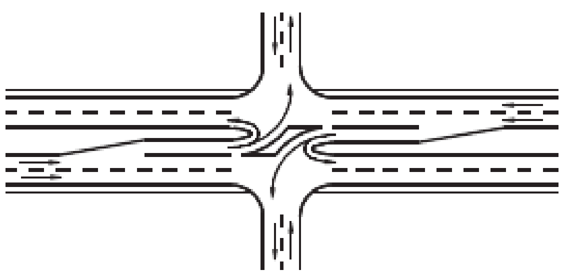
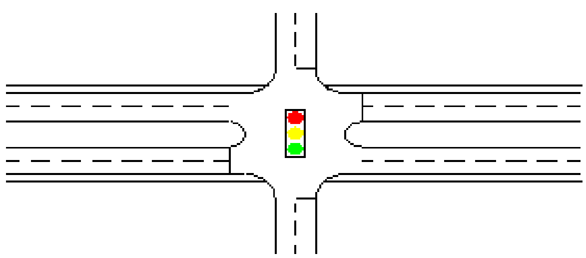
Type 1		Midblock Median Opening
Type 2		Three-Leg Intersection (no median opening)
Type 3		Three-Leg Intersection (full median opening)
Type 4		Three-Leg Intersection (directional median opening 1)

Table 7 (continued)

Type 5		Three-Leg Intersection (signalized)
Type 6		Four Leg Intersection (no median opening)
Type 7		Four Leg Intersection (full median opening)
Type 8		Four Leg Intersection (directional median opening 1)
Type 9		Four Leg Intersection (signalized)

(1) Improve safety by limiting the number and location of conflict points and by precluding direct crossings.

(2) Right-angle crashes are avoided, because vehicles are prevented from crossing where the median width is not sufficient for drivers to cross one traffic steam at a time.

(3) The directional median opening can be signalized without interfering with traffic progression.

Similarly, the directional median opening for left turns and U-turns has two disadvantages:

(1) Cross-median movements are limited to specific locations and to specific turns.

(2) It is not practical to design for U-turns executed by large vehicles in all locations.

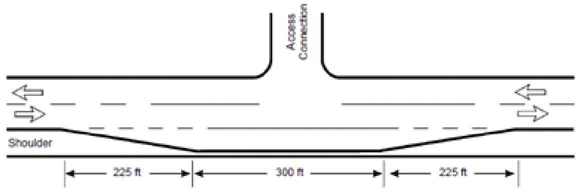
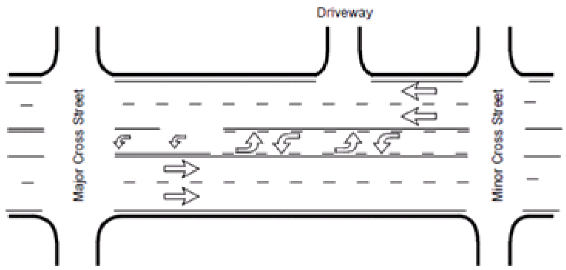
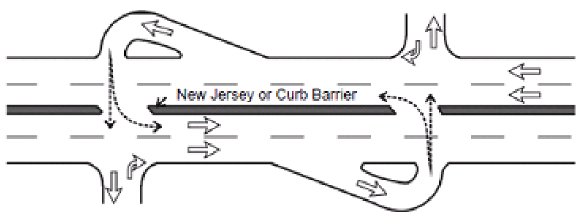
In unusual access types listed in Table 8, a continuous Two-way Left Turn Lane (TWLTL) is a flush painted median lane intended for vehicles that are making left turns from both directions on a roadway. TWLTL provides a place for drivers of left-turning vehicles to wait for an acceptable gap in the conflicting traffic. The technique of continuous TWLTL is applied to the following conditions:

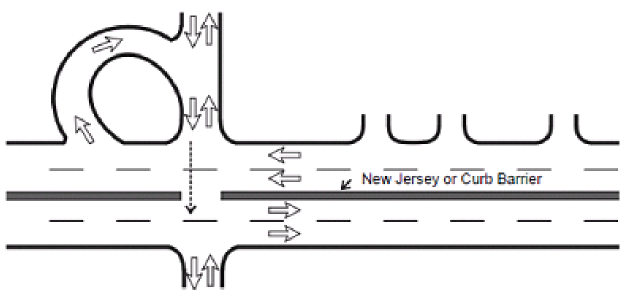
(1) Roadway sections where numerous, closely spaced, low-volume access connections already exist and the projected AADT is less than 24,000.

(2) Urban and suburban roadways that are intended to provide access to small commercial parcels.

(3) Ring roads of large shopping centers and internal circulation roadways of office and industrial parks.

Table 8 Unusual Access Types

<table>
<tr><td>Type 1</td><td>
</td><td>Michigan shoulder bypass</td></tr>
<tr><td>Type 2</td><td>
</td><td>Continuous two-way left-turn lane</td></tr>
<tr><td>Type 3</td><td>

(a)


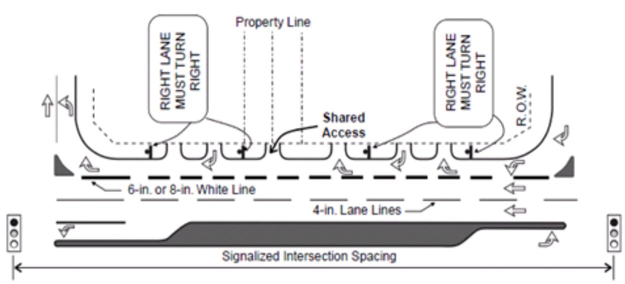
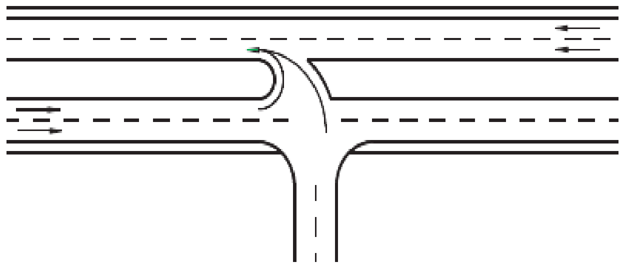
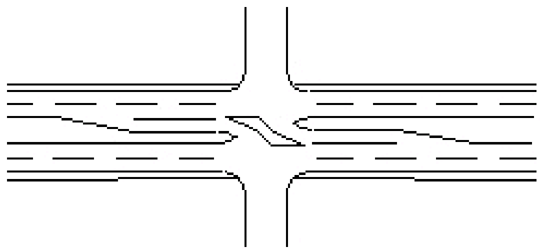
(b)</td><td>Indirect left turn
Alternative A
Alternative B</td></tr>
<tr><td>Type 4</td><td>
</td><td>Continuous right-turn lane</td></tr>
</table>

Table 8 (continued)

Type 5		Three-Leg Intersection (direction median opening 2)
Type 6		Four-Leg Intersection (directional median opening 2)

The continuous TWLTL has four advantages:

(1) TWLTLs are safer than undivided roadways. Average crash rates on roadways with TWLTLs are about 35 percent lower than on undivided roadways.

(2) The technique increases capacity compared with the undivided roadway.

(3) A TWLTL reduces delay compared with the undivided roadway.

(4) It is typically less controversial than a nontraversable median.

Similarly, the continuous TWLTL also has six disadvantages:

(1) TWLTLs are less safe than divided roadways with nontraversable medians. The average crash rates for roadways with TWLTLs are approximately 25–40 percent higher than the average crash rates for divided roadways. A synthesis of 16 studies shows the median crash rate for divided roadways is 27 percent less than that for roadways with TWLTLs.

(2) TWLTLs promote strip development.

(3) A TWLTL does not provide a refuge area for pedestrians crossing roadways. This results in a higher vehicular-pedestrian crash rate than for a roadway with a raised median.

(4) A TWLTL necessitates long pedestrian clearance intervals at the signalized intersection.

(5) Conflicting left turns from opposite directions can often result from TWLTLs.

(6) A TWLTL makes it difficult to provide dual left turns at major intersections at a later date.

(7) Left turns from abutting properties are difficult when the roadway is operating at high volumes.

4.2 Speed Fluctuation Area

Traffic speed varies significantly while approaching/leaving an access point. Figure 10 shows the CORSIM simulation results of traffic speed variation for a roadway segment without any access points, while Figure 11 shows the results with an access point, a signalized intersection. The X-axis represents the number of spot sites. The Y-axis represents the traffic speed in mile per hour (mph), combining all lanes in one direction. The dotted lines on the top of both plots in the figure represent the operating speeds of traffic; the dotted lines at the bottom represent the difference between operating speeds and posted speeds. Comparing Figures 10 and Figure 11, it is easy to see that traffic speeds fluctuate significantly due to the access point. Figure 12 shows the combined curve of speed fluctuation area with intersection. As traffic approaches the intersection, the speed decreases.

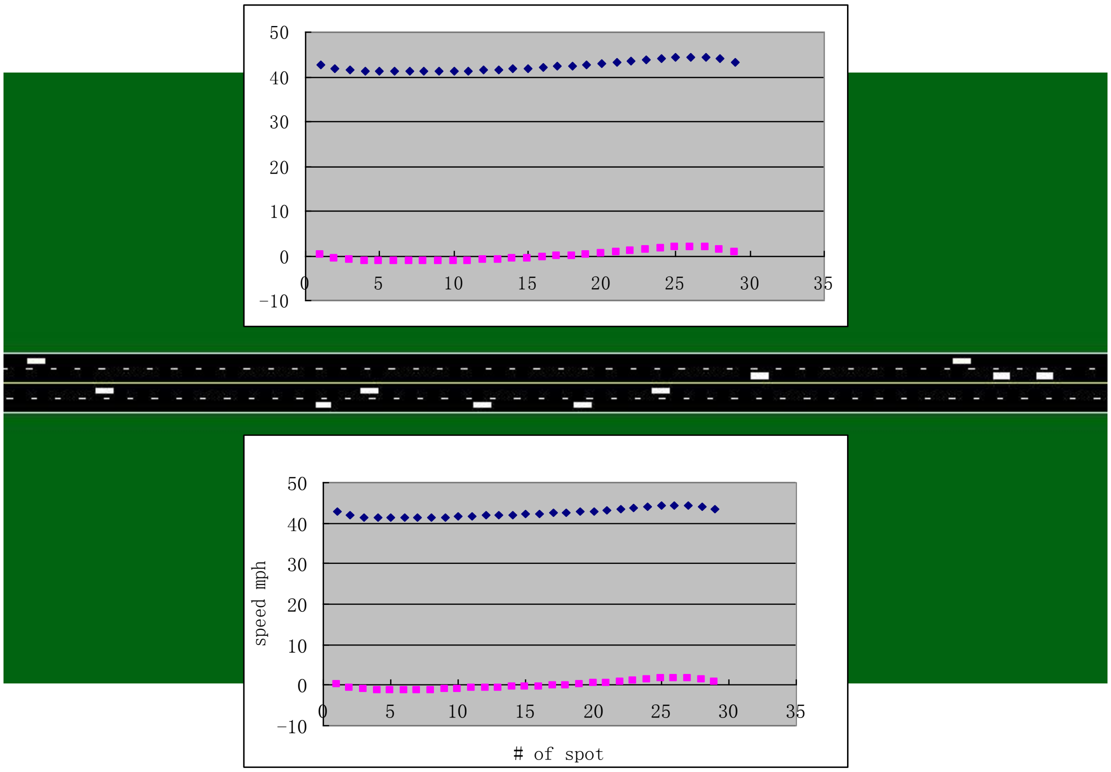


Figure 10 Curve of Speed Fluctuation without Intersection

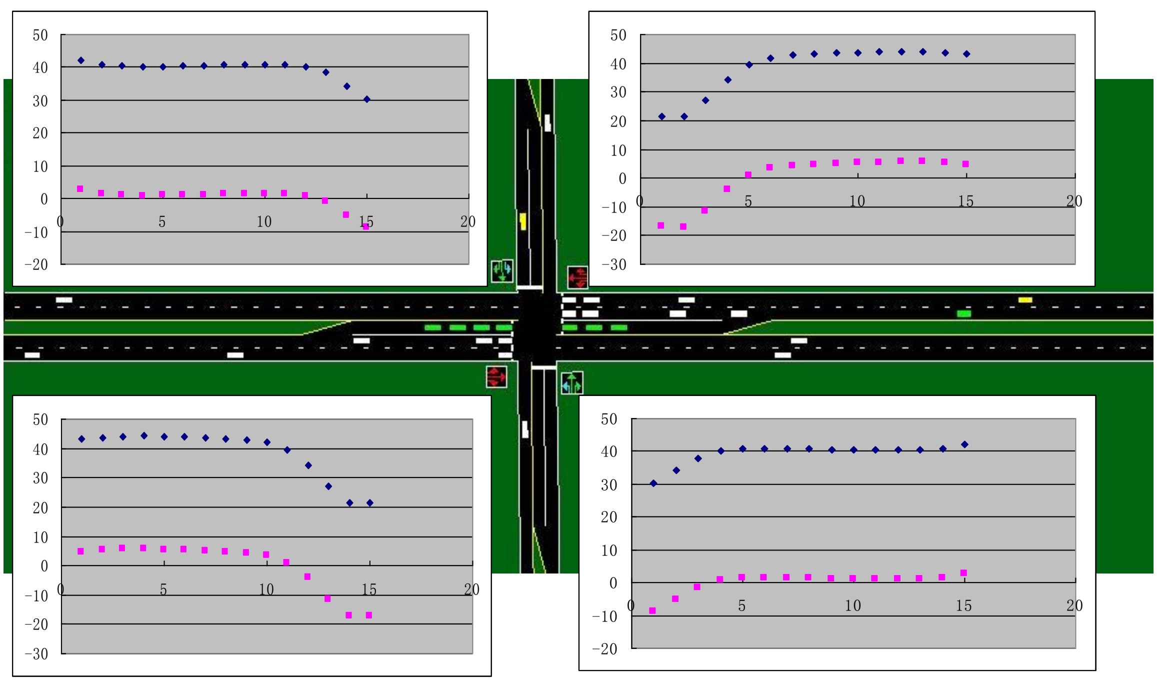
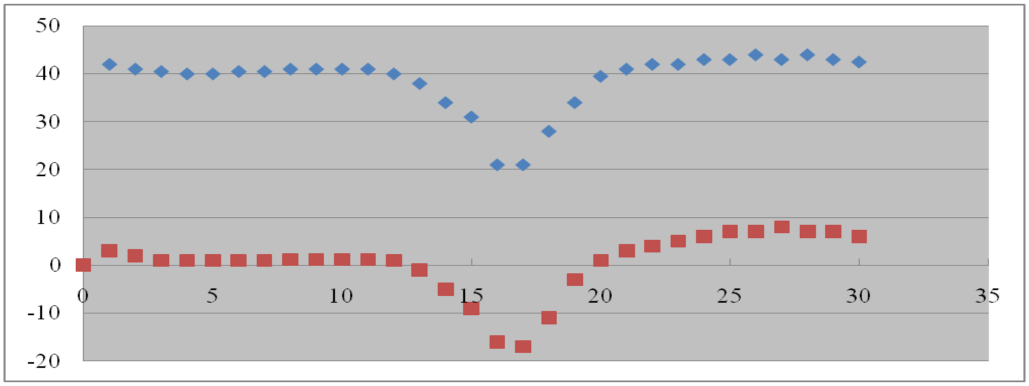
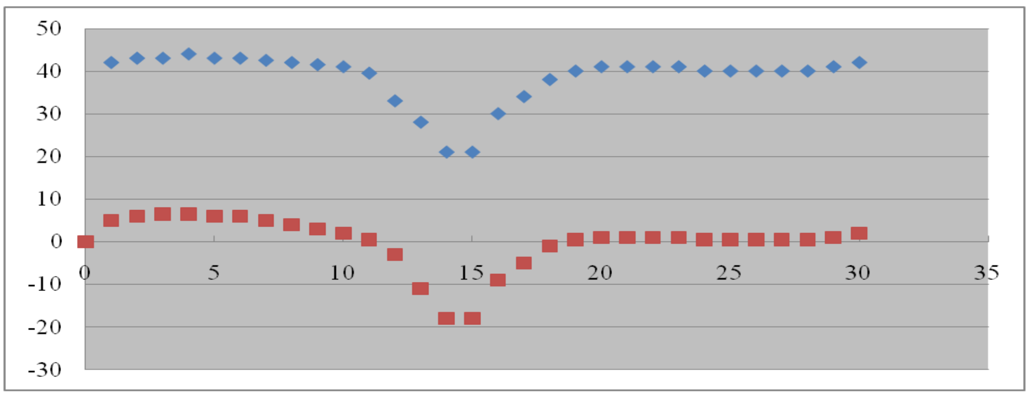


Figure 11 Curve of Speed Fluctuation with Intersection



Westbound



Eastbound

Figure 12 Combined Curve of Speed Fluctuation with Intersection

A speed fluctuation area is defined as an area in which traffic speed varies significantly due to an access point. It is different for each access type and could be different for various directions at a same access point. Generally, the further the traffic from the access point, the less fluctuation the traffic speed. The starting point of a speed fluctuation area is set as the center of an access point. The end point of a speed fluctuation area is the closest spot site where the Speed Standard Deviation (SSD) of that site is less than 0.5 percent of the limited speed. For instance, given the speed limit of a major arterial roadway is 50 mph, then the end point of the speed fluctuation area is the closet spot site with SSD less than 0.5 of the limited speed, i.e., 50x0.5% = 0.25 mph.

4.3 Simulation Scenarios

Multiple-run simulation is conducted for different combinations of access type, number of lanes, speed limit, and level of service. Nine access types are used in multiple-run simulation, as stated earlier. The number of lanes (two-way) includes three categories: 4, 6, and 8. The speed limit includes four categories: 45, 50, 55, and 60 mph. Level of Service (LOS) includes three categories: high, medium, and low. LOS is determined by traffic volume on the roadway. The traffic volume standards used in this study are shown in Table 9. The traffic volumes of both major streets and minor streets comply with the *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 Edition (MUTCD Manual) (AASHTO 2009).

Table 9 Traffic Volume Standards

Road Classification	LOS					
	Low		Medium		High	
Major Street	350	350	600	600	800	800
Minor Street	530		280		170	

Table 10 shows the simulation settings of this study. It lists under different speed limit and different level of service, the input total traffic volume of both eastbound and westbound directions in simulation models. Considering nine access types listed previously, there are total 468 different simulation scenarios.

Table 10 Simulation Settings for Obtaining Access Weight

Free-Flow Speed	Criteria	LOS		
		Low	Medium	High
60 mph	Traffic Volume (Sum of Eastbound and Westbound Direction of Major Street in Simulation Models)			1746, 2246, 3245, 3494, 3993, 4242, 4492, 5740, 6737, 6988, 7487, 7736, 7985, 8485, 8984, 9233, 9483, 9733
55 mph			1248	1746, 2496, 3743, 4492, 4742, 5490, 5740, 5989, 6239, 6488, 6988, 7487, 7985, 8236, 8734, 9483
50 mph			1248, 1497	2495, 2496, 2745, 2994, 3494, 3743, 3993, 4492, 4742, 4991, 5490, 5989, 6239, 6488, 6988, 7736, 8485, 8734, 8984, 9233, 9733
45 mph			1497	1997, 2246, 2495, 2496, 2745, 2994, 3245, 3494, 3993, 4242, 4492, 5240, 5490, 5740, 5989, 6239, 6488, 7237, 8236

4.4 Access Weight

It is well known that different access driveways have distinct impacts on speed variation. Access weight is defined considering traffic speed variations around access point. We believe that larger the traffic speed variations at spot sites in the speed fluctuation area of the access point, the more likely there will be a crash occurring. In addition, more significant traffic speed difference between one spot site and the consecutive one, more likely there will a crash as well. Given these hypothesis, the following mathematical formulas are proposed to calculate the access weight.

$$SSD_i = \sqrt{\frac{\sum_{n=1}^{I}\left(v_i^n - \overline{v_i}\right)^2}{I-1}}$$

$$SSD_i' = \sqrt{\frac{\sum_{n=1}^{I}\left(v_{i+1}^n - v_i^n\right)^2}{I-1}}$$

$$SSD_i^c = \sqrt{SSD_i \times SSD_i^{'}}$$

$$AW = \frac{1}{L_d} \sum_{i=1}^{I} SSD_i^c$$

Where,

AW – Access weight

SSD_i – Speed Standard Deviation at spot site i

SSD_i' – Speed Standard Deviation variance between spot site i and consecutive spot site i+1

SSD_i^c – Combined speed variation measurement

v_i^n –Traffic speed at spot site i in the n^{th} running of the simulation

$\overline{v_i}$ – Average traffic speed at spot site i of all runs of simulation

I – Total number of simulation runs

L_d – Length of speed fluctuation area (assumed as 100 ft in the simulation)

In Appendix A, the 468 sample access weights are listed. Each weight corresponds to one scenario with a specific access type, number of lanes, speed limit, and LOS. For instance, the access weight of an access type 8 in a roadway segment with 4 lanes and speed limit 45 mph is 0.144 when the LOS is low. Figure 13 illustrates the traffic speed variation metrics for this particular scenario. The lower square dashed line represents the SSD, the triangle dashed line represents the SSD', and the cross dashed line represents the SSD^c.

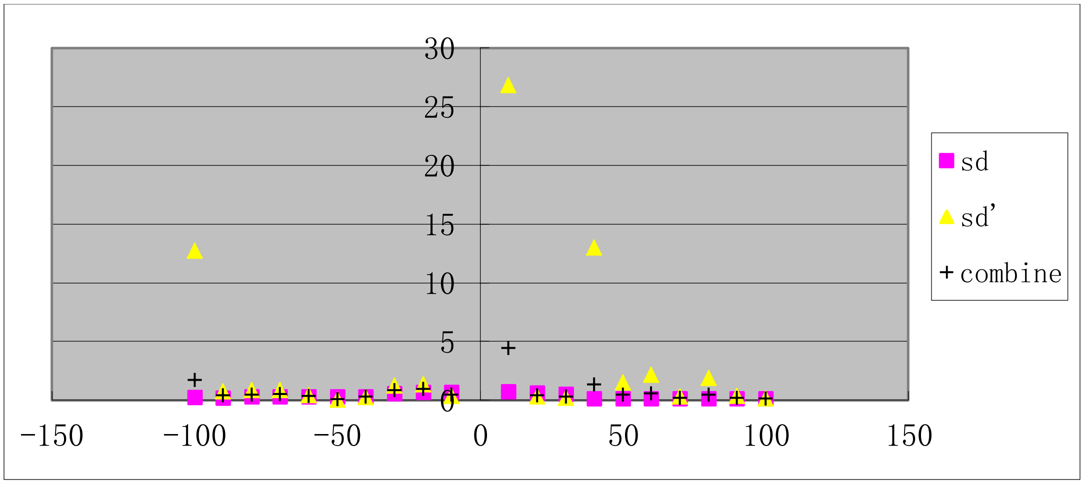


Figure 13 Example of SSD, SSD' and Combined SSD for Access Type 8 with 4 Lanes, Speed Limit 45 mph, and Low Level of Traffic Volume

4.5 Aggregate Weights and Density for Segment

Sometimes, a roadway segment has several speed fluctuation areas, so the aggregate weights and density for segment need to be calculated. There are two methods to calculate aggregate weights and density: non-overlap speed fluctuation area and overlap speed fluctuation area, as shown in Figure 14 and Figure 15. Figure 16 shows the calculation of overlap weight.

4.5.1 Case I

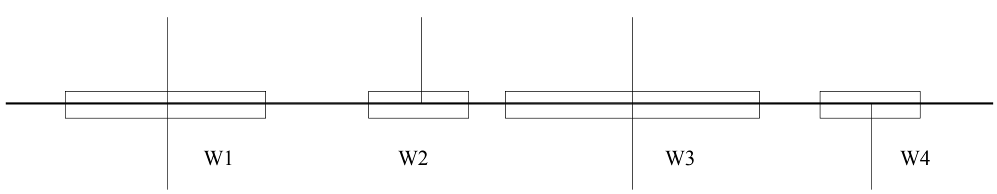


Figure 14 Aggregate Weights of Non-overlap Speed Fluctuation Area

The equation below shows the calculation of aggregate weights and density for non-overlap speed fluctuation area.

$$W_{Total} = \sum_{i}^{n} W_i$$

$$D_{Total} = \frac{W_{Total}}{L_{Total}}$$

4.5.2 Case II

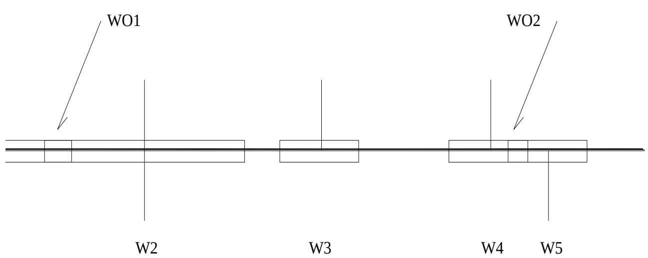


Figure 15 Aggregate Weights of Overlap Speed Fluctuation Area

The equation below shows the calculation of aggregate weights and density for overlap speed fluctuation area. Overlap of speed fluctuation area can cause more speed variation, which should be considered as an additional access weight.

$$W_{Total} = \sum_{i}^{n} W_i + \sum_{i}^{n} W_{Oi}$$

$$D_{Total} = \frac{W_{Total}}{L_{Total}}$$

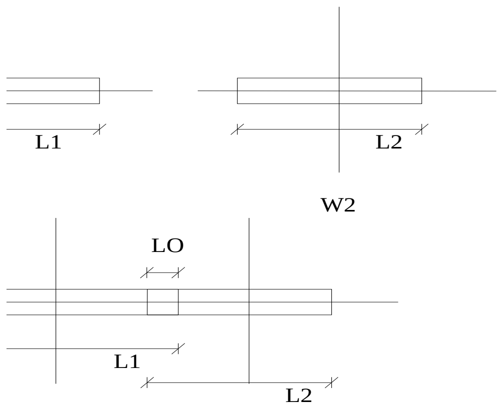


Figure 16 Overlap Weight

The equation below shows the calculation of overlap weight.

$$W_O = \sqrt{(W_1 \times \frac{L_O}{L_1})(W2 \times \frac{L_O}{L_2})}$$

Where,

W_o – Overlap Weight

L_o – Overlap Length

Actually, in the simulation process of this study, overlap of speed fluctuation area was overlooked. In the access weight calculation process of this study, overlap weight was not included. Because sometimes two access points along the arterials are too close, it is not convenient to calculate overlap length.

4.6 Access Density

Access density is defined as the sum of access weights of different access points on one road segment divided by the length of that roadway segment, formula is shown as follows:

$$AD = \sum_{m=1}^{M} AW_m / L$$

Where,

AD – Access Density

AW_m – Access Weight of access point m

M – The total number of access points in the roadway segment

L – Length of road segment

The access weight is determined by traffic speed variation and the length of speed fluctuation area for a given combination of access type, number of lanes, speed limit, and level of service requirement, which will be elaborated later. Simulation software, Traffic Software Integrated System (TSIS), is used for obtaining the measurements of traffic speed variation. As the access weights sought in this study are for general conditions, called as theoretical access weights, we keep the default parameters in TSIS which reflect normal driver behaviors, as shown in Table 11.

Table 11 TSIS Default Parameters

Driver Type	1	2	3	4	5	6	7	8	9	10
Driver Type Percentage (%)	17	12	12	11	10	10	9	7	7	5
Acceptable Deceleration (fpss)	21	18	15	12	9	7	6	5	4	4
Acceptable Gap – Cross (s)	5.6	5.0	4.6	4.2	3.9	3.7	3.4	3.0	2.6	2.0
Acceptable Gap – Left (s)	7.8	6.6	6.0	5.4	4.8	4.5	4.2	3.9	3.6	2.7
Acceptable Gap – Right (s)	10.0	8.8	8.0	7.2	6.4	6.0	5.6	5.2	4.8	3.6

4.7 Influence Area

Influence Area means the area that speed fluctuates, as shown in Figure 17. Default values can be changed based on simulation results to make all types of weights reasonable. Fluctuation area for different access point varies, however, in traffic simulation, fluctuation area is same, it is assumed that the length of speed fluctuation area is 100 ft. Red lines represent the detectors installed in the speed fluctuation area. Figure 18 illustrates speed changes along a roadway segment. The x-axis represents distance, and y-axis represents speed. When traffic passes the intersection, the traffic speed decreases to 0.

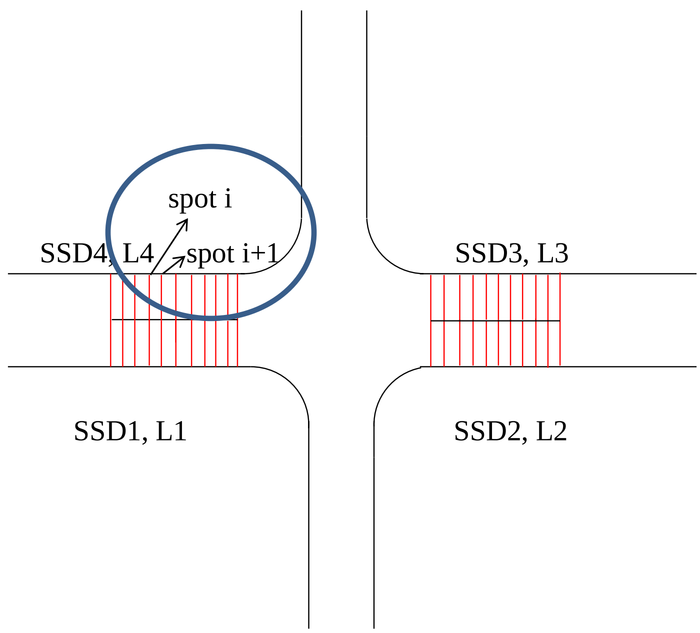


Figure 17 Influence Area

Example:

SSD_d – 5 mph

L_d – 100 ft (assumed)

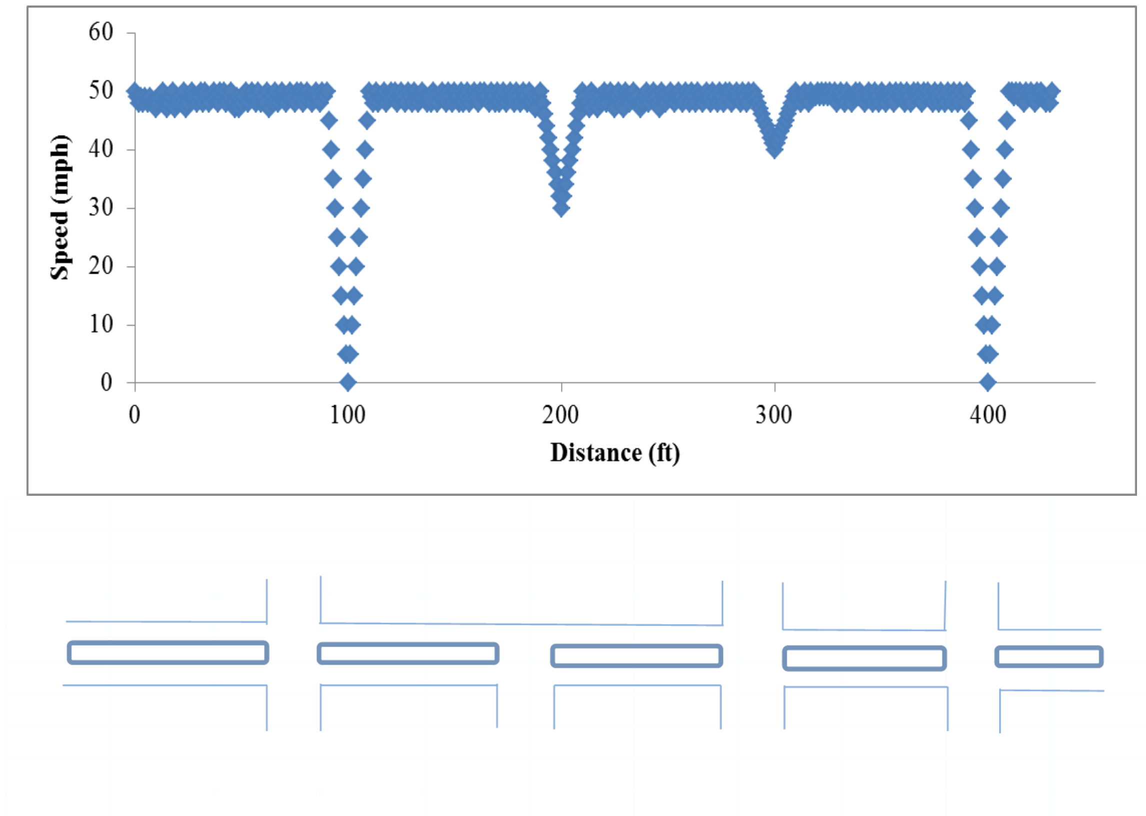


Figure 18 Speed Changes along a Roadway Segment

4.8 Developing Estimated Model

According to previous studies, some parameters are considered to impact the speed variation including access density, traffic volume data (average annual daily traffic or AADT), speed data, number of lanes, and etc. All such data could be acquired by field data collection. In terms of all necessary data being obtained, a mathematical model will be developed to present the relationship between Speed Standard Deviation (SSD) and access weight on roadway segment.

Before calibration, the predicted model is shown as follows:

$$f = \frac{\sum SSD_i \times D_i}{\sum D_i} = (AccessDensity, AADT, NOL, SL)$$

Where,

AADT – Annual Average Daily Traffic (Traffic Volume)

NOL – Number of Lanes

SL – Posted Speed Limit

As shown in Figure 19, x-axis represents distance, and y-axis represents SSD.

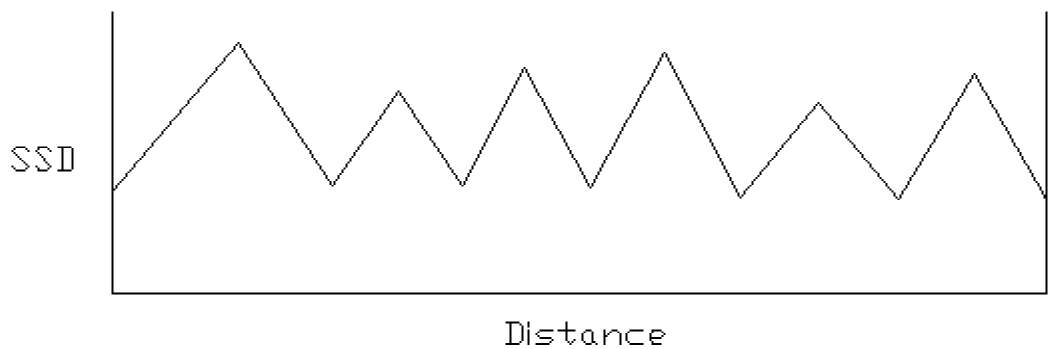


Figure 19 Distance vs. SSD Before Calibration

After calibration, another mathematical model is presented, whose format is same as that of predicted model before. Figure 20 shows the curve after calibration.

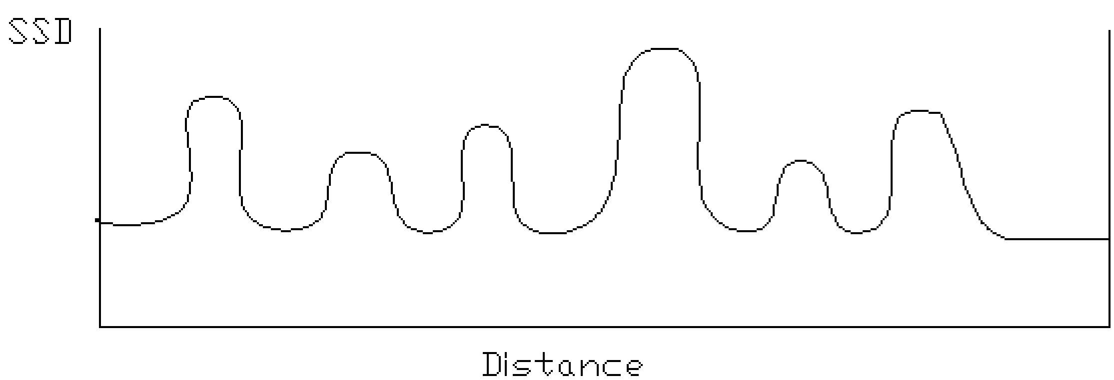


Figure 20 Distance vs. SSD After Calibration

The data used to represent the curves in both Figure 19 and Figure 20 are not actual data and are non-representational.

In this study, based on the mathematical model to demonstrate access weight, access weight is calculated from SSD, so the input parameter is SSD, and the output parameter is access weight. However, in the estimated mathematical model that models the relationship between SSD and access weight, the output parameter is SSD, and the input parameter is access weight. It looks like a loop between SSD and access weight. To avoid this loop appearance, before modeling, the correlation among different independent variables should be checked.

As access density (i.e., access points per mile) increases, crash rates increase. The more traffic on highways, the more crashes will occur, so SSD increases. As traffic volume (AADT) increases, SSD increases. As a result, simply reducing posted speed limits may do little to reduce actual traffic speeds. Effective speed reduction generally requires changing roadway design or significantly increasing enforcement, so increasing or decreasing the posted speed may have an impact on SSD. The number of lanes is one important parameter in geometric design when transportation planners consider building a roadway. As the number of lanes of one roadway increases, the highway capacity increases; this may attract more traffic use this roadway. As traffic volume increases, SSD increases, so increasing the number of lanes may increase SSD.

4.9 Data Collection

This section provides information on field data collection. Observing-site selection, data collection equipment, data collection procedures, and data reduction are included. All field data collected conform to input requirements and traffic simulation modeling. The precision of traffic simulation results is influenced by the quality of data collection.

4.9.1 Observation Site Selection

Site selection is the first and most important step before data collection. As defined in the original project proposal, it was anticipated that more than 15 sites would be selected for data collection. All sites are multi-lane highway segments. A total of 15 sites were selected for data collection in Florida. The selection criteria for all the sites met the following requirements:

(1) The road should be a state or county road.

(2) The road should be straight.

(3) The number of lanes should be equal to or more than 4.

(4) Speed limit should be equal to or higher than 40 mph.

(5) The road grade should be equal to 0%.

Table 12 shows all the locations, traffic volumes, posted speed limits, and number of lanes of the 15 selected data collection sites, all of which are in the Tampa Bay area. All sites were marked on a Google Earth map, as shown in Figure 21. The blue line represents the six sites at which no crashes occurred during a 10-year period, from 2001 to 2010: E Fowler Ave, Bruce B Downs Blvd–SB, Bruce B Downs Blvd–NB, CR 582, US 19-1, and US 19-2. The red line represents the remaining nine sites.

Table 12 Observed Sites in Florida

No.	Road Name	Traffic Volume	Posted Speed Limit (mph)	Number of Lanes
1	E Fowler Ave	2830	50	6
2	N Dale Mabry Hwy	1832	55	6
3	SR 54	1453	50	6
4	US 41	2120	45	6
5	CR 60	1062	55	4
6	Bruce B Downs Blvd–SB	1475	45	4
7	Temple Terrace Hwy	889	45	4
8	W Hillsborough Ave–1 (beginning @ Tudor Dr)	1933	50	6
9	W Hillsborough Ave–2 (beginning @ Montague Street)	1860	50	6
10	W Hillsborough Ave–3 (beginning @ Strathmore Gate Dr)	912	45	6
11	Bruce B Downs Blvd–NB	2394	45	4
12	CR 582	1081	45	4
13	US 19-1	2769	55	8
14	US 19-2	2730	55	6
15	E Dr Martin Luther King Jr Blvd (CR 579)	1528	50	6

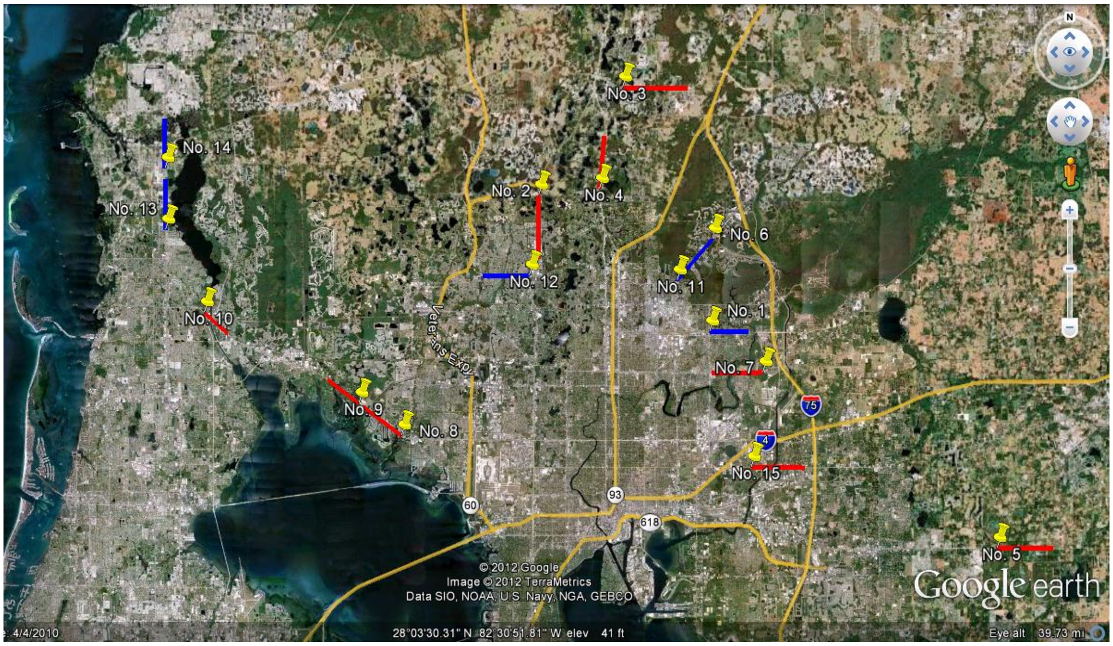


Figure 21 Scattergram of 15 Observed Sites in Florida

4.9.2 Data Collection Equipment and Purpose and Function of Equipment

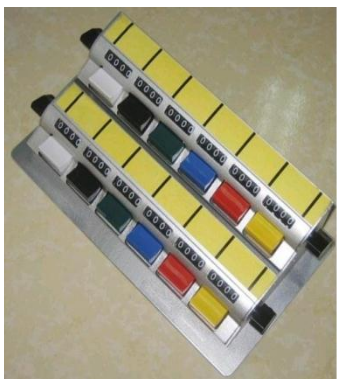
Several types of equipments were used in field data collection, including a Roadway Video Log Surveillance System (RVLS), a radar gun, a traffic counter, a stop watch, etc. The purpose and function of these equipments are shown in Table 13. Figure 22 shows all the equipments used in data collection.

Table 13 Data Collection Equipment Used, Purpose, and Function

Equipment Name	Purpose and Function of Equipment
Roadway Video Log Surveillance System (RVLS)	Collect operating speed data
Radar gun	Detect operating speed data on roadway
Traffic counter	Capture traffic volume/number of vehicles in a queue
Stop watch	Obtain signal timing for each intersection
Rough measure	Measure geometry dimension
Flash coat	Protect observers by cautioning other drivers

(a) Roadway Video Log Surveillance system (RVLS)

(b) Radar Gun



(c) Traffic Counter

(d) Stop Watch

(e) Rough Measurer

(f) Flash Coat

Figure 22 Data Collection Equipment

4.9.3 Data Collection Procedures

Several kinds of data were collected during data collection period, including traffic volume, operating speed, signal timing plan, number of lanes, turn bay length, etc. In order to capture the high volume situation of operation, all the traffic data were collected at peak hour. Due to the length of the observation period, the peak hour time was extended to two hours for both morning and afternoon peaks (7:00–9:00 am, and 4:00–6:00 pm). The time interval for traffic volume collection was 15 minutes. Based on traffic data already obtained, the range of the peak hour time is appropriate as a result of the relatively constant traffic. Operating speed data were captured 50 times for each selected driveway. Data collection was concentrated on upstream and downstream intersection. The hourly traffic volume of each lane was collected using a traffic counter, and operating speed was collected using a radar gun. In addition to the hourly traffic volume for each lane, the queuing length at each approach for each lane was also captured using a traffic counter. Signal timing at intersections was collected by using a stop watch. Most were signalized intersections. Geometric data, which includes number of lanes, turn bay length at intersections, lane width, etc., was collected by Google Earth.

4.9.4 Sample Data Description

Some sample data were collected on E Fowler Ave (Bruce B Downs Blvd→N 60th Street), which includes traffic volume, operating speed, turn bay length, signal timing plan and travel time (Bruce B Downs Blvd→N 60th Street).

4.9.4.1 Traffic Volume

Traffic volume on the intersection of N 56^{th} Street and E Fowler Ave were collected during peak hour in the afternoon (4:00-6:00 PM) for four directions: eastbound, westbound, northbound, and southbound, as shown from Table 14-17.

Table 14 Traffic Volume of Eastbound Direction of Intersection of N 56^{th} Street and E Fowler Ave

Time	Left	Through	Right
5:00-5:30 PM	165	1099	151
Actual	330	2198	302

Table 15 Traffic Volume of Westbound Direction of Intersection of N 56^{th} Street and E Fowler Ave

Time	Left	Through	Right
5:00-5:30 PM	125	626	206
Actual	250	1252	412

Table 16 Traffic Volume of Northbound Direction of Intersection of N 56^{th} Street and E Fowler Ave

Time	Left	Through	Right
5:00-6:00 PM	270	708	540

Table 17 Traffic Volume of Southbound Direction of Intersection of N 56^{th} Street and E Fowler Ave

Time	Left	Through	Right
5:00-6:00 PM	123	298	104
Actual	246	596	208

4.9.4.2 Operating Speed

Table 18 shows the operating speed that was captured by 50 times on the eastbound direction of N 56^{th} Street and E Fowler Ave. The average operating speed is 37.86 mph.

Table 18 Operating Speed of Eastbound Direction of Intersection of N 56th Street and E Fowler Ave

Number	Speed
1	34
2	37
3	35
4	36
………	………
49	41
50	31
Average	37.86

4.9.4.3 Turn Bay Length

Table 19 shows the turn bay length of intersection of N 56th Street and E Fowler Ave, which includes four approaches: eastbound, westbound, northbound and southbound. The turn bay length was observed from Google Earth.

Table 19 Turn Bay Length of Intersection of N 56th Street and E Fowler Ave

Approach	Lane Assignment	Turn Bay Length
Eastbound	Two Left, Three Through and One Right	Left: 358 ft Right: 396 ft
Westbound	Two Left, Three Through	Left: 540ft
Northbound	Three Left, Two Through and One Right	Left: 452ft Right: 353ft
Southbound	Two Left, Three Through and One Right	Left: 321ft Right: 104ft

4.9.4.4 Signal Timing Plan

Besides traffic volume, operating speed and turn bay length, signal timing of intersection of N 56th Street and E Fowler Ave was also collected by stop watch. Table 20 shows the signal timing data.

Table 20 Signal Timing of Intersection of N 56th Street and E Fowler Ave

Phase	Maneuver	Time (s)
Phase I	Eastbound & Westbound Left	22+3+1
Phase II	Eastbound Through and Right, Westbound Through and Right	76+3+1
Phase III	Westbound Right, Southbound Left, Through and Right	16+3+1
Phase IV	Northbound & Southbound Left	10+3+1
Phase V	Eastbound Right, Northbound Left, Through and Right	17+3+1

4.9.4.5 Travel Time (Bruce B Downs Blvd→N 60th Street)

The travel time from intersection of Bruce B Downs Blvd and E Fowler Ave to intersection of N 60th Street and E Fowler Ave was collected, as shown in Table 21. Two people participated in data collection of travel time. GPS was set up on the car, which was connected with the computer and the cigarette lighter. A software was installed in the computer, which can record time duration of each back and forth. Then, one person drove the car from intersection of Bruce B Downs Blvd and E Fowler Ave to intersection of N 60th Street and E Fowler Ave on E Fowler Ave 10 back and forths. Three categories of lanes were defined: inside, medium and outside. One lane was selected for each back and forth. The other person read the number on the computer screen and wrote it down. Finally, 20 groups of travel time data were collected on E Fowler Ave (Bruce B Downs Blvd→N 60th Street). The travel data time was divided into two groups: eastbound and westbound direction. Average travel time was calculated for each direction, which can be used for comparison with simulated travel time and calibrated travel time, and calculate the fitness factor for further calibration.

Table 21 Travel Time From Intersection of Bruce B Downs Blvd and E Fowler Ave to Intersection of N 60th Street and E Fowler Ave

No.	Direction	Time (min:s)	Time (s)	Lane
1	BBD→N 60th Street	4:45	285	Middle
	N 60th Street→ BBD	4:42	282	Middle
2	BBD→N 60th Street	4:03	243	Inside
	N 60th Street→ BBD	6:08	368	Inside
3	BBD→N 60th Street	4:13	253	Outside
	N 60th Street→ BBD	6:40	400	Outside
4	BBD→N 60th Street	4:26	266	Inside
	N 60th Street→ BBD	6:27	387	Inside
5	BBD→N 60th Street	5:50	350	Middle
	N 60th Street→ BBD	4:31	271	Middle
6	BBD→N 60th Street	4:15	255	Outside
	N 60th Street→ BBD	5:18	318	Outside
7	BBD→N 60th Street	4:27	267	Inside
	N 60th Street→ BBD	3:12	192	Inside
8	BBD→N 60th Street	3:58	238	Middle
	N 60th Street→ BBD	4:58	298	Middle
9	BBD→N 60th Street	3:36	216	Outside
	N 60th Street→ BBD	4:40	280	Outside
10	BBD→N 60th Street	3:32	212	Inside
	N 60th Street→ BBD	4:00	240	Inside

4.9.5 Data Reduction

Data reduction was conducted after data collection work was completed. Peak-hour traffic volume was obtained from multi-hour volume. Traffic volume of one hour was calculated from the actual collected traffic volume. Speed variation, average speed, and other speed related data were calculated from the collected operating speed data in an Excel spreadsheet. For each observed site, field data are shown below, which includes traffic operating speed and traffic volume. Tables 22–50 show the field speed data and field traffic volume at the 15 sites. The plot of distance vs. average speed and SSD for each observed site is shown in Figure 23–37. The X-axis represents the distance from the beginning driveway of operating speed data collection. The Y-axis represents the average traffic speed in mile per hour (mph) and traffic speed standard deviation (SSD). The blue dotted line in the figure represents the average speed, and the red dotted line in the figure represents SSD.

Table 22 Field Speed Data (E Fowler Ave)

No.	Origin	Relative Position	Distance to 56th Street(m)	Distance to 56th Street(ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	East of 56th Street, start point of the first left bay	W 50m	50	164	29	30	…	35	31.06	29.5677551	5.437624031
2	East of 56th Street, start point of the first left bay	0	100	328	34	37	…	31	37.86	26.16367347	5.115043838
3	East of 56th street, start point of the first left bay	E 50m	150	492	23	20	…	38	37.74	34.52285714	5.875615469
4	West of Ridgedale RD, start point of the first left bay	0	275	902	32	49	…	34	42.28	38.04244898	6.167856109

Table 22 (continued)

5	West of Ridgedale RD, start point of the first left bay	E 50m	325	1066	48	51	…	40	43.86	30.2044898	5.495861151
6	West of Summit W Blvd, start point of the first left bay	0	450	1476	37	45	…	47	43.38	32.85265306	5.731723394
7	West of Summit W Blvd, start point of the first left bay	E 50m	500	1640	31	40	…	40	43.94	25.73102041	5.072575323
8	East of Summit W Blvd, start point of the first left bay	E 50m	640	2099	53	55	…	42	44.96	14.24326531	3.77402508
9	Moffat Pl Approach	W 50m	1170	3838	50	51	…	45	47.94	17.11877551	4.137484201
10	Moffat Pl Approach	0	1220	4002	42	39	…	49	47.78	11.60367347	3.406416514

Table 22 (Continued)

11	Gillette Ave Approach	W 100m	1480	4854	48	48	…	38	41.18	29.37510204	5.419880261
12	Gillette Ave Approach	W 50m	1530	5018	22	31	…	57	48.06	80.75142857	8.986179865
13	Gillette Ave Approach	E 100m	1680	5510	45	34	…	47	43.32	38.71183673	6.221883697
14	N Riverhills Dr Approach	W 100m	2280	7478	41	44	…	46	43.66	21.24938776	4.609705821
15	N Riverhills Dr Approach	W 50m	2330	7642	40	44	…	44	33.74	178.5636735	13.36277192
16	N Riverhills Dr Approach	E 100m	2480	8134	34	41	…	49	39.76	80.67591837	8.98197742

Table 23 Field Speed Data (N Dale Mabry)

No	Origin	Distance to Van Dyke Rd (m)	Distance to Van Dyke Rd (ft)	Val1	Val2	Val…	Val58	Average Speed	Speed Variation	SSD
1		195	639	47	44	…	0	38.38	292.5553539	17.10424959
2		403	1322	48	52	…	0	38.24	284.4319419	16.8651102
3	Little Rd	623	2045	54	62	…	0	42.19	344.1563823	18.5514523
4	Valley Ranch Dr	1119	3673	55	59	…	0	44.33	346.715366	18.62029447
5	N Lakeview Dr	1684	5525	20	10	…	0	27.05	212.084997	14.56313829
6	100 ft behind N Lakeview Dr	1714	5625	57	56	…	0	42.29	363.0529341	19.05394799
7		2549	8364	34	30	…	0	30.57	241.6881428	15.54632248
8	Northgreen Ave	2673	8770	19	16	…	0	24.97	193.0163339	13.89303185
9	100 ft behind Northgreen Ave	2703	8870	24	43	…	0	26.26	160.7214156	12.67759502
10		3710	12172	23	32	…	0	21.67	151.592559	12.312293
11	Mapledale Blvd	3840	12600	17	21	…	0	32.22	167.0190563	12.92358527
12		4003	13135	36	22	…	26	27.03	76.38475499	8.739837241
13		4138	13577	41	39	…	0	29.43	124.9513007	11.17816177
14		4248	13937	35	40	…	0	35.00	102.0701754	10.10297854
15		4345	14255	28	23	…	0	30.62	74.30973987	8.620309731
16	Northdale Blvd									

Table 24 Field Traffic Volume (N Dale Mabry)

Time	**Lane 1**	**Lane 2**	**Lane 3**	**Total**
4:55-5:25PM	239	378	329	946
5:25-5:55PM	230	350	380	960
5:55-6:25PM	200	305	337	842
Total				**1832**

Table 25 Field Speed Data (State 54)

No.	**Origin**	**Distance to Helen Cove Dr. (m)**	**Distance to Helen Cove Dr. (ft)**	**Val1**	**Val2**	**Val…**	**Val50**	**Average Speed**	**Speed Variation**	**SSD**
1	Helen Cove Dr.	0	0	57	50	…	37	51.76	29.41061224	5.423155193
2	St Thomas Cir.	544	1784	59	50	…	57	49.94	21.73102041	4.661654257
3	Collier Pkwy (-150ft)	1046	3431	17	23	…	36	29.56	62.33306122	7.895128956
4	Collier Pkwy	1092	3582	11	10	…	43	31.36	233.6636735	15.28606141
5	Collier Pkwy (+150ft)	1138	3733	41	45	…	39	42.00	60.53061224	7.780142174
6	Segment	1378	4520	59	53	…	37	49.34	35.73918367	5.978225796
7	Livingston Rd (-150ft)	2051	6727	49	41	…	41	37.90	189.9693878	13.78293828
8	Livingston Rd	2097	6878	42	45	…	42	38.68	274.9159184	16.5805886
9	Livingston Rd (+150ft)	2143	7029	18	19	…	51	32.18	126.8444898	11.26252591
10	Median Divider	2490	8167	52	34	…	39	52.12	64.72	8.044874144
11	Foggy Ridge Pkwy	3093	10145	52	54	…	50	51.90	78.78571429	8.876131719

Table 25 (continued)

12	Oak Grove Blvd (-150ft)	3461	11352	50	42	…	54	49.88	57.08734694	7.555616913
13	Oak Grove Blvd	3507	11503	53	50	…	57	49.04	126.202449	11.23398634
14	Oak Grove Blvd (+150ft)	3552	11651	56	58	…	43	49.04	52.16163265	7.222301064
15	Carpeners Run Blvd	4057	13307	46	45	…	55	55.18	41.57918367	6.44819228

Table 26 Field Traffic Volume (State 54)

Time	Total
7:30-8:00AM	708
8:00-8:30AM	745
Total	**1453**

Table 27 Field Speed Data (US 41)

No.	Origin	Distance to Lakeside Road (m)	Distance to Lakeside Road (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Lakeside Rd	0	0	42	52	…	52	49.84	28.42285714	5.33130914
2	No Name	261	856	55	47	…	43	47.66	26.88204082	5.18478937
3	Crystal Lake Rd (-150 ft)	441	1448	40	45	…	24	40.42	176.4934694	13.28508447

Table 27 (continued)

4	Crystal Lake Rd	487	1598	31	33	…	54	44.84	74.79020408	8.648132982
5	Crystal Lake Rd (+150ft)	533	1748	16	17	…	38	31.92	71.99346939	8.484896545
6	Crystal Grove Blvd	1230	4035	25	17	…	19	29.68	83.32408163	9.128202541
7	4th AVE SE	1815	5955	45	47	…	38	41.90	40.74489796	6.383173032
8	2nd AVE SE	2008	6588	51	32	…	40	43.02	61.20367347	7.823277668
9	W Lutz Lake Fern Rd	2180	7152	51	50	…	38	40.88	142.72	11.94654762
10	2nd Ave NE	2390	7841	42	11	…	45	45.30	64.98979592	8.061624893
11	5th Ave NE	2636	8648	46	38	…	47	49.84	48.6677551	6.976227856
12	Newberger Rd	3176	10420	54	53	…	52	47.44	100.1289796	10.0064469

Table 28 Field Traffic Volume (US 41)

Time	Lane 1	Lane 2	Lane 3	Total
3:50-4:05 PM	117	122	139	378
4:05-4:20 PM	123	139	174	436
4:20-4:35 PM	158	154	200	512
4:35-4:50 PM	164	177	202	543
4:50-5:05 PM	190	200	218	608
5:05-5:20 PM	204	190	217	611

Table 28 (continued)

5:20-5:35 PM	183	185	187	555
5:35-5:50 PM	202	188	207	597
Total				2120

Table 29 Field Speed Data (CR 60)

No.	Origin	Distance to first point (m)	Distance to first point (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1		0	0	66	67	…	68	57.50	36.13265306	6.011044257
2	Median Opening	250	820	60	43	…	55	55.76	34.34938776	5.860835073
3		755	2477	58	58	…	45	57.50	21.52040816	4.639009395
4	Median Opening	1558	5112	62	49	…	58	60.84	40.87183673	6.393108535
5	Median Opening	1858	6096	68	63	…	66	59.30	30.5	5.522680509
6	Median Opening	2207	7241	49	48	…	54	54.80	40.32653061	6.350317363
7		2479	8133	57	56	…	64	54.46	24.58	4.957822102
8	Jerry Smith Rd	2754	9035	61	45	…	48	54.14	80.49020408	8.971633301
9	Median Opening	3011	9879	51	50	…	61	57.06	47.07795918	6.861338002
10	Median Opening	3264	10709	64	61	…	60	57.16	35.44326531	5.95342467
11	S Farkas Rd	3508	11509	64	58	…	52	54.90	36.21428571	6.017830649

Table 30 Field Traffic Volume (CR 60)

Time	Total
16:08-16:23	244
16:25-16:40	256
16:40-16:55	291
16:55-17:10	269
17:10-17:25	268
Total	**1062**

Table 31 Field Speed Data (Bruce B Downs Blvd-SB)

No	Origin	Distance to Fire Station (m)	Distance to Fire Station (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Fire Station	0	0	41	37	…	46	40.68	31.40571429	5.604080146
2	Segment	368	1205	50	40	…	54	44.90	25.15306122	5.015282766
3	Median Opening	798	2617	42	46	…	20	33.22	139.4812245	11.81021695
4	Tampa Palms Blvd (-150 ft)	953	3128	34	39	…	49	33.12	81.45469388	9.02522542
5	Tampa Palms Blvd	999	3278	20	12	…	47	32.16	78.13714286	8.839521642
6	Tampa Palms Blvd (+150 ft)	1045	3428	27	32	…	37	33.62	34.77102041	5.896695719
7	Segment	1528	5013	40	43	…	36	37.90	33.84693878	5.817812198

Table 31 (continued)

8	Amberly Dr (-150 ft)	2012	6602	32	38	…	34	37.32	27.69142857	5.262264586
9	Amberly Dr	2058	6752	14	14	…	37	32.94	66.75142857	8.170154746
10	Amberly Dr (+150 ft)	2104	6902	43	44	…	42	37.08	75.05469388	8.663411215
11	Cypress Creek	2633	8638	28	25	…	48	33.98	48.06081633	6.932590881
12	No Name	2878	9442	47	44	…	45	41.94	6.792244898	2.606193565
13	Gilligaris Way	2985	9793	44	44	…	42	43.34	14.51469388	3.809815465
14	N 42nd Street	3313	10868	51	31	…	40	39.12	19.00571429	4.359554368

Table 32 Field Traffic Volume (Bruce B Downs Blvd-SB)

Time	Lane 1	Lane 2	Total
7:07-7:22 AM	190	168	358
7:22-7:37 AM	159	157	316
7:37-7:52 AM	228	200	428
7:52-8:07 AM	199	174	373
Total			**1475**

Table 33 Field Speed Data (Temple Terrace Hwy)

No	Origin	Distance to First Point (m)	Distance to First Point (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Median Opening-1	0	0	39	44	…	42	43.62	23.8322449	4.881828028
2	Median Opening-2	216	708	48	39	…	42	46.04	29.01877551	5.386907787
3	Median Opening-3	439	1441	53	38	…	42	46.72	41.92	6.474565622
4	Knights Branch St.	750	2462	34	34	…	49	43.62	29.87306122	5.465625419
5	N 78th St (-150 ft)	858	2814	25	14	…	42	40.24	77.24734694	8.789046987
6	N 78th St	903	2964	47	48	…	32	35.30	125.0714286	11.18353381
7	N 78th St (+150 ft)	949	3114	24	24	…	47	30.06	129.2004082	11.36663575
8	Temple Park Dr. (-150 ft)	1274	4181	19	18	…	35	36.52	72.09142857	8.490667145
9	Temple Park Dr.	1320	4331	11	14	…	33	33.12	143.3322449	11.97214454
10	Temple Park Dr.(+150 ft)	1366	4481	18	18	…	31	34.80	100.0408163	10.00204061
11	Central Park Cir	1610	5281	41	40	…	45	45.04	15.4677551	3.932906699
12	Riverchase Dr E	1818	5963	42	37	…	38	45.14	22.89836735	4.785223855
13	S Glen Arven Ave (-150 ft)	2335	7661	35	37	…	46	36.92	27.46285714	5.240501612
14	S Glen Arven Ave	2381	7811	45	39	…	25	27.10	83.92857143	9.161253813

Table 33 (continued)

15	S Glen Arven Ave (+150 ft)	2427	7961	38	39	…	32	31.12	25.74040816	5.073500583
16	N Burlingame Ave	2763	9063	45	42	…	30	33.34	24.06571429	4.905681837
17	Ridgedale Rd	2912	9552	42	35	…	31	32.04	24.52897959	4.952673984
18	T-type Signalized Intersection	3187	10453	27	25	…	26	29.34	15.33102041	3.915484696

Table 34 Field Traffic Volume (Temple Terrace Hwy)

Time	Total
7:20-7:35 AM	236
7:35-7:50 AM	233
7:50-8:05 AM	220
8:05-8:20 AM	200
Total	889

Table 35 Field Speed Data (W Hillsborough Ave-1, Begin with Tudor Dr)

No	Origin	Distance to Tudor Dr (m)	Distance to Tudor Dr (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Tudor Dr	0	0	54	53	…	35	46.26	77.54326531	8.805865392
2	Sussex Dr	246	807	57	56	…	49	50.38	37.05673469	6.087424307
3	Little River Dr	574	1883	54	23	…	48	47.98	39.53020408	6.287304994

Table 35 (continued)

4	Elliott Dr	1181	3873	31	51	…	47	47.14	55.5922449	7.456020715
5	Mertens Ave	1270	4165	34	35	…	32	39.02	97.53020408	9.875738154
6	W Longboat Blvd (-150 ft)	1425	4674	49	24	…	32	43.68	82.38530612	9.076635176
7	W Longboat Blvd	1471	4824	18	19	…	42	40.56	156.4963265	12.50984918
8	W Longboat Blvd (+150 ft)	1517	4974	21	37	…	42	39.66	72.35142857	8.505964294
9	Tampa Shores Blvd	1765	5788	37	49	…	43	44.90	7.071428571	2.659215781
10	Silvermill Dr (-150 ft)	2519	8262	27	38	…	52	29.56	89.27183673	9.448377466
11	Silvermill Dr	2565	8412	43	42	…	47	39.10	149.0714286	12.20948109
12	Silvermill Dr (+150 ft)	2611	8562	37	23	…	28	41.40	88.08163265	9.385181546
13	Pistol Range Rd	2907	9535	46	46	…	37	42.10	64.94897959	8.059092976
14	Last One	3067	10060	53	53	…	41	46.26	70.27795918	8.383195046

Table 36 Field Traffic Volume (W Hillsborough Ave-1, Begin with Tudor Dr)

Time	Lane 1	Lane 2	Lane 3	Total
4:15-4:30 PM	138	184	138	460
4:30-4:45 PM	159	181	129	469
4:45-5:00 PM	151	199	149	499
5:00-5:15 PM	164	197	144	505
Total				**1933**

Table 37 Field Speed Data (W Hillsborough Ave-2, Begin with Montague Street)

No	Origin	Distance to Montague St. (m)	Distance to Montague St. (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Montague St.	0	0	24	21	…	44	44.50	66.58163265	8.159756899
2	No Name	50	164	24	49	…	44	45.06	106.0167347	10.29644282
3	No Name	418	1371	32	27	…	52	41.80	70.28571429	8.383657572
4	Countryway Blvd (-150 ft)	740	2428	40	40	…	44	44.92	38.85061224	6.23302593
5	Countryway Blvd	786	2578	57	56	…	52	33.66	175.8208163	13.2597442
6	Countryway Blvd (+150 ft)	832	2728	24	28	…	38	39.46	143.3555102	11.97311614
7	Souther Brook Bend	1197	3925	43	44	…	39	50.62	32.77102041	5.724597838
8	Double Branch Rd	2403	7881	59	59	…	61	55.70	20.94897959	4.577005527
9	No Name	3276	10746	44	37	…	46	49.22	40.82816327	6.389691954
10	No Name	3532	11586	38	30	…	41	43.38	44.64857143	6.681958652

Table 38 Field Traffic Volume (W Hillsborough Ave-2, Begin with Montague Street)

Time	Lane 1	Lane 2	Lane 3	Total
4:30-4:45 PM	165	186	122	473
4:45-5:00 PM	150	167	140	457
Total				**1860**

Table 39 Field Speed Data (W Hillsborough Ave-3, Begin with Strathmore Gate Dr)

No	Origin	Distance to Strathmore Gate Dr (m)	Distance to Strathmore Gate Dr (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Strathmore Gate Dr	0	0	48	52	…	36	42.60	17.55102041	4.1893938
2	Calibre Downs Ln	202	664	49	55	…	46	40.02	74.99959184	8.660230472
3	No Name	494	1623	49	55	…	38	42.50	25.76530612	5.075953716
4	Ramp	623	2047	15	20	…	20	37.16	118.4636735	10.88410187
5	McMullen Booth Road (-150 ft)	700	2301	42	38	…	32	39.60	62.16326531	7.884368415
6	McMullen Booth Road	746	2451	43	36	…	22	34.62	195.9138776	13.99692386
7	McMullen Booth Road (+150 ft)	792	2601	46	48	…	48	41.52	131.8057143	11.48066698
8	No Name	933	3214	43	40	…	50	43.16	32.42285714	5.69410723
9	Windward PI	1429	4842	44	50	…	41	49.34	20.43306122	4.520294374

Table 39 (continued)

10	E Lake Woodlands Pkwy (-150 ft)	1903	6399	41	48	…	35	39.50	143.4795918	11.9782967
11	E Lake Woodlands Pkwy	1949	6549	50	44	…	46	41.74	87.17591837	9.336804505
12	E Lake Woodlands Pkwy (+150 ft)	1995	6699	41	51	…	51	35.42	72.16693878	8.495112641

Table 40 Field Traffic Volume (W Hillsborough Ave-3, Begin with Strathmore Gate Dr)

Time	Lane 1	Lane 2	Lane 3	Total
5:30-6:00 PM	173	143	140	456
Total				**912**

Table 41 Field Speed Data (Bruce B Downs Blvd–NB)

No	Origin	Distance to N 42nd Street (m)	Distance to N 42nd Street (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	N 42nd Street	0	0	36	43	…	36	39.90	16.66326531	4.082066303
2	Gilligaris Way	328	1075	32	30	…	43	35.18	46.06897959	6.787413321
3	No Name	435	1426	35	37	…	45	40.26	36.40040816	6.033275078
4	Cypress Creek	680	2230	40	34	…	34	41.80	23.67346939	4.865538962

Table 41 (continued)

5	Amberly Dr (-150 ft)	1209	3966	32	30	…	35	32.20	10.32653061	3.213491965
6	Amberly Dr	1255	4116	25	27	…	43	30.78	37.07306122	6.088765164
7	Amberly Dr (+150 ft)	1301	4266	37	33	…	36	35.74	56.84938776	7.539853298
8	Segment	1785	5855	41	40	…	19	28.82	70.06897959	8.370721569
9	Tampa Palms Blvd (-150 ft)	2268	7440	29	41	…	52	40.44	36.41469388	6.034458872
10	Tampa Palms Blvd	2314	7590	40	43	…	47	40.36	54.43918367	7.378291379
11	Tampa Palms Blvd (+150 ft)	2360	7740	51	44	…	50	44.84	47.36163265	6.881978833
12	Median Opening	2515	8251	38	39	…	47	41.68	27.36489796	5.231146907
13	Segment	2945	9663	39	50	…	47	44.76	17.20653061	4.148075531
14	Fire Station	3313	10868	53	55	…	44	44.48	21.19346939	4.603636539

Table 42 Field Traffic Volume (Bruce B Downs Blvd–NB)

Time	Lane 1	Lane 2	Total
5:30-5:45 PM	353	305	658
5:45-6:00 PM	275	264	539
Total			**2394**

Table 43 Field Speed Data (CR 582)

No	Origin	Distance to Par Club Cir (m)	Distance to Par Club Cir (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Par Club Cir	0	0	45	32	…	36	39.44	47.31265306	6.878419372
2	Towne Square Plaza	134	439	36	37	…	46	41.62	54.28122449	7.367579283
3	CarroHwood Springs Blvd	375	1230	42	45	…	44	44.80	16.7755102	4.095791768
4	Casey Rd (-150 ft)	839	2752	36	35	…	41	34.02	138.2240816	11.7568738
5	Casey Rd	885	2902	16	19	…	47	33.78	143.4812245	11.97836485
6	Casey Rd (+150 ft)	931	3052	11	12	…	27	30.58	189.2281633	13.7560228
7	Otto Rd	1083	3552	36	33	…	38	33.68	38.30367347	6.18899616
8	Evershine St.	1252	4108	46	43	…	44	41.84	34.99428571	5.915596818
9	Devonshire Woods PI	1337	4386	38	49	…	21	45.16	34.83102041	5.901781122
10	Winterwind Dr	1532	5027	46	42	…	26	42.88	33.20979592	5.762794107
11	Summerwind Dr	1778	5833	45	46	…	38	45.14	25.30653061	5.030559672
12	Bashor & Legondre	1958	6425	51	52	…	42	43.08	20.23836735	4.498707297
13	Burrington Dr	2147	7046	42	41	…	42	42.24	31.81877551	5.640813373
14	Aire PI	2347	7701	31	33	…	31	41.00	37.3877551	6.114552731
15	Pennington Rd (-150 ft)	2457	8062	38	22	…	41	36.72	150.0016327	12.24751537
16	Pennington Rd	2503	8212	38	16	…	36	39.26	109.4208163	10.46044054

Table 43 (continued)

17	Pennington Rd (+150 ft)	2549	8362	19	21	…	51	42.60	69.51020408	8.337277978
18	Pizza Hut	2955	9695	28	45	…	34	33.62	38.07714286	6.170667943

Table 44 Field Traffic Volume (CR 582)

Time	**Total**
7:30-7:45 AM	315
7:45-8:00 AM	286
8:00-8:15 AM	292
8:15-8:30 AM	303
8:30-8:45 AM	251
8:45-9:00 AM	266
9:00-9:15 AM	206
9:15-9:30 AM	242
Total	1081

Table 45 Field Speed Data (US 19-1)

No	Origin	Distance to Par Club Cir (m)	Distance to Par Club Cir (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Eagle Chase Blvd	0	0	61	58	…	56	52.26	30.89020408	5.557895652
2	Dolly Bay Dr	203	664	43	58	…	49	51.06	54.9555102	7.413198379
3	Meadowbrook Dr	420	1375	59	58	…	60	54.98	23.04040816	4.800042517
4	Cyprus Dr	509	1666	51	53	…	44	49.46	63.43714286	7.964743741
5	Timberlane Rd	696	2281	51	54	…	50	51.88	136.5567347	11.68574921
6	Grand Cypress Blvd	912	2990	53	55	…	60	50.56	24.78204082	4.978156367
7	Rita Ln	1130	3705	48	50	…	40	53.84	58.79020408	7.667477035
8	Stix Billards	1471	4825	47	47	…	59	38.64	115.1738776	10.73190932
9	K Losterman Rd (-150 ft)	1512	4960	13	10	…	40	34.00	103.5510204	10.17600218
10	K Losterman Rd	1558	5110	54	23	…	52	43.64	244.357551	15.63194009
11	K Losterman Rd (+150 ft)	1604	5260	39	31	…	40	39.32	102.997551	10.14877091
12	Bus Stop (US Hwy 19 N & K Losterman Rd)	1639	5374	27	21	…	49	37.32	111.8546939	10.57613795
13	Tarponaire Mobile Home Park	1697	5564	34	42	…	52	49.58	24.28938776	4.928426499

Table 45 (continued)

14	Median Opening 1	1789	5866	33	31	…	55	45.82	70.19142857	8.3780325
15	Median Opening 2	1870	6130	57	54	…	43	49.62	13.01591837	3.60775808
16	Tookes Rd	2321	7611	49	49	…	49	51.88	40.63836735	6.374822927
17	Bus Stop (US Hwy 19 N & #38999)	2589	8489	60	58	…	45	52.16	44.30040816	6.655855179
18	U-Hall	3029	9934	47	46	…	65	53.74	40.19632653	6.340057297

Table 46 Field Traffic Volume (US 19-1)

Time	Total
4:00-4:15 PM	626
4:15-4:30 PM	619
4:30-4:45 PM	691
4:45-5:00 PM	698
5:00-5:15 PM	753
5:15-5:30 PM	767
Total	**2769**

Table 47 Field Speed Data (US 19-2)

No	Origin	Distance to E Oakwood St (m)	Distance to E Oakwood St (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	E Oakwood St	0	0	40	29	…	48	44.62	47.66897959	6.904272561
2	E Lime St	94	307	40	48	…	43	38.78	27.39959184	5.234461943
3	E Boyer St	185	605	31	29	…	22	33.08	57.78938776	7.601933159
4	E Lemon St	280	917	36	40	…	44	39.64	62.03102041	7.875977426
5	E Court St	372	1219	49	51	…	23	45.88	66.23020408	8.138194154
6	E Tarpon Ave (-150 ft)	420	1379	42	23	…	25	35.78	94.05265306	9.698074709
7	E Tarpon Ave	466	1529	22	21	…	46	34.02	63.69346939	7.980818842
8	E Tarpon Ave (+150 ft)	512	1679	42	42	…	17	37.42	102.4118367	10.11987336
9	Three Leg Intersection-1	725	2378	42	40	…	47	46.96	14.36571429	3.79021296
10	E Pine St	980	3214	41	40	…	49	51.82	31.98734694	5.655735756
11	Three Leg Intersection-2	1070	3510	49	51	…	50	47.74	15.21673469	3.900863327
12	Spruce St	1200	3935	44	46	…	51	49.80	17.71428571	4.208834246
13	Three Leg Intersection-3	1262	4137	44	42	…	50	49.26	19.33918367	4.397633872
14	E Live Oak St	1354	4438	33	53	…	56	50.40	20.7755102	4.558016038
15	Three Leg Intersection-4	2646	8677	55	54	…	47	50.18	23.53836735	4.851635533

Table 47 (continued)

16	Beckett Way (-150 ft)	2698	8847	59	58	…	34	42.22	178.1342857	13.34669569
17	Beckett Way	2744	8997	30	39	…	33	37.82	148.0689796	12.16835977
18	Beckett Way (+150 ft)	2790	9147	26	23	…	54	40.68	185.5281633	13.62087234
19	Three Leg Intersection-5	2995	9820	45	44	…	42	46.86	23.22489796	4.819221717

Table 48 Field Traffic Volume (US 19-2)

Time	Total
3:45-4:00 PM	682
4:00-4:15 PM	741
4:15-4:30 PM	697
4:30-4:45 PM	757
4:45-5:00 PM	356
5:00-5:15 PM	862
Total	2730

Table 49 Field Speed Data (E Dr Martin Luther King Jr Blvd)

No	Origin	Distance to E Oakwood St (m)	Distance to E Oakwood St (ft)	Val1	Val2	Val…	Val50	Average Speed	Speed Variation	SSD
1	Beechwood Blvd	0	0	43	54	…	44	45.54	30.70244898	5.540979063
2	Danny Bryan Blvd	300	984	43	29	…	51	43.36	36.64326531	6.053368096
3	301/43 (-150 ft)	640	2099	32	30	…	37	29.06	53.60857143	7.321787448
4	301/43	686	2249	25	25	…	22	25.92	25.87102041	5.0863563
5	301/43 (+150 ft)	732	2399	35	32	…	35	32.22	30.78734694	5.548634691
6	Coconut Palm Dr	1722	5649	51	42	…	51	50.24	26.96163265	5.192459211
7	Riga Blvd	2047	6717	47	48	…	47	45.46	44.90653061	6.701233514
8	Cragmont Dr	2511	8239	51	51	…	50	49.12	21.41387755	4.627513107
9	N Falkenburg Rd (-150 ft)	3101	10172	30	29	…	41	24.70	79.68367347	8.926571205
10	N Falkenburg Rd	3146	10322	38	15	…	37	21.90	140.4591837	11.85154773
11	N Falkenburg Rd (+150 ft)	3192	10472	14	15	…	14	22.90	62.70408163	7.918590887
12	Queen Palm Dr	3389	11119	48	43	…	27	30.96	73.4677551	8.571333333

Table 50 Field Traffic Volume (E Dr Martin Luther King Jr Blvd)

Time	Total
4:10-4:25 PM	390
4:25-4:40 PM	347
4:40-4:55 PM	380

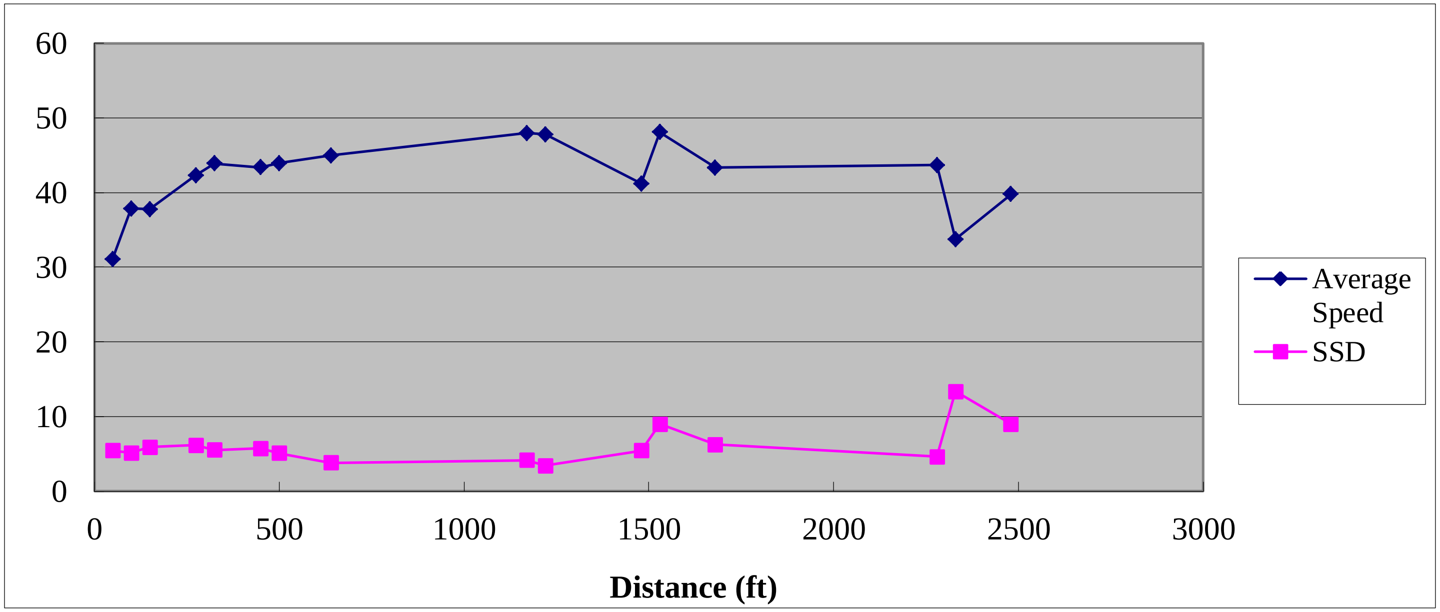


Figure 23 Distance vs. Average Speed, SSD (E Fowler Ave)

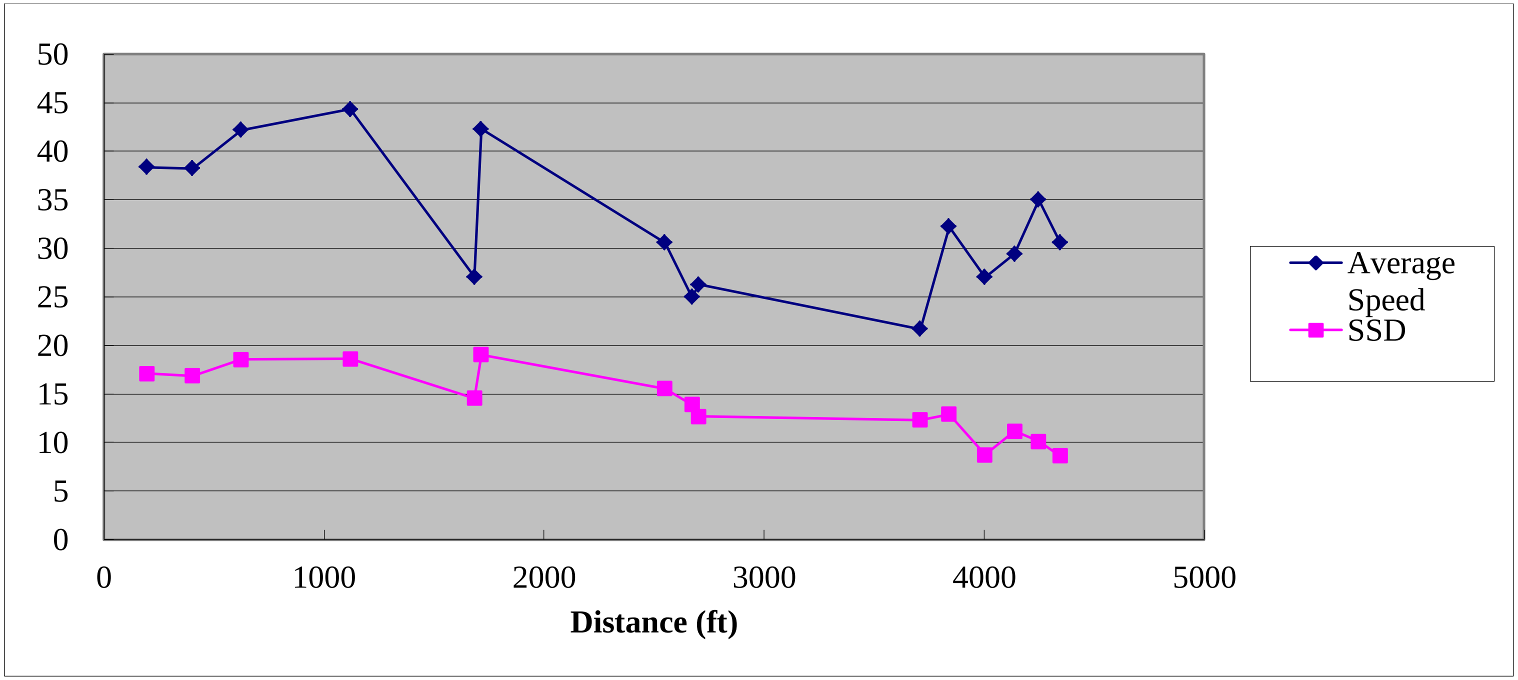


Figure 24 Distance vs. Average Speed, SSD (N Dale Mabry)

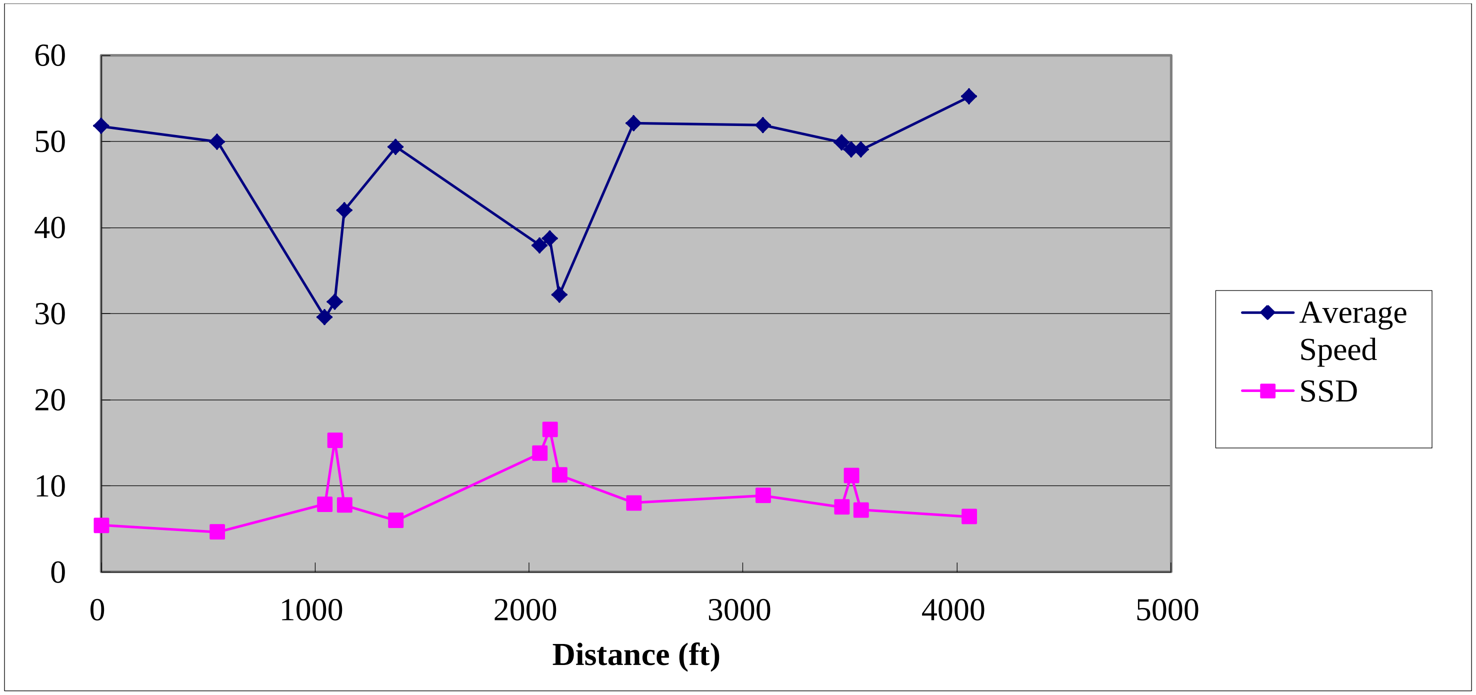


Figure 25 Distance vs. Average Speed, SSD (SR 54)

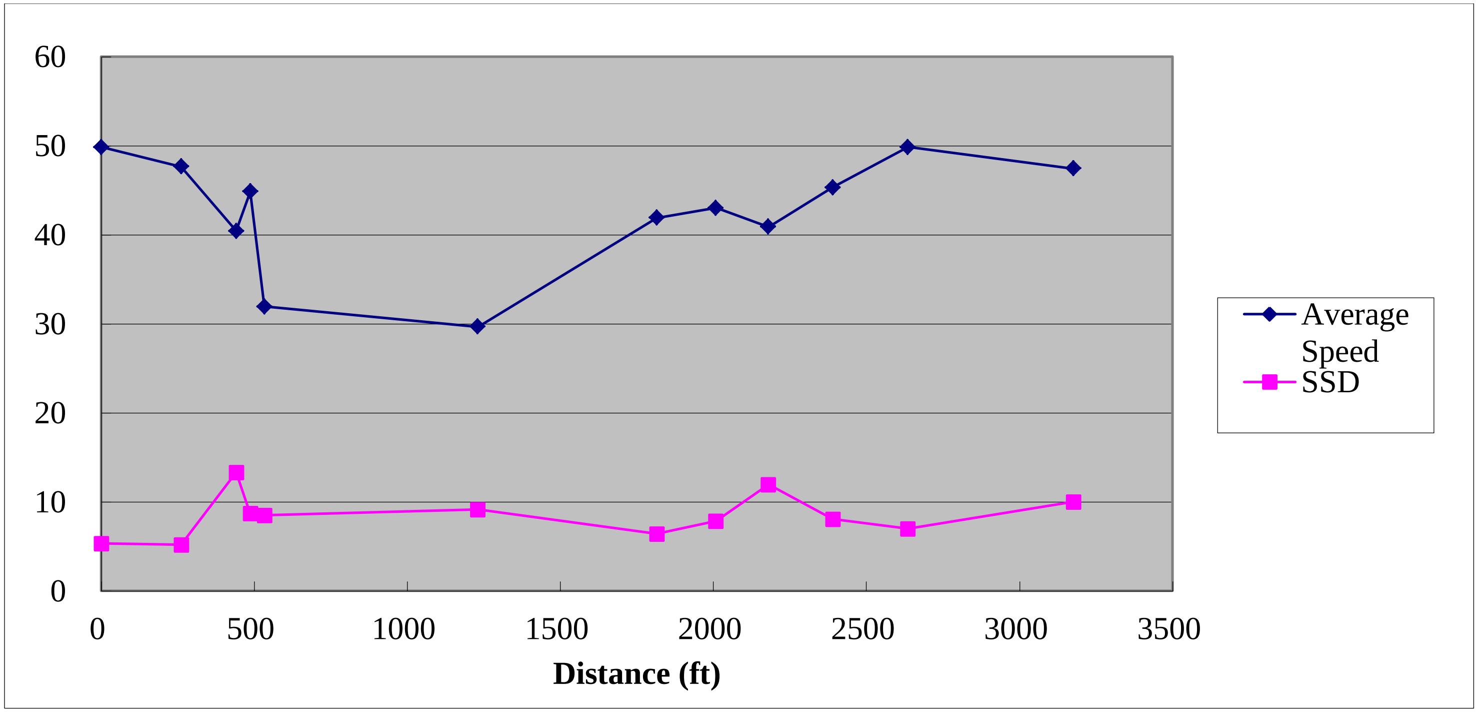


Figure 26 Distance vs. Average Speed, SSD (US 41)

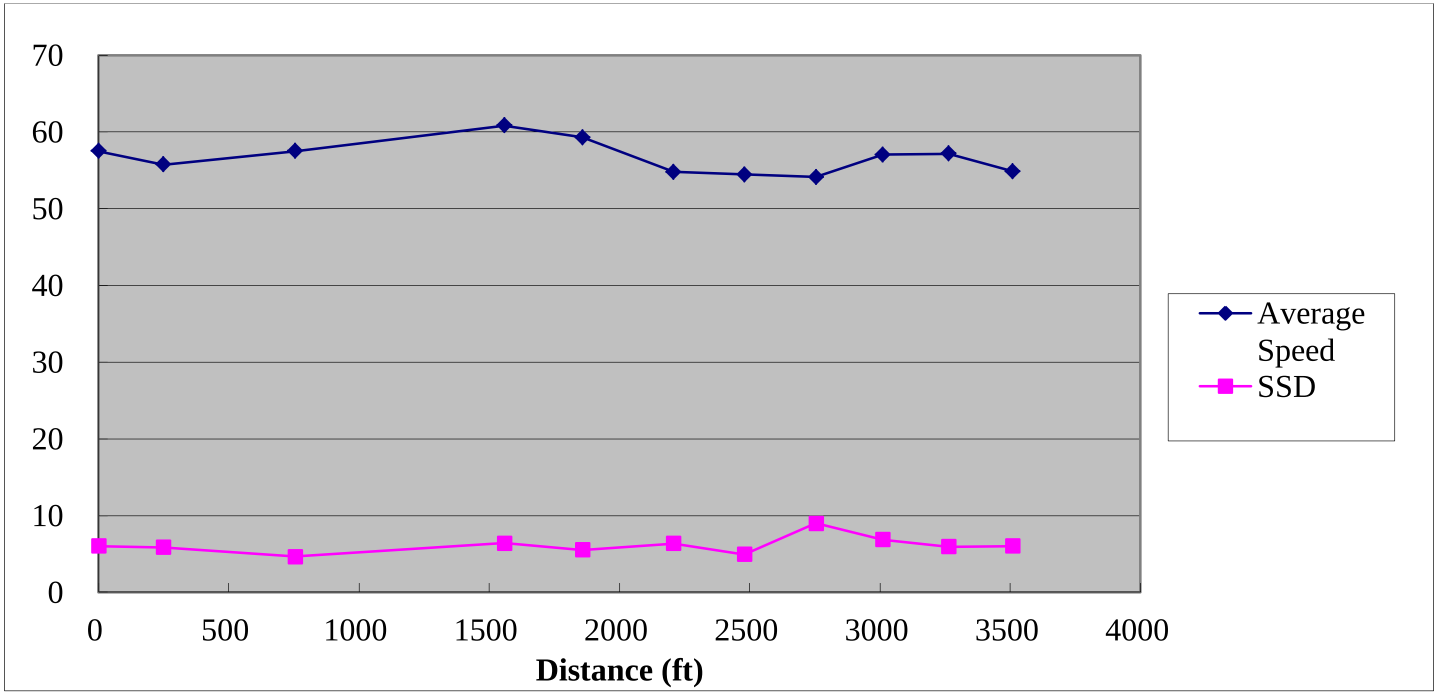


Figure 27 Distance vs. Average Speed, SSD (CR 60)

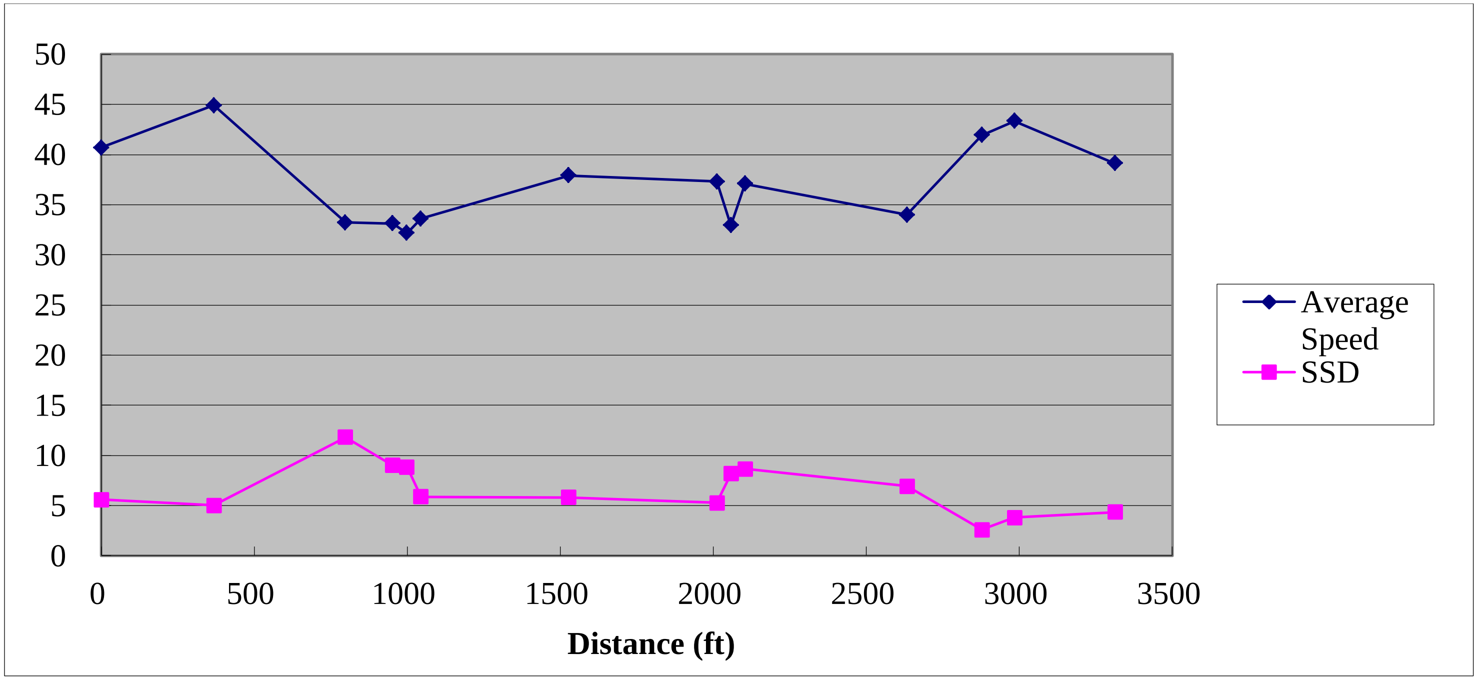


Figure 28 Distance vs. Average Speed, SSD (Bruce B Downs Blvd–SB)

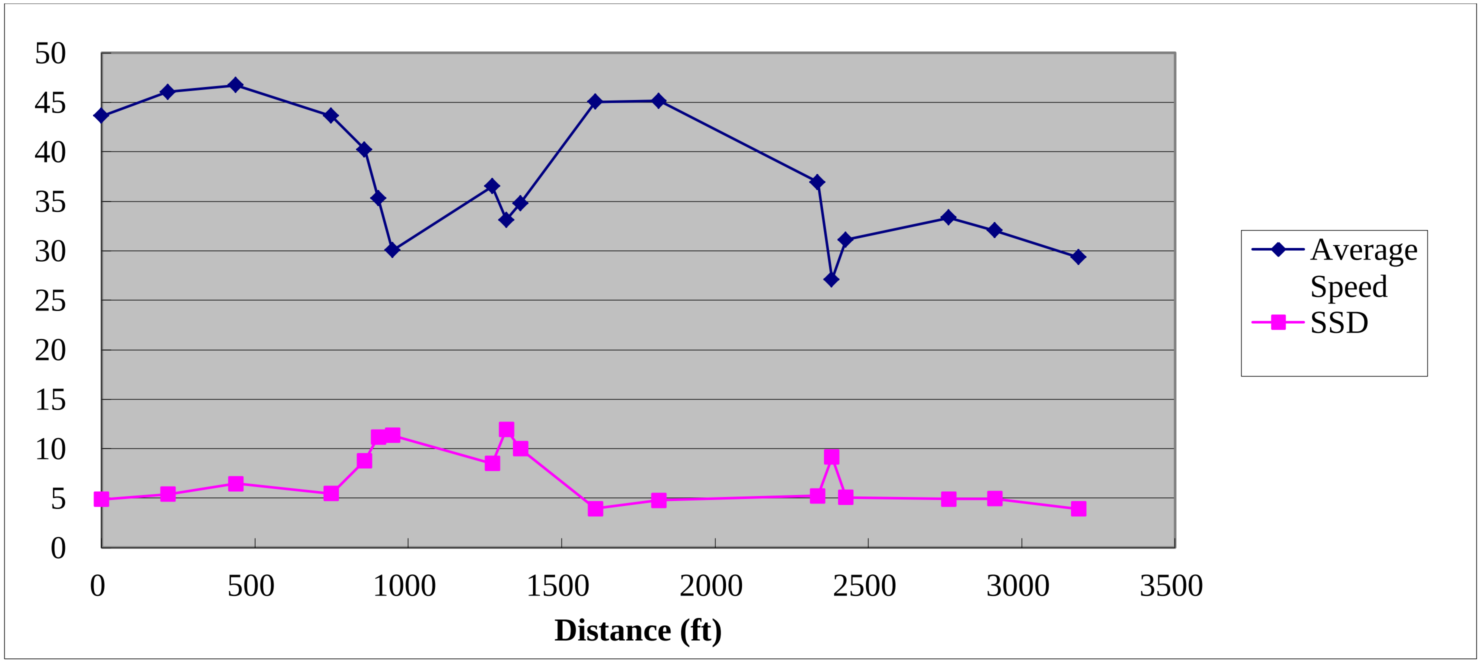


Figure 29 Distance vs. Average Speed, SSD (Temple Terrace Hwy)

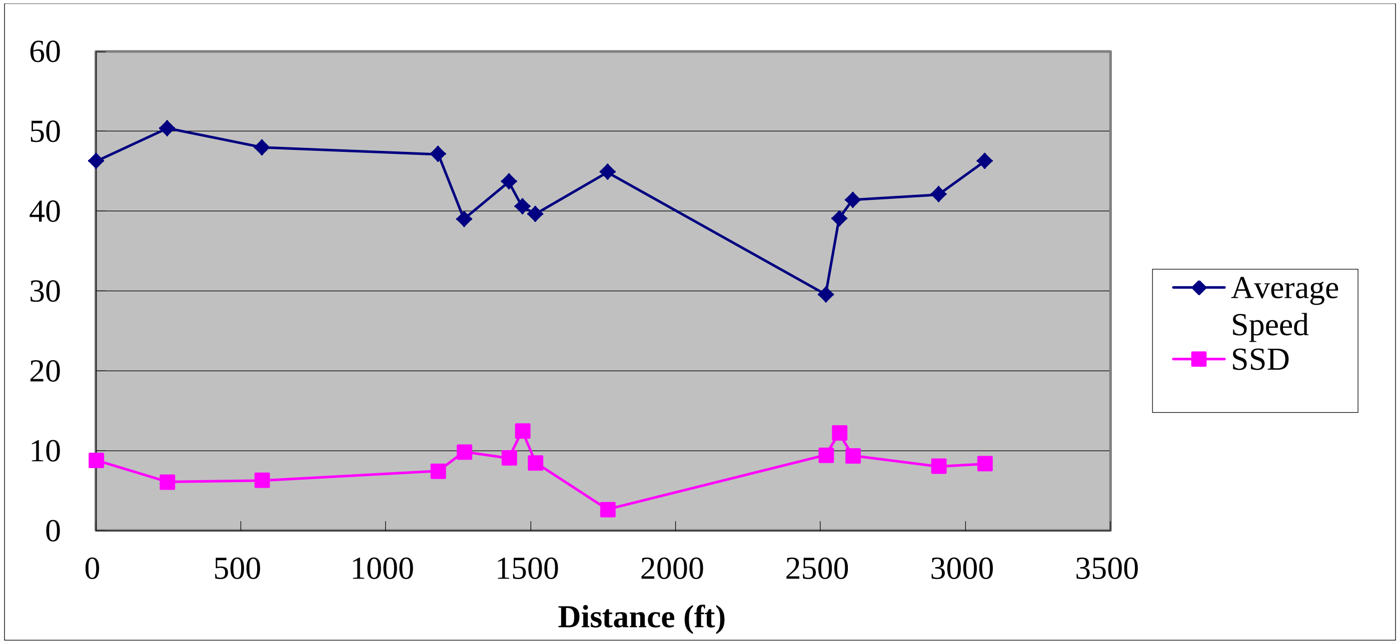


Figure 30 Distance vs. Average Speed, SSD (W Hillsborough Ave-1, begin with Tudor Dr)

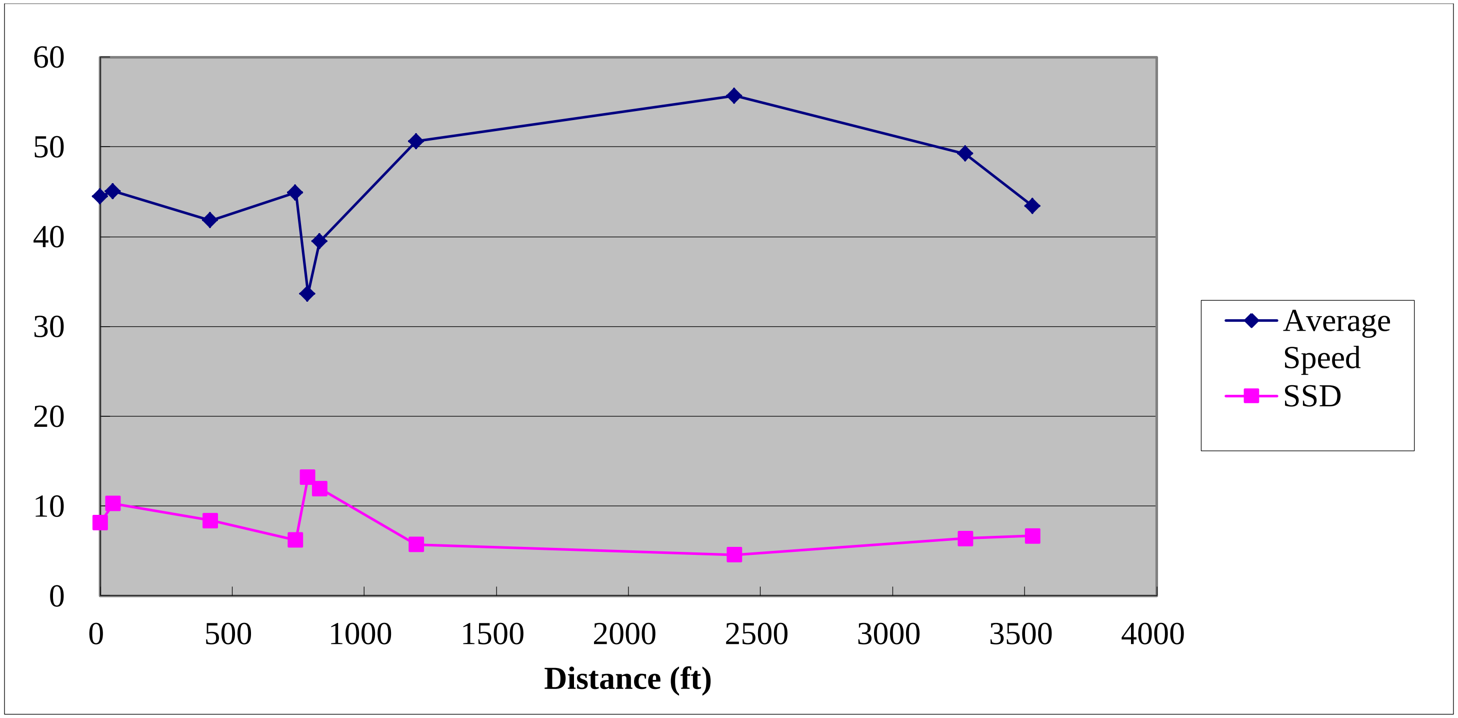


Figure 31 Distance vs. Average Speed, SSD (W Hillsborough Ave-2, begin with Montague Street)

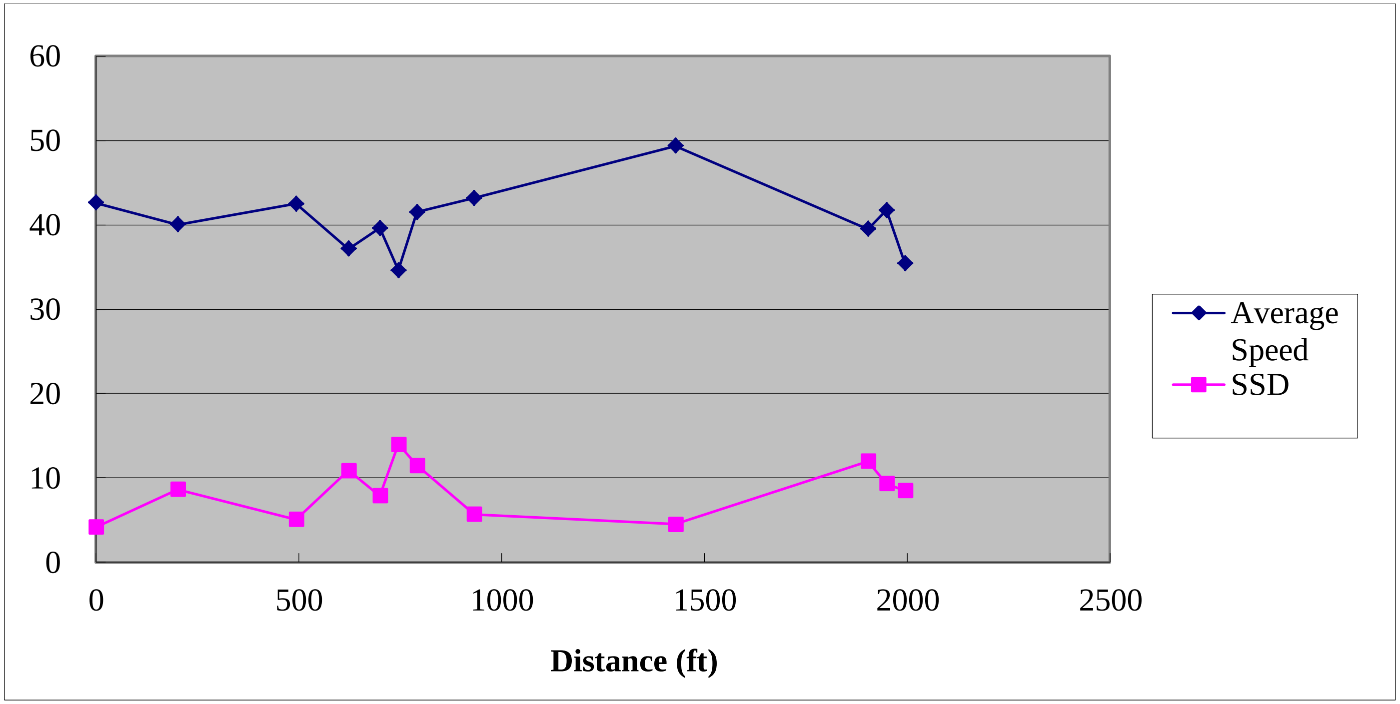


Figure 32 Distance vs. Average Speed, SSD (W Hillsborough Ave-3, begin with Strathmore Gate Dr)

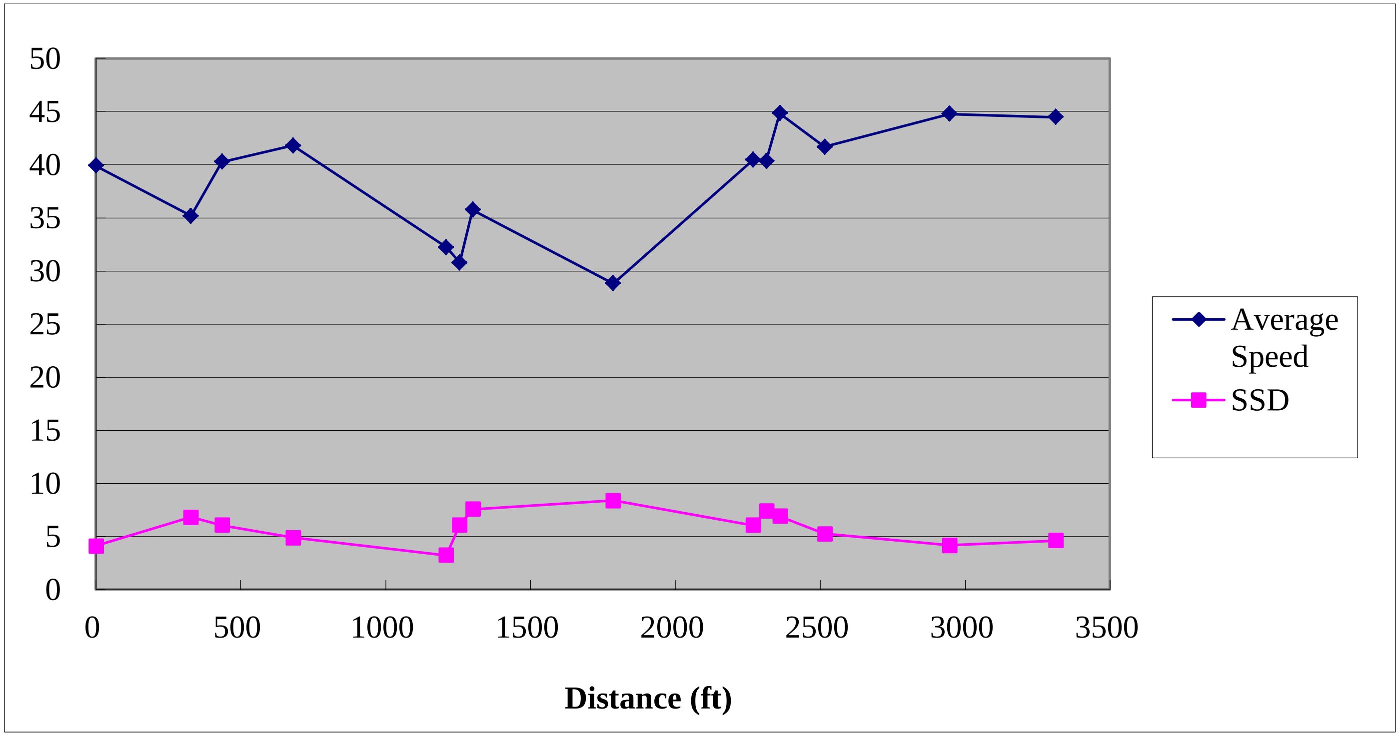


Figure 33 Distance vs. Average Speed, SSD (Bruce B Downs Blvd–NB)

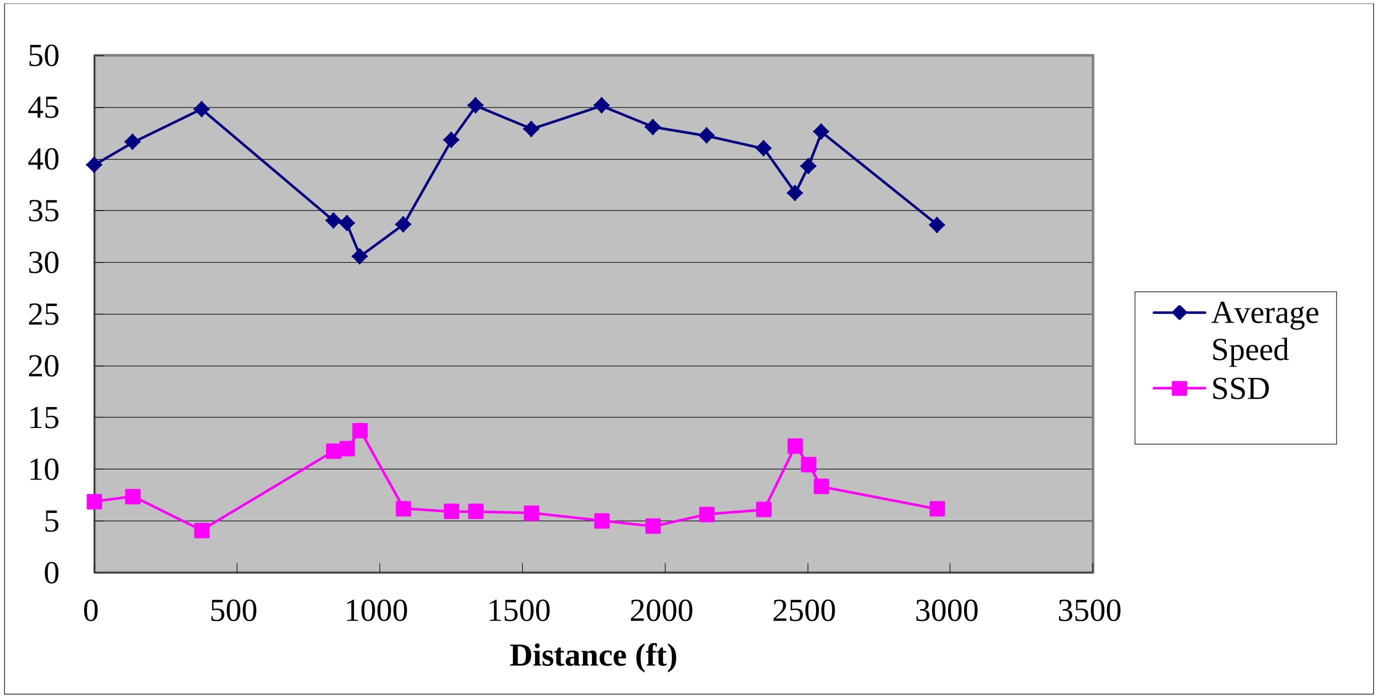


Figure 34 Distance vs. Average Speed, SSD (CR 582)

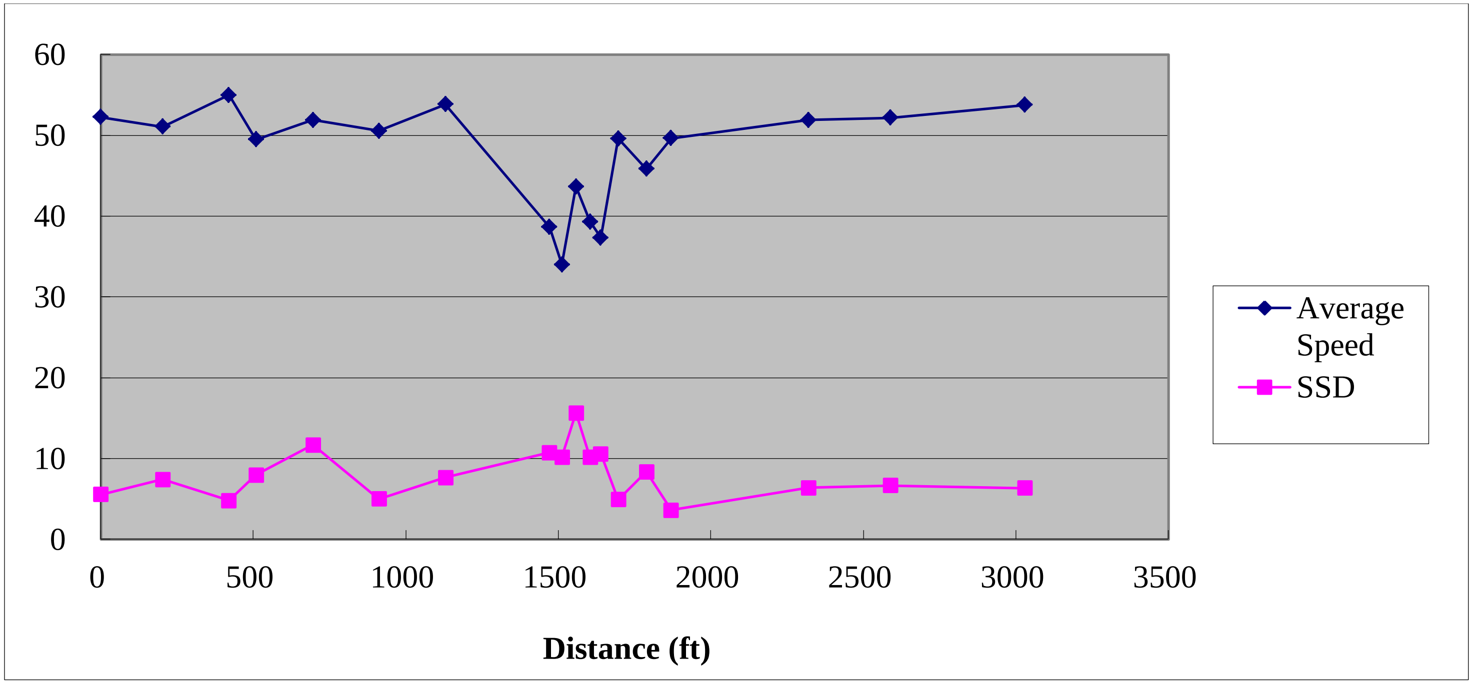


Figure 35 Distance vs. Average Speed, SSD (US 19-1)

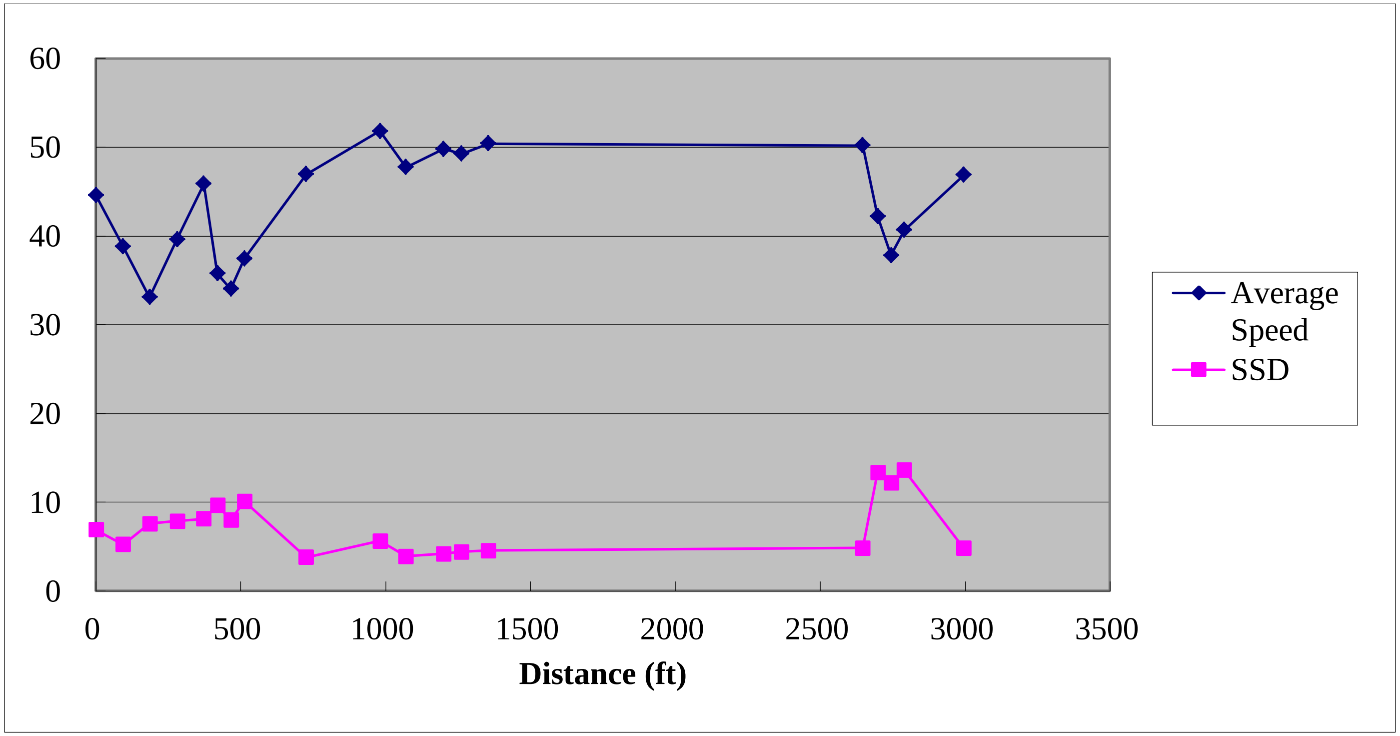


Figure 36 Distance vs. Average Speed, SSD (US 19-2)

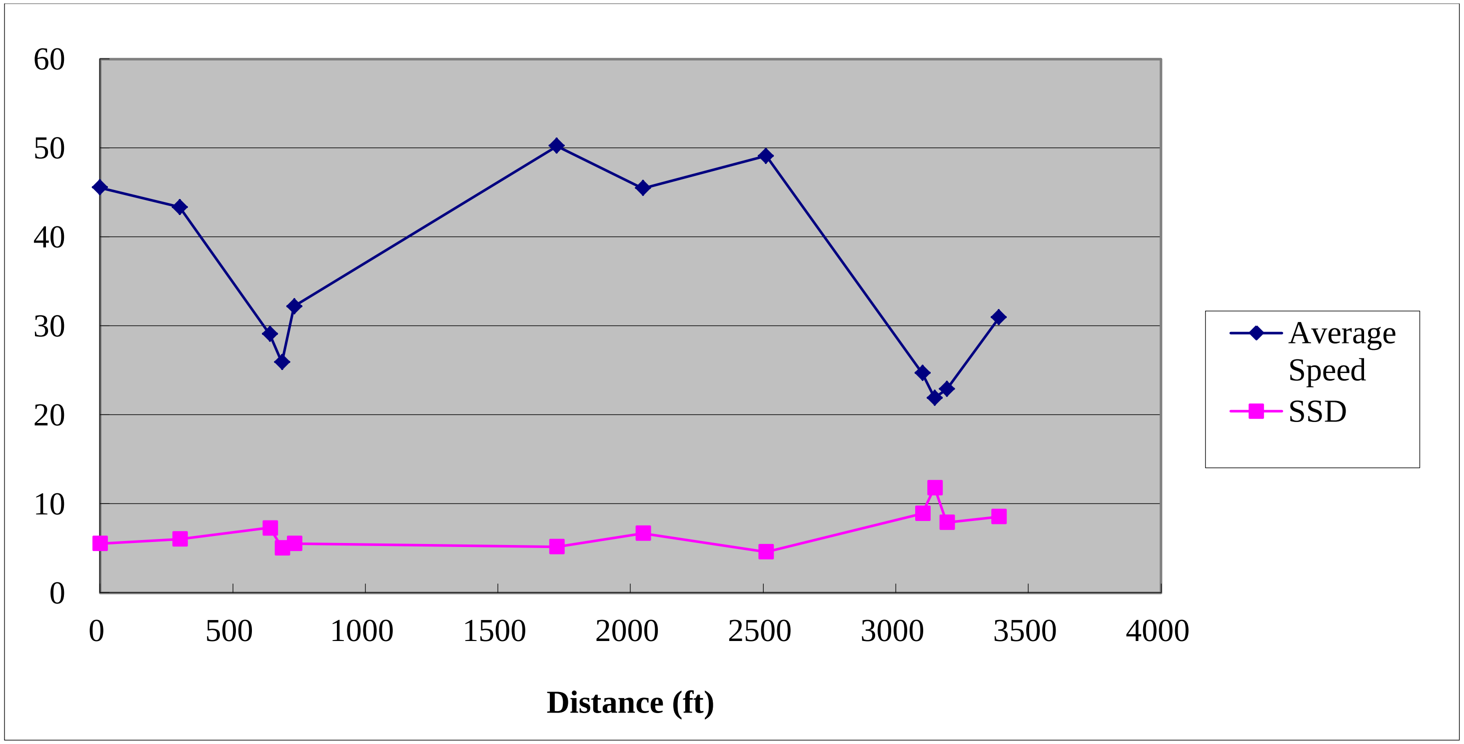


Figure 37 Distance vs. Average Speed, SSD (E Dr Martin Luther King Jr Blvd [CR 579])

4.10 Correlation between Crash Rates and Access Density

4.10.1 Site Selection

The selected roadways were 15 field data sites located in the Tampa Bay area in Florida. The length of each selected arterial is 1 to 3 miles. The posted speed limits are 45, 50, and 55 mph. The geometry information of the access points for the selected roadway was obtained from Google Earth. The selected roadway segments are primarily straight, which avoids unpredictable safety impacts due to geometry curves.

4.10.2 Crash Rates

The crash information on the selected roadway segments was extracted from the Florida State Crash Database from 2001 to 2010. The crash rate definition used in this study is crashes per million vehicle miles traveled (MVMT). It is a function of the number of crashes, the traffic volume, and the length of roadway segment, as shown below.

$$R = \frac{1{,}000{,}000 \times A}{365 \times T \times V \times L}$$

Where,

R – Crash rate for the section (in crashes per MVMT)

A – Number of reported crashes

T – Time frame of data (years)

V– AADT (average annual daily traffic) of roadway segment

L – Length of roadway segment (miles)

4.10.3 Statistical Analysis

Table 51 shows the crash rate and calculated access density for nine field data sites whose crash rates do not equal 0 and the correlation between the crash rate and the calculated access density. Similar information is presented in Figure 38 with linear trend lines. The X-axis represents the access density, and the Y-axis represents the crash rate. When the access density increases, the crash rate increases as well. Statistical analysis of this study shows that the access density calculated following the new proposed method has a higher correlation with the crash rates than the access density calculated following the existing method. For the existing method, the access density equals to the number of access points along the roadway segments divided by the length of roadway segments.

Table 51 Location, Crash Rate, Access Density, and Correlation Coefficients of 9 Field Data Sites

No.	Road Name	Crash Rate	Access Density (New Method)	Access Density (Access Mgt Manual)
1	N Dale Mabry	41.04	0.460	1.039
2	State 54	56.62	0.640	0.595
3	US 41	25.02	0.571	0.609
4	CR 60	24.85	0.438	0.505
5	Temple Terrace Hwy	131.97	1.413	0.909
6	W Hillsborough Ave-1 (begin with Tudor Dr)	150.60	0.788	0.733
7	W Hillsborough Ave-2 (begin with Montague St)	47.79	0.418	0.457
8	W Hillsborough Ave-3 (begin with Strathmore Gate Dr)	66.16	1.008	0.968
9	E Dr MLK Jr Blvd (CR 579)	61.30	0.683	0.569
Average			**0.71**	**0.71**
Correlation Coefficient			**0.71**	**0.34**

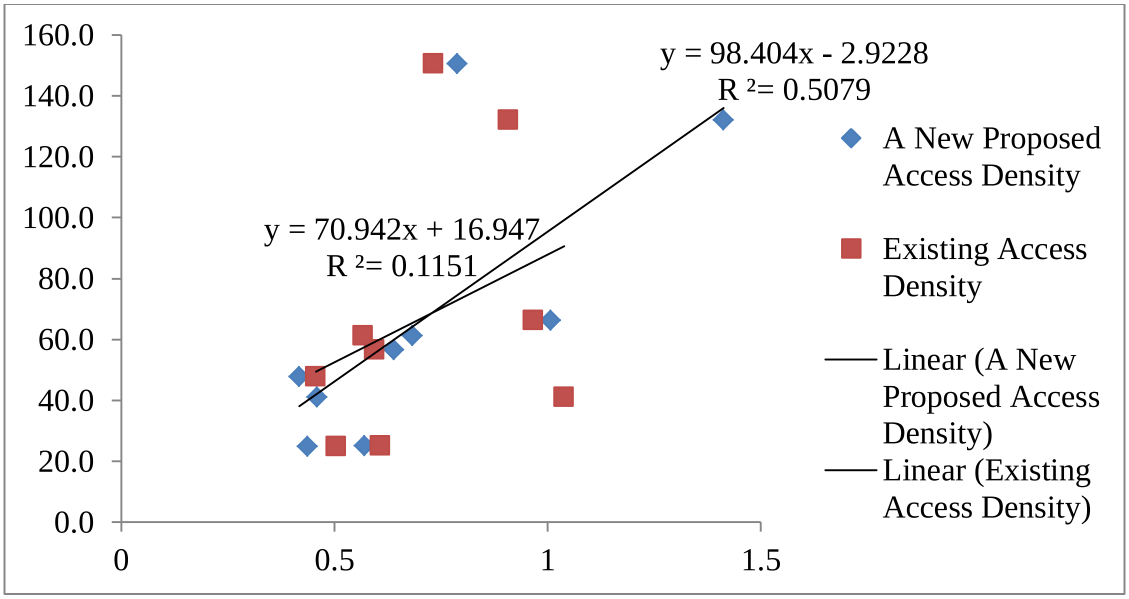


Figure 38 Crash Rate vs. Access Density of Nine Field Data Sites

Chapter 5 Modeling the Speed Variation of Roadway Segment Using the New Definition of Access Density

To do traffic simulation using simulation software, field data collection alone cannot provide enough data. Several parameters can be changed in simulation models, such as traffic volume, number of lanes, speed limit, access types, and etc., which can extend the simulation samples from the initial 1 to 210 sites. Hence, it is an efficient and reliable approach to produce a great deal of data that can develop statistical models. Since all data were prepared well, statistical models were presented to estimate relationships among SSD and its contributing factors, which include access density, traffic volume (AADT), number of lanes, and speed limit. Here, SSD is the dependent variable. Access density, traffic volume, number of lanes, and speed limit are independent variables.

5.1 Descriptive Statistics of Access Weight

Table 52 shows the summary statistics of the access weight of the nine access types.

Table 52 Descriptive Statistics of Access Weight by All Nine Access Types

Access Type	N	Mean	Standard Deviation	Max	Min
1	36	0.050	0.004	0.058	0.043
2	72	0.066	0.037	0.132	0.026
3	72	0.118	0.027	0.213	0.077
4	72	0.100	0.020	0.150	0.059
5	72	0.133	0.024	0.194	0.082
6	36	0.099	0.022	0.131	0.066
7	36	0.169	0.039	0.252	0.118
8	36	0.130	0.018	0.167	0.089
9	36	0.157	0.024	0.235	0.116

The mean values of access weight are compared in Figure 39. Access type 7 has the highest average access weight value of 0.169. Conversely, Access type 1 has the lowest average access weight value of 0.050.

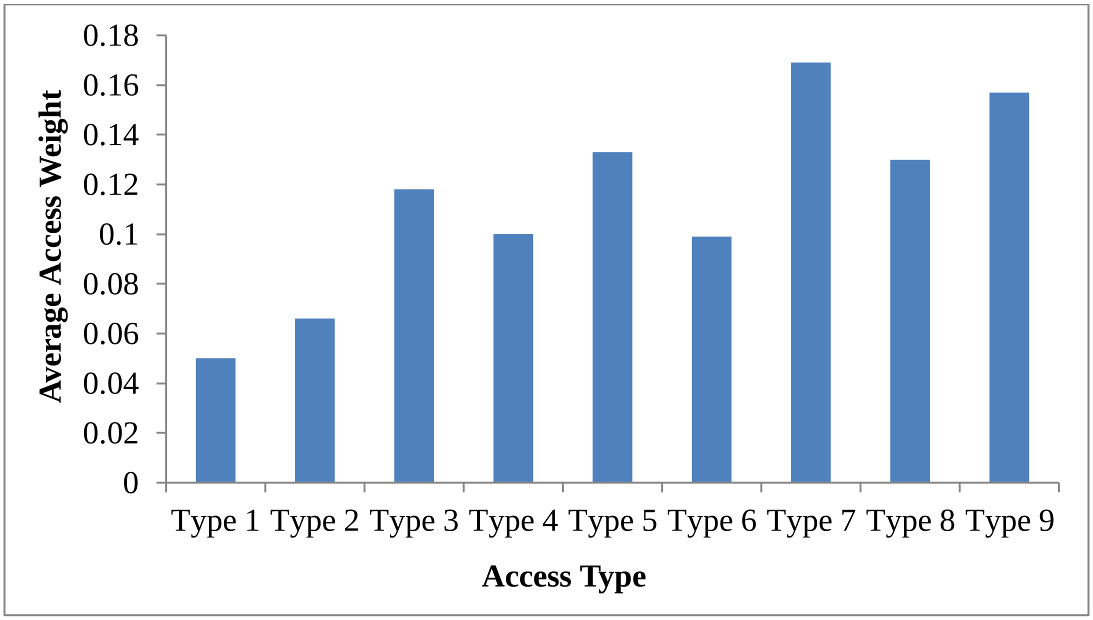


Figure 39 Comparison of Access Weight by Nine Access Types

In addition to comparison of access weight of all nine access types, the access weight of one specific access type was also compared. For access type 7, the distributions of access weight by specific access type, number of lanes, speed limit, and LOS were plotted, as shown in Figures 40–43.

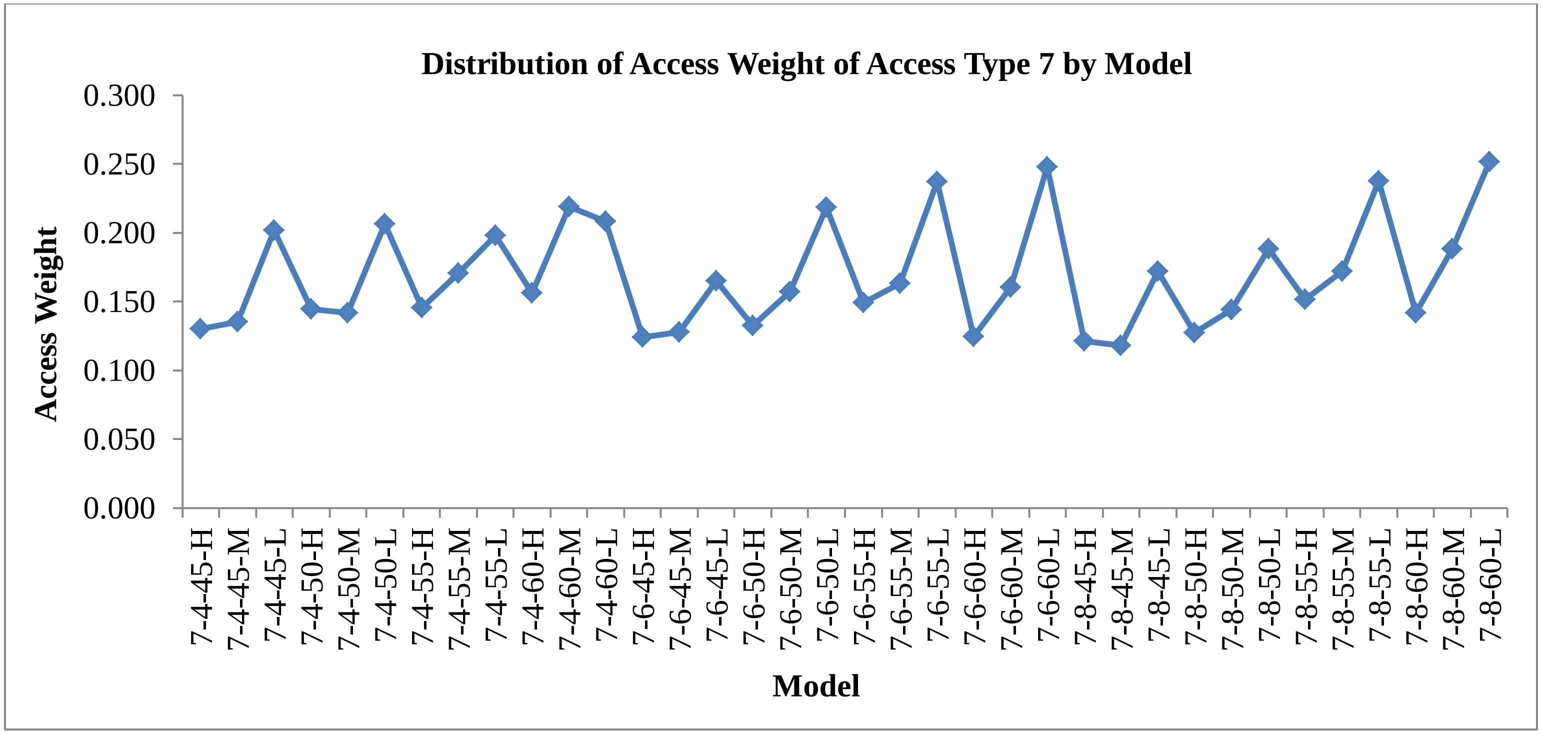


Figure 40 Distribution of Access Weight of Access Type 7

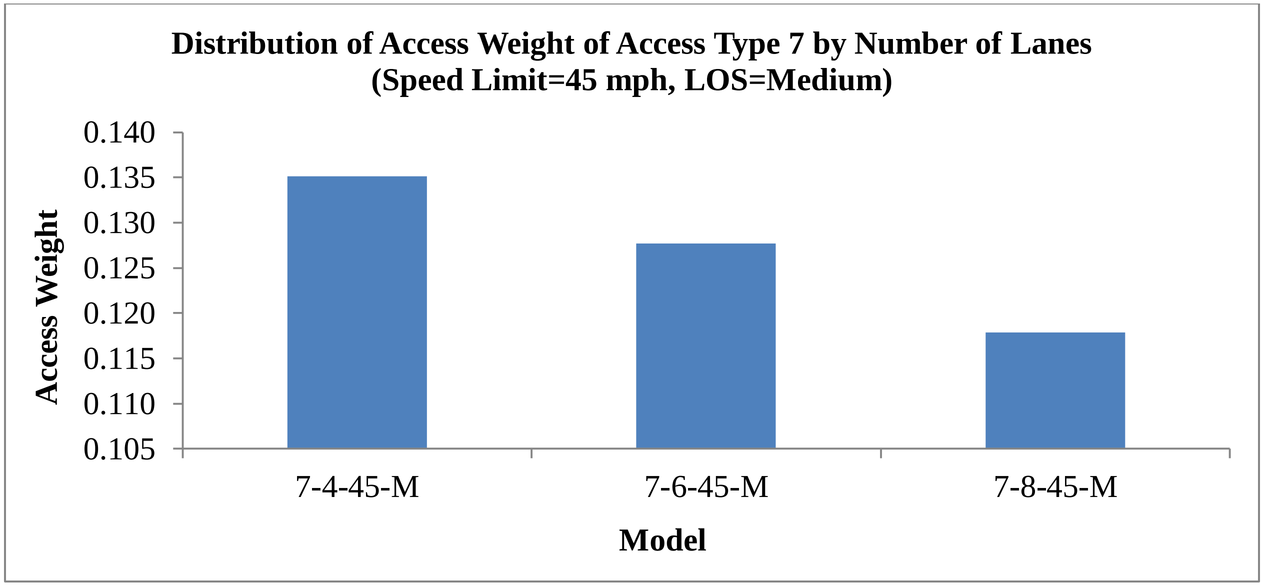


Figure 41 Distribution of Access Weight of Access Type 7 by Number of Lanes

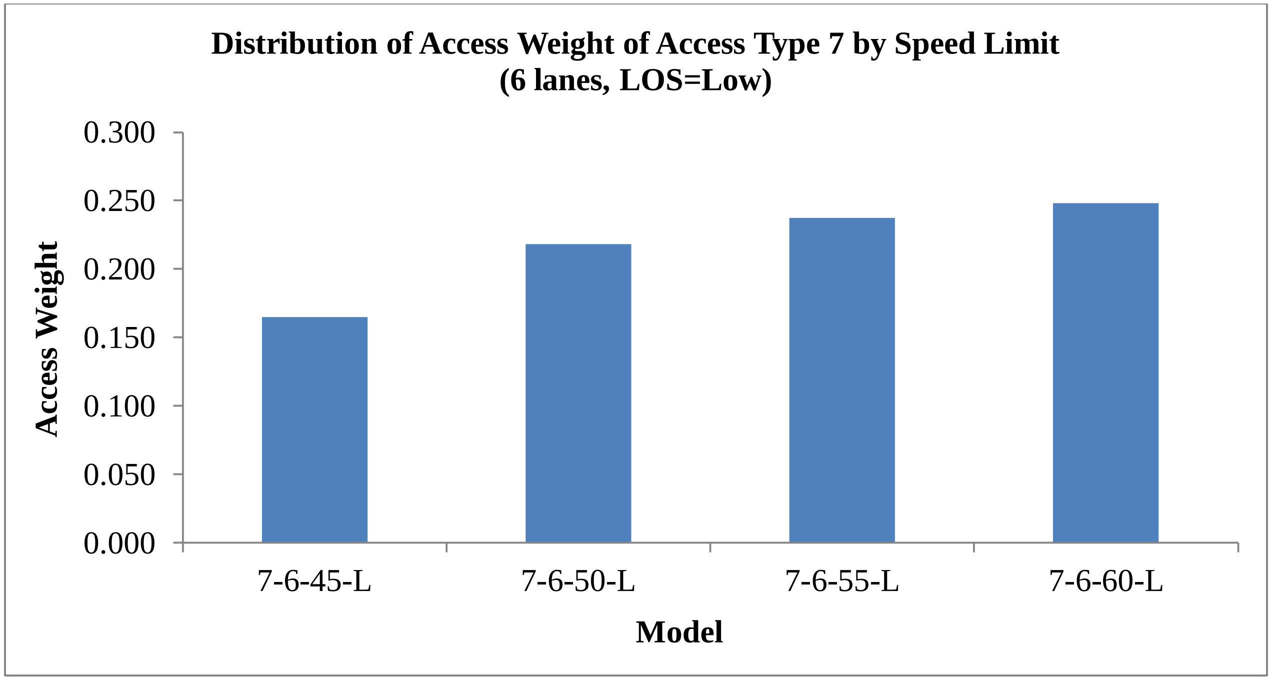


Figure 42 Distribution of Access Weight of Access Type 7 by Speed Limit

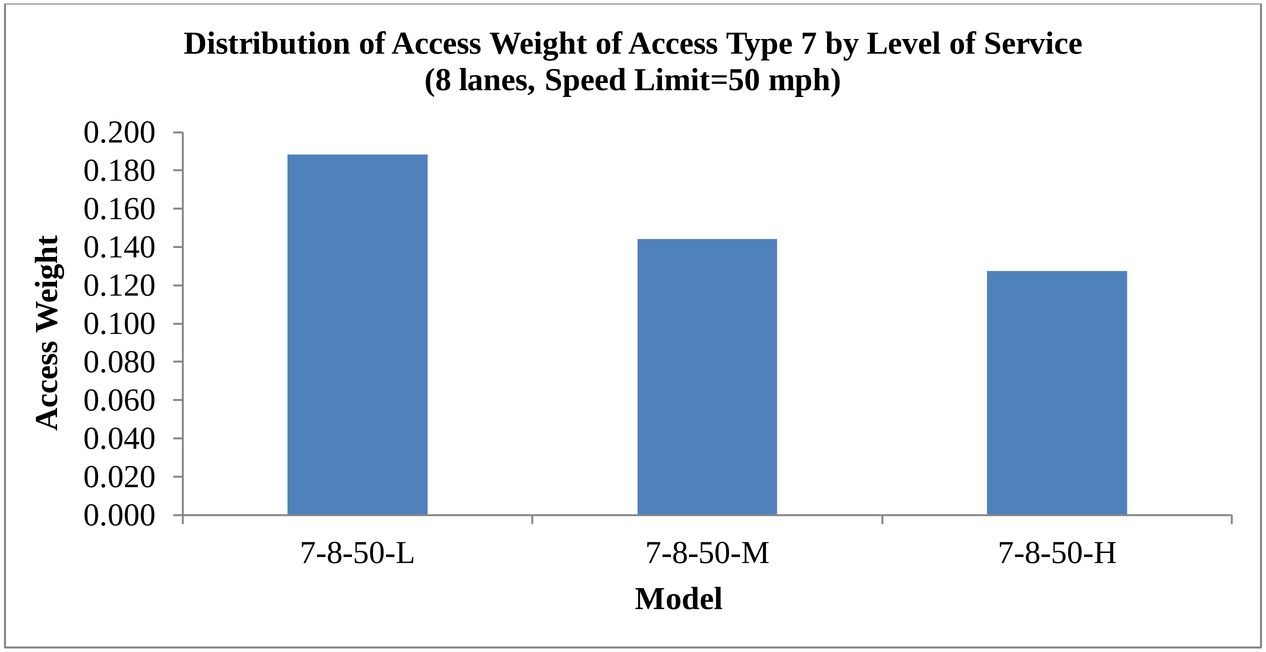


Figure 43 Distribution of Access Weight of Access Type 7 by Level of Service

As shown in Figure 40, the access weight of access type 7 on a roadway segment with 8 lanes, speed limit 60 mph, and low traffic volume is 0.252, which is the largest among all of models of access type 7. Access Type 7 is four-leg intersection (full median opening). Figure 41 shows that when speed limit is 45 mph with medium traffic volume, the access weight of access type 7 on a roadway segment with 4 lanes is largest. The distribution shown in Figure 41 indicates that for a type 7, four-leg intersection (full median opening), access weights decrease with the increase of number of lanes. Similarly, as shown in Figure 43, when the number of lanes equals 8 and the speed limit is 50 mph, the access weight of access type 7 on a roadway segment with low traffic volume is largest. It indicates for a type 7, four-leg intersection (full median opening), access weights decrease with the increase of level of service. Figure 42 shows the opposite trend; when the number of lanes is 6 with low traffic volume, the access weight of access type 7 on a roadway segment with a speed limit 60 mph is highest (0.248). It indicates that for a type 7, four-leg intersection (full median opening), access weights increase with the increase of speed limit.

5.2 Speed Variation Analysis

As shown in Table 53, data for traffic volume, number of lanes, and posted speed limits were collected by different methods: traffic counter, Google Earth, and field test. Each site includes 10 to 20 spot sites. First, the SSD of each spot site was calculated in the Excel sheet. Then, the SSD of each spot site was multiplied by the distance between that spot site and the adjacent spot site; they were summed together and divided by 5280 to get the final refined SSD of each site. Also, access densities of all 15 field sites were calculated. First, the access weight of each access opening was found according to 468 sample access weights. Then, the sum of all these access weights was divided by the total length of this site to get the access density of each site. To refine it, the access density of each site was multiplied by 5280. Figure 44 shows the distribution of the SSD of all 15 sites. It clearly shows that N Dale Mabry has the largest SSD (39.152). Conversely, E Fowler Ave has the lowest SSD (8.263).

5.3 Simulation and Calibration

Traffic simulation analysis was used to collect speed data. Thus, on the test sites, speed data was collected in field through radar gun. Additionally, simulation models, which were calibrated and validated by the collected field data, was developed by traffic simulation software TSIS/CORSIM package for collecting speed data. The main objective to perform simulation analysis is to promote support the analysis findings obtained through field speed analysis. Since data collection and reduction was completed, traffic data analysis was implemented to achieve the objectives. Meanwhile, simulation analysis was performed. Outcomes from both analyses were compared and combined to obtain models that could characterize the impacts of access management treatments and geometric design on traffic operational speed variation. Simulation and calibration are the two important steps in traffic simulation analysis.

The reason why simulation is used in this study is mainly because it is timing consuming and costly to collect enough field data. Simulation in this study is used to generate more data points that can be used for the regression model. Validation is conducted to make sure the simulation settings synthesize what would happen on the real roadway. The reason why calibration is used in this study is because of finding the set of parameter values for the model that best reproduces local traffic conditions.

Table 53 Traffic Volume, Number of Lanes, Speed Limit, Access Density and SSD of 15 Observed Sites in Florida

No	Road Name	Traffic Volume	Number of Lanes	Speed Limit (mph)	Access Density	SSD
1	E Fowler Ave	2830	6	50	1.248	8.263
2	N Dale Mabry	1832	6	55	0.46	39.152
3	State 54	1453	6	50	0.64	21.478
4	US 41	2120	6	45	0.571	16.782
5	CR 60	1062	4	55	0.438	13.278
6	Bruce B Downs Blvd-SB	1475	4	45	0.832	13.22
7	Temple Terrace Hwy	889	4	45	1.413	11.699
8	W Hillsborough Ave-1 (Begin with Tudor Dr)	1933	6	50	0.788	14.809
9	W Hillsborough Ave-2 (Begin with Montague St)	1860	6	50	0.418	13.458
10	W Hillsborough Ave-3 (Begin with Strathmore Gate Dr)	912	6	45	1.008	10.082
11	Bruce B Downs Blvd-NB	2394	4	45	0.832	11.37
12	CR 582	1081	4	45	1.142	13.189
13	US 19-1	2769	8	55	0.965	14.05
14	US 19-2	2730	6	55	1.095	10.527
15	E Dr Martin Luther King Jr Blvd (CR 579)	1528	6	50	0.683	13.742

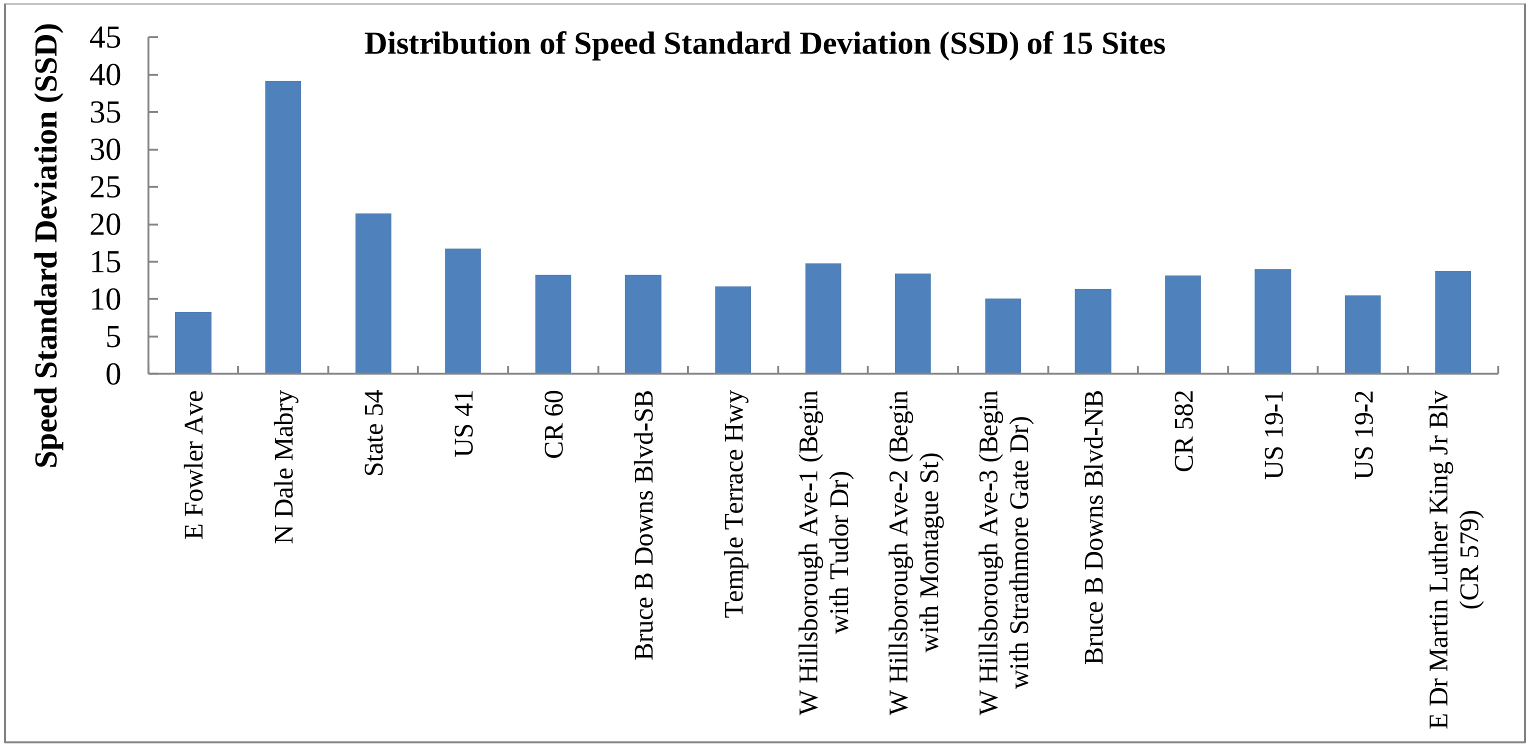


Figure 44 Distribution of Speed Standard Deviation (SSD) of 15 Data Collection Sites

5.3.1 Simulation

In this study, the study area of first data collection was located on E Flower Ave (Bruce B Downs Blvd→N 60th St) in Tampa, Florida. The intersection of E Fowler Ave and Bruce B Downs Blvd is a four-leg signalized intersection. The intersection of E Fowler Ave and N 60th St is a four-leg full median opening intersection. Figure 45 shows the study area of first data collection.

Figure 45 Study Area of First Data Collection

Traffic volume, operation speed, turn bay length, signal timing plan and travel time were collected. After all filed data were prepared well, a base model was built and simulated in CORSIM to generate the simulated data, as shown in Figure 46. For travel time, field and simulated data were compared, as Table 54 below shows.

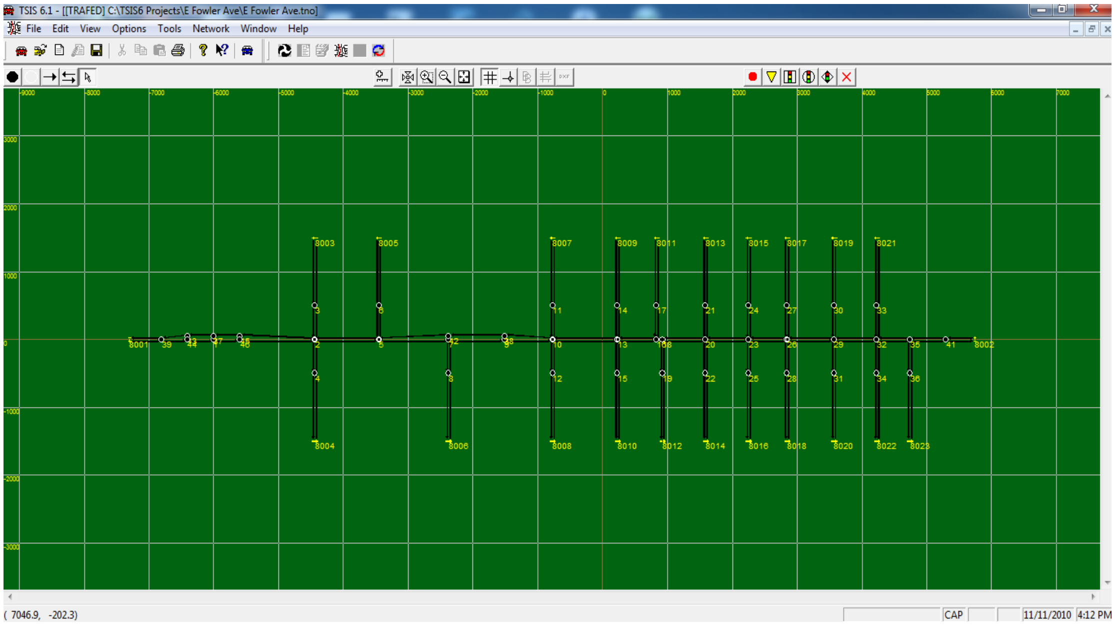


Figure 46 Simulation Model of First Data Collection

Table 54 Comparison of Field Travel Time and Simulated Travel Time

Direction	Travel Time (Field Test)	Travel Time (Simulation)	Fitness Factor
Eastbound	258.5	298.5	15.47%
Westbound	303.6	274.5	-9.58%

In Table 54, the results show that for eastbound of E Fowler Ave (Bruce B Downs Blvd→N 60th Street), the simulation data of travel time is longer than the field data. For westbound of E Fowler Ave (Bruce B Downs Blvd→N 60th Street), the simulation data of travel time is shorter than the field data. To decrease the simulation data of travel time of eastbound to match the field data and also increase the simulation data of travel time of westbound to match the filed data, calibration is needed.

5.3.2 Calibration

The Multiple Parameter Calibration method was used for this study. The calibration parameter is travel time, and the adjusting parameters include amber interval response, distribution of multiplier for discharge headway percentage, start-up lost time, cross traffic, mean startup delay, and mean discharge headway. Figure 47-51 demonstrate the calibration process. The calibration target is to make the fitness factor smaller than 15 percent. The equation below shows the calculation of fitness factor.

$$Fitness\ Factor = \left|\frac{Value_{sim} - Value_{field}}{Value_{field}}\right| \le 15\%$$

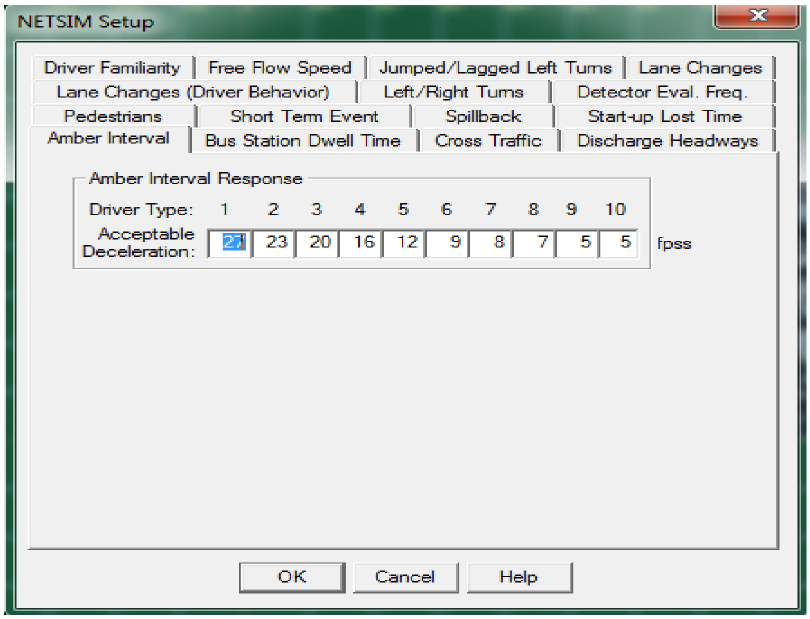


Figure 47 Adjust Amber Interval Response +30%

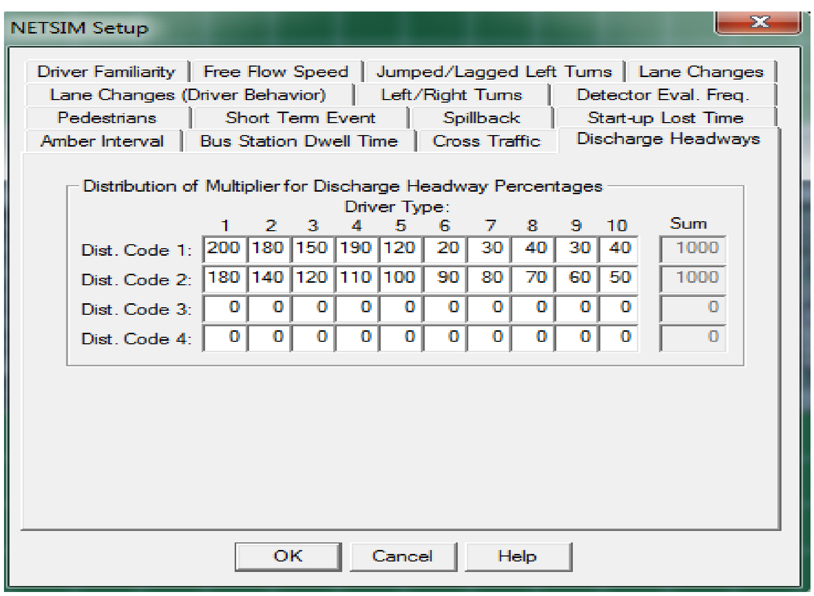


Figure 48 Adjust Discharge Headways

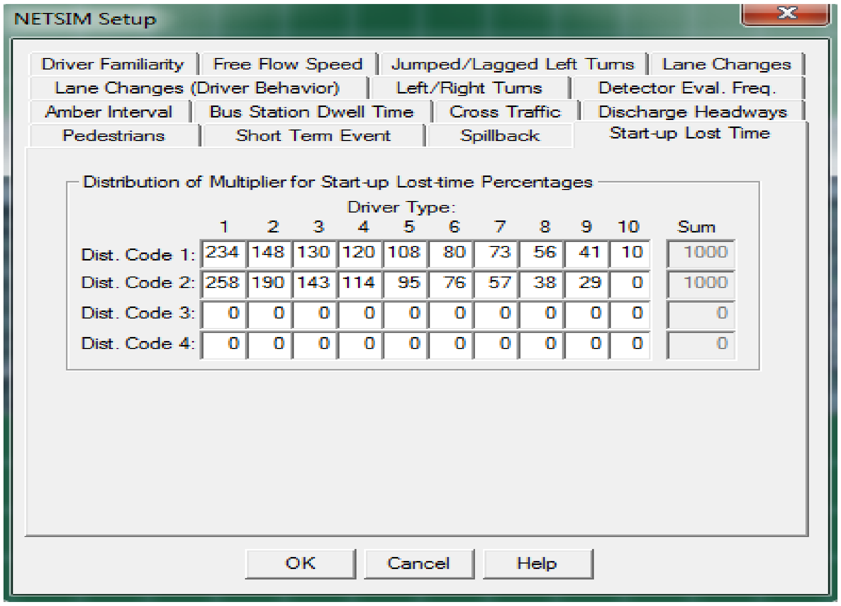


Figure 49 Adjust Start-up Lost Time

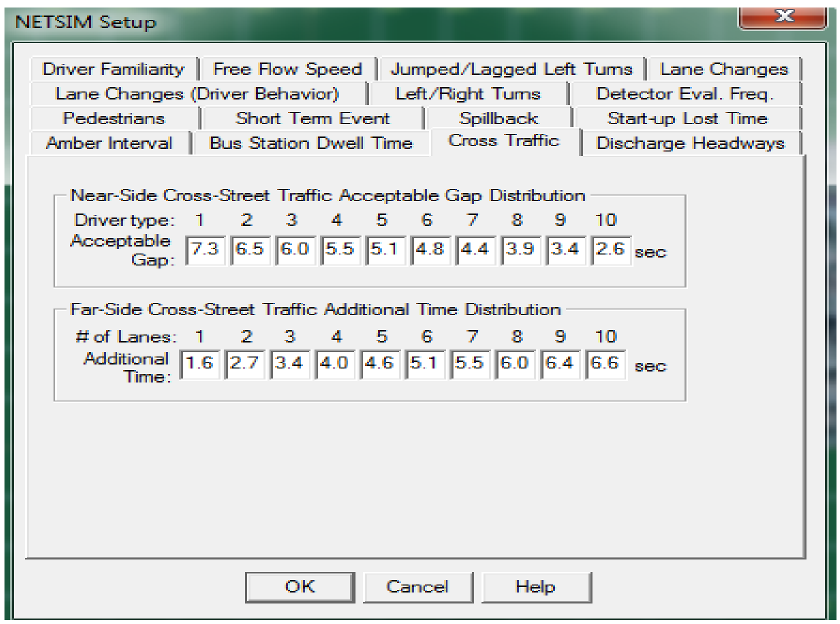


Figure 50 Adjust Cross Traffic +30%

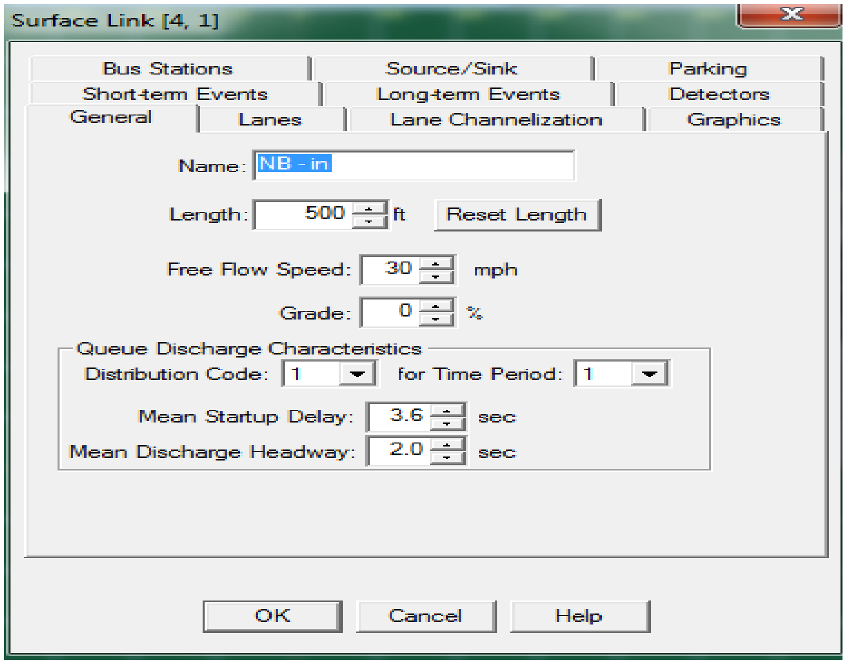


Figure 51 Adjust Mean Startup Delay and Mean Discharge Headway

Table 55 shows the comparison of field travel time and calibrated travel time. The calibrated travel times of both the eastbound and westbound directions are close to field travel times. The fitness factor of both the eastbound and westbound directions by comparing the calibrated travel time with the field travel time are 2.59 and -1.71 percent, respectively. It is much better than the fitness factor of both the eastbound and westbound directions (15.47%, -9.58%) by comparing the simulated travel time with the field travel time. 2.59 and -1.71 percent of fitness factor meet the calibration target. So, there is no need to do further calibration.

Table 55 Comparison of Field Travel Time and Calibrated Travel Time

Direction	Travel Time (Field Test)	Travel Time (Calibrated)	Fitness Factor
Eastbound	258.5	265.2	2.59%
Westbound	303.6	298.4	-1.71%

5.4 Obtaining Extended Data from Simulation

Field data collection provided limited data for traffic simulation software. Simulation models changed several parameters causally, such as traffic volume, number of lanes, speed limit, and access type. All these changes extended the number of simulation samples from the initial 1 to 210. The initial model is called Base Model with Detectors, which is the study area in this study, E Flower Ave (Bruce B Downs Blvd→N 60th St). A total of 250 detectors were distributed on the link of this model, 125 eastbound and 125 westbound. The entry traffic flow of eastbound is 2507, and the entry traffic flow of westbound is 2484, so the total traffic volume of the Base Model with Detectors is 4991. The base model has six lanes in both directions. The speed limit of the base model is 50 mph, the access density is 0.7452, and the SSD is 1.288.

To develop the statistical model, more samples were needed. Changing parameters in simulation models was an efficient and reliable approach to producing additional samples. The parameters include traffic volume, number of lanes, speed limit and access types. For traffic volume, the total traffic volume was adjusted by -75%, -70%, -65%, -60%, -55%, -50%, -45%, -40%, -35%, -30%, -25%, -20%, -15%, -10%, -5%, +10%, +15%, +20%, +25%, +30%, +35%, +40%, +45%, +50%, +55%, +60%, +65%, +70%, +75%, +80%, +85%, +90% and +95%. For number of lanes, normally a roadway has three categories of lanes: 4, 6, and 8. The base model has 6 lanes. The number of lanes was increased from 6 to 8 or was decreased from 6 to 4. For speed limit, there are normally four categories: 45 mph, 50 mph, 55 mph, and 60 mph. The speed limit of the base model is 50 mph. The speed limit was increased from 50 mph to 55 mph and 60 mph or was decreased from 50 mph to 45 mph. For access types, normally there are two methods to generate more simulation samples to develop statistical models. First, access types can be changed between directional median opening and full median opening: Access Types 4 (Three-Leg Directional Median Opening Intersection)→Access Type 3 (Three-Leg Full Median Opening Intersection), Access Type 3 (Three-Leg Full Median Opening Intersection)→Access Types 4 (Three-Leg Directional Median Opening Intersection), Access Type 8 (Four-Leg Directional Median Opening Intersection)→Access Types 7 (Four-Leg Full Median Opening Intersection), Access Type 7 (Four-Leg Full Median Opening Intersection)→Access Type 8 (Four-Leg Directional Median Opening Intersection), and the combination of them. Second, access points or driveways are removed. There are 15 access points and driveways along E Fowler Ave (Bruce B Downs Blvd→N 60th St). From 1 up to 13 access points along the roadway were removed. The names of driveways and corresponding numbers are shown in Table 56. In simulation models, only one parameter can be changed—for example, N 46th St, Access Type 4→Access Type 3. Also, multiple parameters can be changed. For example, Volume -15%, 4 lanes, speed limit 60 mph with detectors, remove access points 3,4,6,7,8,9,10,11,12,13,14 and 15. Table 57 lists the number, name, traffic volume, number of lanes, speed limit, access density, and SSD of the 210 simulation models.

Table 56 Names and Corresponding Numbers of the 15 Driveways and Access Points Along E Flower Ave (Bruce B Downs Blvd→N 60th St)

Driveway (Access Point) No.	Driveway Name
1	N/A (too small)
2	N 40th St
3	Leroy Collins Blvd
4	N 46th St
5	N/A
6	Bull Run Dr
7	N 50th St
8	N 51st Street (N)

Table 56 (continued)

9	N 51st Street (S)
10	N 52nd St
11	N 53rd St
12	N 56th St
13	N 58th St
14	N 60th St
15	N/A (too small)

Table 57 Sample Number, Sample Name, Traffic Volume, Number of Lanes, Speed Limit, Access Density, and SSD of 210 Simulation Models

No.	Sample	Volume	Number of lanes	Speed Limit	Access Density	SSD
1	Base Model with Detectors	4991	6	50	0.745	1.288
2	Volume +10%, 6 lanes, SL 50 mph with Detectors	5490	6	50	0.745	1.243
3	Volume +10%, 6 lanes, SL 45 mph with Detectors	5490	6	45	0.708	0.972
4	Volume +20%, 6 lanes, SL 50 mph with Detectors	5989	6	50	0.745	1.779
5	Volume +20%, 6 lanes, SL 45 mph with Detectors	5989	6	45	0.708	1.297
6	Volume +20%, 4 lanes, SL 50 mph with Detectors	5989	4	50	0.973	3.444
7	Volume +20%, 4 lanes, SL 45 mph with Detectors	5989	4	45	0.926	3.865
8	Volume +30%, 6 lanes, SL 50 mph with Detectors	6488	6	50	0.745	1.535
9	Volume +30%, 6 lanes, SL 45 mph with Detectors	6488	6	45	0.745	1.207
10	Volume -10%, 6 lanes, SL 50 mph with Detectors	4492	6	50	0.745	1.225
11	Volume -10%, 6 lanes, SL 45 mph with Detectors	4492	6	45	0.708	1.248
12	Volume -20%, 6 lanes, SL 50 mph with Detectors	3993	6	50	0.745	1.131
13	Volume -20%, 6 lanes, SL 45 mph with Detectors	3993	6	45	0.708	1.020
14	Volume -30%, 6 lanes, SL 50 mph with Detectors	3494	6	50	0.745	1.112
15	Volume -30%, 6 lanes, SL 45 mph with Detectors	3494	6	45	0.708	0.977
16	Volume -30%, 8 lanes, SL 45 mph with Detectors	3494	8	45	0.655	0.895
17	Volume -40%, 6 lanes, SL 50 mph with Detectors	2994	6	50	0.745	1.010
18	Volume -40%, 6 lanes, SL 45 mph with Detectors	2994	6	45	0.708	0.947
19	Volume -40%, 4 lanes, SL 50 mph with Detectors	2994	4	50	0.973	1.222
20	Volume -50%, 6 lanes, SL 50 mph with Detectors	2495	6	50	0.745	0.954
21	Volume -50%, 6 lanes, SL 45 mph with Detectors	2495	6	45	0.708	0.851
22	Number of lanes on Major Road (Decrease from 6 to 4)	4991	4	50	0.973	4.222
23	Number of lanes on Major Road (Increase from 6 to 8)	4991	8	50	0.791	1.023
24	N 46th Street, Access Type 4→Access Type 3	4991	6	50	0.749	1.268
25	N 51st Street (North), Access Type 4→Access Type 3	4991	6	50	0.757	1.285
26	N 51st Street (South), Access Type 4→Access Type 3	4991	6	50	0.749	1.385
27	N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.755	1.229

Table 57 (continued)

28	N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.755	1.291
29	N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.755	1.206
30	N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.736	1.285
31	Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.741	1.281
32	N 46th Street, Access Type 4→Access Type 3 & N 51st Street (North), Access Type 4→Access Type 3	4991	6	50	0.761	1.249
33	N 46th Street, Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3	4991	6	50	0.753	1.254
34	N 46th Street, Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.378
35	N 46th Street, Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.278
36	N 46th Street, Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.274
37	N 46th Street, Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.739	1.257
38	N 46th Street, Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.745	1.327
39	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3	4991	6	50	0.761	1.223
40	N 51st Street (North), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.767	1.344
41	N 51st Street (North), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.767	1.297

Table 57 (continued)

42	N 51st Street (North), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.767	1.302
43	N 51st Street (North), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.748	1.198
44	N 51st Street (North), Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.754	1.318
45	N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.302
46	N 51st Street (South), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.308
47	N 51st Street (South), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.759	1.214
48	N 51st Street (South), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.739	1.296
49	N 51st Street (South), Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.745	1.291
50	N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.764	1.227
51	N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.764	1.297
52	N 52nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.745	1.352

Table 57 (continued)

53	N 52nd Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.751	1.303
54	N 53th Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.764	1.214
55	N 53th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.745	1.291
56	N 53th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.751	1.333
57	N 58th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.745	1.206
58	N 58th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.751	1.234
59	N 60th Street, Access Type 7→Access Type 8 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.732	1.295
60	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3	4991	6	50	0.765	1.242
61	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.265
62	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.278
63	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.435

Table 57 (continued)

64	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.752	1.322
65	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.757	1.185
66	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.763	1.363
67	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.763	0.004
68	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.763	0.004
69	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.743	1.345
70	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & Summit W Blvd, Access Type 3→Access Type 4	4991	6	50	0.749	1.227
71	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.768	1.391

Table 57 (continued)

72	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.768	1.380
73	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.749	1.383
74	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.755	1.350
75	N 46th Street, Access Type 4→Access Type 3, N 53nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.768	1.359
76	N 46th Street, Access Type 4→Access Type 3, N 53nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.749	1.241
77	N 46th Street, Access Type 4→Access Type 3, N 53nd Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.755	1.300
78	N 46th Street, Access Type 4→Access Type 3, N 58th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.749	1.388
79	N 46th Street, Access Type 4→Access Type 3, N 58th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.755	1.313
80	N 46th Street, Access Type 4→Access Type 3, N 60th Street, Access Type 7→Access Type 8 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.736	1.211

Table 57 (continued)

81	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.327
82	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.230
83	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.771	1.289
84	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.752	1.204
85	N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.757	1.295
86	N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.768	1.293
87	N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.768	1.331

Table 57 (continued)

88	N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.749	1.303
89	N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.755	1.316
90	N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.774	1.379
91	N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.755	1.290
92	N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.761	1.275
93	N 53th Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.755	1.307
94	N 53th Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.761	1.271
95	N 58th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.741	1.258

Table 57 (continued)

96	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7	4991	6	50	0.775	1.394
97	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.775	1.313
98	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.775	1.330
99	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.756	1.308
100	N 46th Street, Access Type 4→Access Type 3, N 51st Street (North), Access Type 4→Access Type 3 & N 51st Street (South), Access Type 4→Access Type 3 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.761	1.162
101	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7	4991	6	50	0.772	1.263

Table 57 (continued)

102	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.772	1.320
103	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.753	1.314
104	N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 52nd Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.759	1.364
105	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7	4991	6	50	0.778	1.259
106	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.759	1.401
107	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 53th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.764	1.385
108	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8	4991	6	50	0.759	1.359

Table 57 (continued)

109	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 58th Street, Access Type 8→Access Type 7 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.764	1.374
110	N 46th Street, Access Type 4→Access Type 3, N 52nd Street, Access Type 8→Access Type 7 & N 60th Street, Access Type 7→Access Type 8 & Summit W Blvd, Type 3→Access Type 4	4991	6	50	0.745	1.452
111	Volume +10%, 4 lanes, SL 55 mph with Detectors	5490	4	55	0.866	5.222
112	Volume +15%, 8 lanes, SL 60 mph with Detectors	5740	8	60	0.809	1.291
113	Volume +20%, 8 lanes, SL 45 mph with Detectors	5989	8	45	0.655	0.891
114	Volume +25%, 4 lanes, SL 50 mph with Detectors	6239	4	50	0.973	3.927
115	Volume +30%, 8 lanes, SL 55 mph with Detectors	6488	8	55	0.805	1.053
116	Volume +35%, 4 lanes, SL 60 mph with Detectors	6737	4	60	1.084	4.777
117	Volume +40%, 8 lanes, SL 50 mph with Detectors	6988	8	50	0.791	1.021
118	Volume +45%, 4 lanes, SL 45 mph with Detectors	7237	4	45	0.926	3.465
119	Volume +50%, 8 lanes, SL 60 mph with Detectors	7487	8	60	0.809	1.261
120	Volume +55%, 4 lanes, SL 50 mph with Detectors	7736	4	50	0.973	4.082

Table 57 (continued)

121	Volume +60%, 6 lanes, SL 55 mph with Detectors	7985	6	55	0.828	1.969
122	Volume +65%, 8 lanes, SL 45 mph with Detectors	8236	8	45	0.655	0.917
123	Volume +70%, 4 lanes, SL 60 mph with Detectors	8485	4	60	1.084	4.867
124	Volume +75%, 8 lanes, SL 55 mph with Detectors	8734	8	55	0.805	1.653
125	Volume +80%, 4 lanes, SL 50 mph with Detectors	8984	4	50	0.973	3.984
126	Volume +85%, 8 lanes, SL 60 mph with Detectors	9233	8	60	0.809	2.485
127	Volume +90%, 4 lanes, SL 55 mph with Detectors	9483	4	55	0.866	3.906
128	Volume +95%, 6 lanes, SL 50 mph with Detectors	9733	6	50	0.745	1.579
129	Volume -10%, 8 lanes, SL 55 mph with Detectors	4492	8	55	0.805	1.166
130	Volume -15%, 4 lanes, SL 45 mph with Detectors	4242	4	45	0.926	2.512
131	Volume -20%, 8 lanes, SL 60 mph with Detectors	3993	8	60	0.809	1.147
132	Volume -25%, 4 lanes, SL 55 mph with Detectors	3743	4	55	0.866	2.273
133	Volume -30%, 8 lanes, SL 50 mph with Detectors	3494	8	50	0.791	0.904
134	Volume -35%, 4 lanes, SL 60 mph with Detectors	3245	4	60	1.084	2.159
135	Volume -40%, 8 lanes, SL 45 mph with Detectors	2994	8	45	0.655	0.906
136	Volume -45%, 4 lanes, SL 50 mph with Detectors	2745	4	50	0.973	1.076
137	Volume -50%, 8 lanes, SL 55 mph with Detectors	2496	8	55	0.805	1.127
138	Volume -55%, 4 lanes, SL 60 mph with Detectors	2246	4	60	1.084	1.337
139	Volume -60%, 6 lanes, SL 45 mph with Detectors	1997	6	45	0.708	0.993

Table 57 (continued)

140	Volume -65%, 8 lanes, SL 60 mph with Detectors	1746	8	60	0.809	1.251
141	Volume -70%, 4 lanes, SL 45 mph with Detectors	1497	4	45	0.809	1.251
142	Volume -75%, 8 lanes, SL 50 mph with Detectors	1248	8	50	0.803	1.178
143	Volume -5%, 4 lanes, SL 55 mph with Detectors	4742	4	55	0.882	1.304
144	6 lanes, SL 50 mph with Detectors, Remove Driveway 15	4991	6	50	0.866	4.036
145	Volume +20%, 4 lanes, SL 45 mph with Detectors, Remove Driveway 15	5989	4	45	0.695	1.286
146	Volume +30%, 8 lanes, SL 55 mph with Detectors, Remove Driveway 15	6488	8	55	0.875	3.477
147	Volume -10%, 4 lanes, SL 60 mph with Detectors, Remove Driveway 15	4492	4	60	0.749	1.165
148	Volume -20%, 8 lanes, SL 50 mph with Detectors, Remove Driveway 15	3993	8	50	1.023	4.094
149	6 lanes, SL 50 mph with Detectors, Remove Driveway 14,15	4991	6	50	0.742	0.957
150	Volume +10%, 6 lanes, SL 55 mph with Detectors, Remove Driveway 14,15	5490	6	55	0.630	1.043
151	Volume +45%, 8 lanes, SL 45 mph with Detectors, Remove Driveway 14,15	7237	8	45	0.701	1.140
152	Volume -25%, 4 lanes, SL 50 mph with Detectors, Remove Driveway 14,15	3743	4	50	0.553	0.686
153	Volume -30%, 8 lanes, SL 60 mph with Detectors, Remove Driveway 14,15	3494	8	60	0.852	1.084
154	6 lanes, SL 50 mph with Detectors, Remove Driveway 13,14,15	4991	6	50	0.680	1.215
155	Volume +25%, 4 lanes, SL 55 mph with Detectors, Remove Driveway 13,14,15	6239	4	55	0.575	1.039

Table 57 (continued)

156	Volume +40%, 6 lanes, SL 60 mph with Detectors, Remove Driveway 13,14,15	6988	6	60	0.680	3.764
157	Volume -5%, 8 lanes, SL 50 mph with Detectors, Remove Driveway 13,14,15	4742	8	50	0.628	1.406
158	Volume -35%, 4 lanes, SL 45 mph with Detectors, Remove Access Points 13,14,15	3245	4	45	0.616	0.851
159	6 lanes, SL 50 mph with Detectors, Remove Driveway 12,13,14,15	4991	6	50	0.746	1.196
160	Volume +15%, 8 lanes, SL 55 mph with Detectors, Remove Driveway 12,13,14,15	5740	8	55	0.515	0.961
161	Volume +35%, 4 lanes, SL 60 mph with Detectors, Remove Driveway 12,13,14,15	6737	4	60	0.547	1.015
162	Volume -15%, 8 lanes, SL 45 mph with Detectors, Remove Driveway 12,13,14,15	4242	8	45	0.759	7.401
163	Volume -50%, 4 lanes, SL 50 mph with Detectors, Remove Driveway 12,13,14,15	2496	4	50	0.452	0.789
164	6 lanes, SL 50 mph with Detectors, Remove Driveway 11,12,13,14,15	4991	6	50	0.682	1.031
165	Volume +50%, 4 lanes, SL 55 mph with Detectors, Remove Driveway 11,12,13,14,15	7487	4	55	0.459	1.035
166	Volume +60%, 8 lanes, SL 60 mph with Detectors, Remove Driveway 11,12,13,14,15	7985	8	60	0.545	4.088
167	Volume -40%, 4 lanes, SL 50 mph with Detectors, Remove Driveway 11,12,13,14,15	2994	4	50	0.497	1.518
168	Volume -45%, 8 lanes, SL 45 mph with Detectors, Remove Driveway 11,12,13,14,15	2745	8	45	0.615	1.100
169	6 lanes, SL 50 mph with Detectors, Remove Driveway 10,11,12,13,14,15	4991	6	50	0.408	0.834

Table 57 (continued)

170	Volume +55%, 4 lanes, SL 60 mph with Detectors, Remove Driveway 10,11,12,13,14,15	7736	4	60	0.404	0.853
171	Volume +70%, 8 lanes, SL 50 mph with Detectors, Remove Driveway 10,11,12,13,14,15	8485	8	50	0.617	5.157
172	Volume -60%, 4 lanes, SL 45 mph with Detectors, Remove Driveway 10,11,12,13,14,15	1997	4	45	0.425	1.332
173	Volume -75%, 6 lanes, SL 55 mph with Detectors, Remove Driveway 10,11,12,13,14,15	1248	6	55	0.520	1.171
174	6 lanes, SL 50 mph with Detectors, Remove Access Points 9,10,11,12,13,14,15	4991	6	50	0.497	1.298
175	Volume +65%, 8 lanes, SL 55 mph with Detectors, Remove Driveway 9,10,11,12,13,14,15	8236	8	55	0.358	0.857
176	Volume +75%, 4 lanes, SL 50 mph with Detectors, Remove Driveway 9,10,11,12,13,14,15	8734	4	50	0.384	1.268
177	Volume -55%, 8 lanes, SL 45 mph with Detectors, Remove Driveway 9,10,11,12,13,14,15	2246	8	45	0.512	4.177
178	6 lanes, SL 50 mph with Detectors, Remove Access Points 8,9,10,11,12,13,14,15	4991	6	50	0.327	1.036
179	Volume +80%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 8,9,10,11,12,13,14,15	8984	4	60	0.323	0.898
180	Volume +85%, 8 lanes, SL 50 mph with Detectors, Remove Access Points 8,9,10,11,12,13,14,15	9233	8	50	0.523	5.653
181	Volume -65%, 4 lanes, SL 55 mph with Detectors, Remove Access Points 8,9,10,11,12,13,14,15	1746	4	55	0.340	1.631

Table 57 (continued)

182	6 lanes, SL 50 mph with Detectors, Remove Access Points 7,8,9,10,11,12,13,14,15	4991	6	50	0.406	1.576
183	Volume +90%, 8 lanes, SL 60 mph with Detectors, Remove Access Points 7,8,9,10,11,12,13,14,15	9483	8	60	0.263	0.864
184	Volume -70%, 4 lanes, SL 45 mph with Detectors, Remove Access Points 7,8,9,10,11,12,13,14,15	1497	4	45	0.287	2.479
185	Volume -75%, 8 lanes, SL 55 mph with Detectors, Remove Access Points 7,8,9,10,11,12,13,14,15	1248	8	55	0.302	1.104
186	6 lanes, SL 50 mph with Detectors, Remove Access Points 6, 7, 8, 9, 10, 11,12,13,14,15	4991	6	50	0.337	1.461
187	Volume +95%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 6, 7, 8, 9, 10, 11,12,13,14,15	9733	4	60	0.203	0.810
188	Volume +5%, 8 lanes, SL 45 mph with Detectors, Remove Access Points 6, 7, 8, 9, 10, 11,12,13,14,15	5240	8	45	0.292	1.606
189	Volume -10%, 4 lanes, SL 55 mph with Detectors, Remove Access Points 6, 7, 8, 9, 10, 11,12,13,14,15	4492	4	55	0.178	0.666
190	Volume -5%, 8 lanes, SL 50 mph with Detectors, Remove Driveway 6,7,8,9,10,11,12,13,14,15	4742	8	50	0.250	1.335
191	6 lanes, SL 50 mph with Detectors, Remove Access Points 4,6,7,8,9,10,11,12,13,14,15	4991	6	50	0.210	0.753
192	Volume +15%, 4 lanes, SL 45 mph with Detectors, Remove Access Points 4, 6, 7, 8, 9, 10, 11,12,13,14,15	5740	4	45	0.158	0.958

Table 57 (continued)

193	Volume +20%, 8 lanes, SL 55 mph with Detectors, Remove Access Points 4, 6, 7, 8, 9, 10, 11,12,13,14,15	5989	8	55	0.224	2.208
194	Volume -25%, 4 lanes, SL 50 mph with Detectors, Remove Access Points 4, 6, 7, 8, 9, 10, 11,12,13,14,15	3743	4	50	0.169	0.833
195	Volume -30%, 8 lanes, SL 60 mph with Detectors, Remove Access Points 4, 6, 7, 8, 9, 10, 11,12,13,14,15	3494	8	60	0.228	0.864
196	6 lanes, SL 50 mph with Detectors, Remove Access Points 3,4,6,7,8,9,10,11,12,13,14,15	4991	6	50	0.169	0.984
197	Volume +10%, 4 lanes, SL 55 mph with Detectors, Remove Access Points 3, 4, 6, 7, 8, 9, 10, 11,12,13,14,15	5490	4	55	0.103	0.758
198	Volume +25%, 8 lanes, SL 45 mph with Detectors, Remove Access Points 3, 4, 6, 7, 8, 9, 10, 11,12,13,14,15	6239	8	45	0.127	1.298
199	Volume -15%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 3, 4, 6, 7, 8, 9, 10, 11,12,13,14,15	4242	4	60	0.100	0.638
200	Volume -20%, 8 lanes, SL 50 mph with Detectors, Remove Access Points 3,4,6,7,8,9,10,11,12,13,14,15	3993	8	50	0.159	1.265
201	6 lanes, SL 50 mph with Detectors, Remove Access Points 2,3,4,6,7,8,9,10,11,12,13,14,15	4991	6	50	0.110	0.818
202	Volume +30%, 4 lanes, SL 45 mph with Detectors, Remove Access Points 2,3,4,6,7,8,9,10,11,12,13,14,15	6488	4	45	0.044	0.556

Table 57 (continued)

203	Volume +40%, 8 lanes, SL 55 mph with Detectors, Remove Access Points 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	6988	8	55	0.046	0.525
204	Volume -35%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 2, 3, 4, 6, 7, 8, 9, 10,11,12,13,14,15	3245	4	60	0.052	0.561
205	Volume -50%, 8 lanes, SL 45 mph with Detectors, Remove Access Points 2, 3, 4, 6, 7, 8, 9, 10,11,12,13,14,15	2496	8	45	0.043	1.077
206	6 lanes, SL 50 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9, 10, 11,12,13,14,15	4991	6	50	0.043	0.627
207	Volume +35%, 8 lanes, SL 60 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9,	6737	8	60	0.103	0.754
208	Volume +60%, 4 lanes, SL 55 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9,	7985	4	55	0.116	1.021
209	Volume -40%, 8 lanes, SL 45 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9,	2994	8	45	0.127	1.213
210	Volume -70%, 4 lanes, SL 50 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9,	1497	4	50	0.100	0.694

5.5 Statistical Modeling

A business version of analytics software SAS 9.2 was used for statistical modeling of the relationship between SSD and all the independent variables, which includes access density, traffic volume (also called AADT), number of lanes, and speed limit. All the SAS codes are attached in Appendix B. The variable of land use is also considered to impact the segment SSD, but it is not listed here due to the difficulty of measurement and the limitations of resources.

The mathematical formula of the relationship between the SSD of roadway segment and all independent variables is: SSD = f (Access Density, Traffic Volume, Number of Lanes, Speed Limit). Based on a couple of comparisons of different model formats, linear regression is the most reasonable and practical. In addition, to make the values of all variables the same magnitude, the value of access density was divided by 10, the value of volume was divided by 1000, and the value of speed limit was divided by 10.

Regression modeling was applied for 210 simulation models. A total of 10 steps was included in the linear regression modeling: assumptions regarding linear regression, examining data prior to modeling, creating the model, testing for assumption validation, writing the equation, testing for multicollinearity, testing for auto correlation, testing for effects of outliers, testing the fit, and modeling without code.

5.5.1 Assumptions Regarding Linear Regression

A basic linear model has the form $Y = b_0 + \sum_i b_i X_i + \varepsilon$,

Where,

$b_0 -$ Intercept

b_i − Parameter Estimate for the Variable X_i

ε − Error term

Most of the assumptions and diagnostics of linear regression focus on the assumptions of ε. When building a linear regression model, the following assumptions must hold.

The dependent variable must be continuous. If trying to predict a categorical variable, linear regression is not the correct method; discrim, logistic, or some other categorical procedure should be investigated. The data modeling here meets the "iid" criterion. That means the error terms, ε, are:

(1) independent from one another

(2) identically distributed

If assumption 2a does not hold, time series or some other type of method needs to be investigated. If assumption 2b does not hold, methods that do not assume normality such as non-parametric procedures need to be investigated. The error term is normally distributed with a mean of zero and a standard deviation of σ^2, N(0,σ^2).

5.5.2 Regression Model Selection

To model the relationship between SSD and all the contributing factors, a regression model needs to be selected for statistical analysis. Before examining the economic properties of various mathematical forms of regression models, two concepts essential to understanding the mathematical characteristics of an equation must be defined. These concepts, used frequently hereafter, are "linear in the variables" and "additive in the variables." Each is discussed separately below.

5.5.2.1 Concepts

5.5.2.1.1 Linear in the Variables

To say that an equation is linear in an independent variable is to say that the marginal effect of that variable on the dependent variable does not depend on the level of the independent variable at which the marginal change occurs. An equation consisting of two independent variables provides an adequate example for demonstrating three propositions:

(1) An equation may be linear in all variables.

(2) An equation may be linear in some variables but not in others.

(3) An equation may be nonlinear in all variables.

5.5.2.1.1.1 Linear in All Variables

Consider the following equation:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$ **Equation 1**

This basic equation is linear in X_1 and in X_2 because the marginal effect of each does not depend on the level at which the marginal effect is calculated. To see this mathematically, write the partial derivatives

$\frac{\partial Y}{\partial X_1} = \beta_1$ **Equation 2**

and

$\frac{\partial Y}{\partial X_2} = \beta_2$ **Equation 3**

The two important characteristics to note are that X_1 does not appear on the right side of Equation 2 the equation that expresses the marginal effect of X_1 on Y, and X_2 does not appear on the right side of Equation 3, the equation that expresses the marginal effect of X_2 on Y. Mathematically, this indicates that the marginal effect of each independent variable is not a function of the variable itself.

5.5.2.1.1.2 Nonlinear in One Variable, Linear in the Other

An equation can be linear in one variable and nonlinear in another. An economic example might be a study of income determinants. Suppose there is reason to believe that income increases with age up to some age level and then decreases at higher age levels, and that income increases linearly with education. This could be expressed by

$$I = \beta_0 + \beta_1 A + \beta_2 A^2 + \beta_3 E \qquad \textbf{Equation 4}$$

The marginal effect of age (A) on income (I) is given by

$$\frac{\partial I}{\partial A} = \beta_1 + 2\beta_2 A \qquad \textbf{Equation 5}$$

and the marginal effect of education (*E*) is given by

$$\frac{\partial I}{\partial E} = \beta_3 \qquad \textbf{Equation 6}$$

The age variable (*A*) appears on the right side of Equation 5, which says that the marginal effect of age on income depends on the age level at which the marginal effect is measured. In other words, the marginal effect of age is itself a function of age. Hence, income is nonlinear in age. According to the definition above, Equation 6 shows income to be linear in education. Thus equation 4 is nonlinear in age and linear in education.

5.5.2.1.1.3 Nonlinear in All Variables

Finally, consider

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 {X_1}^2 + \beta_3 \frac{1}{X_2} \qquad \textbf{Equation 7}$$

Spinning a plausible theory to rationalize this equation is admittedly difficult, but it does have the property being illustrated.

From the discussion above, it is easy to see that Equation 7 is nonlinear in X_1. The marginal effect of X_2 is

$$\frac{\partial Y}{\partial X_2} = -\beta_3 \frac{1}{{X_2}^2} \qquad \textbf{Equation 8}$$

Which, since X_2 appears on the right side, shows the marginal effect of X_2 on Y to depend on the level of X_2 at which the marginal effect is measured. Thus, Equation 7 is nonlinear in both X_1 and X_2.

5.5.2.1.1.4 The General Case

Consider a general case. Let

$$Y = f(X_k), \quad k = 1, \ldots, K \qquad \textbf{Equation 9}$$

be the general form of the regression equation. If

$$\frac{\partial Y}{\partial X_k} \neq g(X_k) \qquad \textbf{Equation 10}$$

That is, if X_k does not appear on the right side of equation 10, then Equation 9 is linear in X_k. If, on the other hand,

$$\frac{\partial Y}{\partial X_k} = g(X_k) \qquad \textbf{Equation 11}$$

That is, if X_k does not appear on the right side of Equation 11, then Equation 9 is nonlinear in X_k.

5.5.2.1.2 Additive in the Variables

Additivity is similar to linearity in that it pertains to the marginal effect of a particular independent variable on the dependent variable. Additivity differs from linearity in that additivity is present if the marginal effect of a variable is not a function of any other variable in the equation. Because the treatment of additivity parallels that of linearity, examples are not necessary. Instead, the general results, using Equation 9 as the base equation, may be stated directly. If

$$\frac{\partial Y}{\partial X_k} \neq g(X_i), \qquad i \neq k \qquad\qquad \textbf{Equation 12}$$

That is, if no X_i appears on the right side of Equation 12, then the marginal effect of X_k on Y does not depend on the level of X_i. Therefore, Equation 12 is not a function of X_i. In this case, Equation 9 is additive in X_k. If, on the other hand,

$$\frac{\partial Y}{\partial X_k} = g(X_i), \qquad i \neq k \qquad\qquad \textbf{Equation 13}$$

That is, if an X_i does appear in the right side of equation 13, then the marginal effect of X_k on Y depends on the level of X_i [i.e., Equation 13 is a function of X_i]. In this case, Equation 9 is nonadditive in X_k. Thus, as with linearity, an equation can be additive in all variables, additive in some variables and nonadditive in others, or nonadditive in all variables.

Equations 10–13 show both the similarity and difference between linearity and additivity. Loosely speaking, linearity is concerned with “own” or “direct” effects, while additivity is concerned with “cross effects.”

5.5.2.2 Data Validation

To validate the linear regression relationship between SSD and all the independent variables, which include access density, traffic volume, number of lanes and posted speed limit, four graphs were plotted to demonstrate the relationship between SSD and access density, SSD and traffic volume, SSD and number of lanes, and SSD and posted speed limit for 210 simulation models respectively. Figures 46–49 show the linear regression plot of 210 simulation models. The X-axis represents access density, traffic volume, number of lanes and speed limit respectively. The Y-axis represents σ, which represents the roadway segment speed variation.

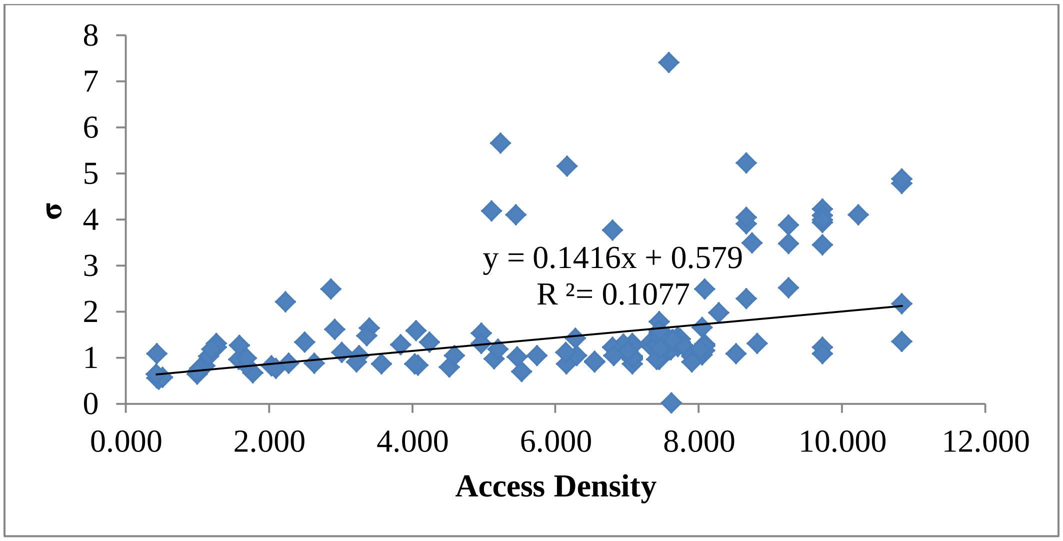


Figure 52 σ vs. Access Density (210 Simulation Models)

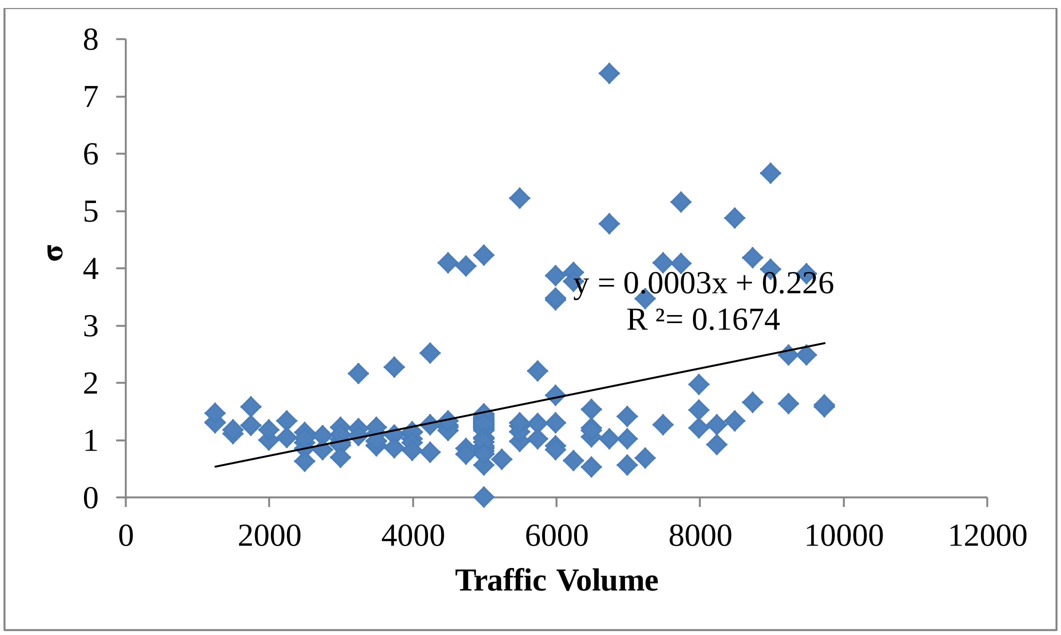


Figure 53 σ vs. Traffic Volume (210 Simulation Models)

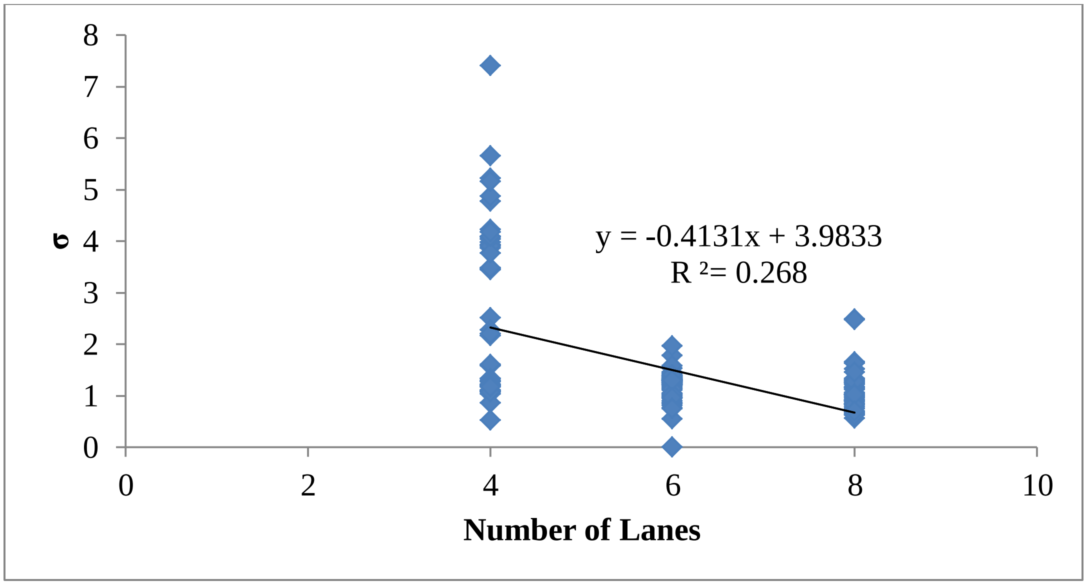


Figure 54 σ vs. Number of Lanes (210 Simulation Models)

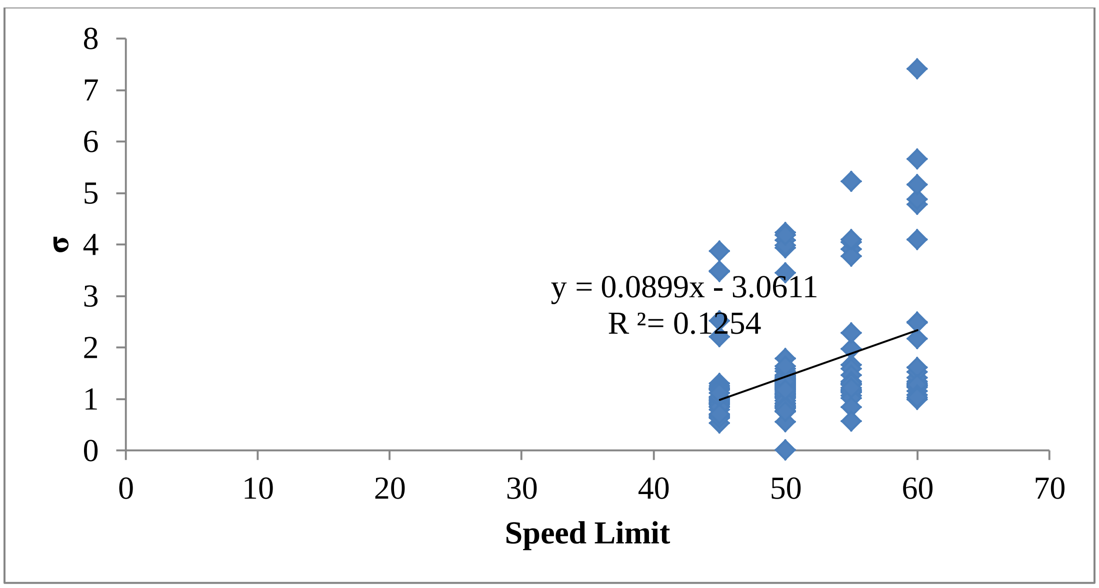


Figure 55 σ vs. Speed Limit (210 Simulation Models)

Based on linear regression plots, SSD vs. number of lanes has the largest R^2 value of 0.268, which indicates that independent variable number of lanes is most correlated to dependent variable σ than other three independent variables: access density, traffic volume, and posted speed limit. The only negative sign for number of lanes indicates that **σ** decreases with the increase in the number of lanes. The coefficients for access density, traffic volume, and speed limit are all positive, indicating that **σ** increases with the increase in access density, traffic volume, and speed limit.

A non-linear regression model was also applied for the 210 simulation models to model the relationship between SSD and all contributing factors (access density, traffic volume, number of lanes and speed limit). In this study, the non-linear regression model includes four types: exponential, logarithmic, polynomial, and power. Table 58 shows R^2 values of plot type by regression type of the 210 simulation models. It shows that when a polynomial regression model was developed to model the relationship between σ (roadway segment speed variation) and all the contributing factors—access density, traffic volume, number of lanes, and speed limit—σ vs number of lanes has the largest R^2, which is 0.3799.

Table 58 R^2 Value of Plot Type by Regression Type of 210 Simulation Models

Plot Type	Regression Type				
	Exponential	Linear	Logarithmic	Polynomial	Power
σ vs Access Density	0.0668	0.1077	0.0735	0.1817	0.055
σ vs Traffic Volume	0.0681	0.1674	0.1102	0.1924	0.04
σ vs Number of Lanes	0.1171	0.268	0.3098	0.3799	0.1344
σ vs Speed Limit	0.0614	0.1254	0.1197	0.1459	0.0592

5.5.3 Linear Regression Model

In this study, 210 simulation models were investigated. All the simulation models were simulated and calibrated in CORSIM, which is embedded in TSIS 6.1. A linear regression model was developed for the 210 simulation models to determine the relationship between the dependent variable SSD and all the independent variables:

access density, traffic volume, number of lanes and speed limit. The R^2 value of the regression model is 0.5443, and the adjusted R^2 value of the regression model is 0.5354. All simulation conditions were used to calculate coefficients in the predicted model. Table 59 shows the results by Generalized Linear Model (GLM). Column B is the coefficients for intercept and all independent variables. Column E is the p value of T-statistics for intercept and all independent variables. T-statistics indicated that the independent variables were statistically significant at a 95% level of confidence. The following shows the final developed regression equation:

$$Y = -1.1323 + 0.0974X_1 + 0.2141X_2 - 0.3737X_3 + 0.6197X_4$$ **Equation 14**

Where,

Y = roadway SSD

X_1 = access density

X_2 = traffic volume

X_3 = number of lanes

X_4 = speed limit

The coefficients for access density, traffic volume and speed limit are all positive, indicating that SSD increases with the increase of access density, traffic volume and speed limit. Oppositely, the coefficient for number of lanes is negative, indicating that SSD decreases with the increase of number of lanes.

Table 59 Coefficient Values by GLM Method of 210 Simulation Models

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1.1323	0.6842	-1.65	0.0995
Access Density	0.0974	0.0208	4.69	<.0001
Traffic Volume	0.2141	0.0304	7.05	<.0001
Number of Lanes	-0.3737	0.0385	-9.72	<.0001
Speed Limit	0.6197	0.1244	4.98	<.0001
$\mathbf{R^2}$ = 0.5443, $\mathbf{R^2_{adj}}$ = 0.5354				

Table 60 shows the Type III SS p-value by GLM method. As a guideline, the value for each of the variables in the regression model should have a Type III SS p-value of 0.05 or less, as shown in the last column of Table 60.

Table 60 Type III SS p-value by GLM Method of 210 Simulation Models

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Access Density	1	10.70534006	10.70534006	21.99	<.0001
Traffic Volume	1	24.20931810	24.20931810	49.73	<.0001
Number of Lanes	1	45.99441889	45.99441889	94.47	<.0001
Speed Limit	1	12.07688871	12.07688871	24.81	<.0001

Table 61 lists the number in the model, adjusted R^2, R^2, and the variables in the model, which is beneficial for choosing the best model for adjusting R^2 value. The highest R^2 value is 0.5443, and adjusted R^2 value is 0.5354.

Table 61 Choosing the Best Model for Adjusting R^2 Value of 210 Simulation Models

Number in Model	Adjusted R-Square	R-Square	Variables in Model
4	0.5354	0.5443	Access Density, Traffic Volume, Number of Lanes and Speed Limit
3	0.4881	0.4954	Traffic Volume, Number of Lanes and Speed Limit
3	0.4817	0.4891	Access Density, Traffic Volume and Number of Lanes
2	0.4356	0.4410	Traffic Volume, Number of Lanes
3	0.4255	0.4337	Access Density, Number of Lanes and Speed Limit
2	0.3754	0.3814	Number of Lanes, Speed Limit
3	0.3246	0.3343	Access Density, Traffic Volume and Speed Limit
2	0.3135	0.3201	Access Density, Number of Lanes
1	0.2645	0.2680	Number of Lanes
2	0.2631	0.2702	Access Density, Traffic Volume
2	0.2244	0.2318	Access Density, Speed Limit
2	0.2241	0.2316	Traffic Volume, Speed Limit
1	0.1634	0.1674	Traffic Volume
1	0.1212	0.1254	Speed Limit
1	0.1034	0.1077	Access Density

Tables 62–64 show the validation process of the "iid" assumption of linear regression by examing the residuals of final model. Table 62 shows the REG printout, which will have a statistic that jointly tests for heteroscedasticity (not identical distributions of error terms) and dependence of error terms. A significant p-value (Pr > ChiSq) of 0.0003 < 0.05 gives the conclusion that error terms in the final developed regression are dependent and not identically distributed. The Durbin-Watson (D-W) statistic is calculated by using the DW option in REG. The D-W statistic tests for first

order correlation of error terms and ranges from 0 to 4.0. Generally, a D-W statistic of 2.0 indicates the data are independent. A small (less than 1.60) D-W indicates positive first order correlation, and a large D-W indicates negative first order correlation. Table 63 shows the D-W statistic test results. Because D-W statistic of 210 simulation models is 2.055, the data are independent. A Shapiro-Wilks statistic test shows that the p-value (Pr < W<0.0001) is less than significant (e.g., 0.05), so the errors are not from a normal distribution. It indicates the error terms are not normally distributed. Table 64 shows the Shapiro-Wilks statistic test results.

Table 62 Test of First and Second Moment Specification of 210 Simulation Models

DF	Chi-Square	Pr > ChiSq
14	39.83	0.0003

Table 63 Durbin-Watson Statistic of 210 Simulation Models

Durbin-Watson D	2.055
Number of Observations	210
1st Order Autocorrelation	-0.028

Table 64 Tests of Normality by Shapiro-Wilk Statistic of 210 Simulation Models

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.828	**Pr < W**	<0.0001

However, the D-W statistic is not valid with small sample sizes. The data set of 210 simulation models has 210 observations, which is larger than 40 observations (210>4*10). Thus, the data set of the 210 simulation models is large, and the D-W statistic is valid with 210 simulation models. Multicollinearity is when the independent, X, variables are correlated. A statistic called the Variance Inflation Factor, VIF, can be used to test for multicollinearity. A cutoff of 10 can be used to test if a regression function is unstable. If VIF> 10, then the causes of multicollinearity should be searched. As shown in Table 65, all the VIF values of 210 simulation models are all smaller than 10. Hence, the regression function of 210 simulation models is stable, and the multicollinearity does not exist.

Table 65 Tests for Multicollinearity of 210 Simulation Models

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	-1.132	0.684	-1.65	0.0995	0
Access Density	1	0.097	0.021	4.69	<.0001	1.043
Traffic Volume	1	0.214	0.03	7.05	<.0001	1.079
Number of Lanes	1	-0.374	0.038	-9.72	<.0001	1.044
Speed Limit	1	0.62	0.124	4.98	<.0001	1.08

To test outliers, Cook's D statistic was applied to the 210 simulation models. For the 210 simulation models, p=4 (access density, traffic volume, number of lanes, speed limit) and n=210. Since $2 \times (4/210)^{1/2} = 0.276 < 1.0$, the dataset of 210 simulation models is considered to be small. Table 66 shows the output of Cook's D statistic for the 210 simulation models. In Table 66, the second to last column Cook's D shows that all the absolute Cook's D values are less than 2, so Cook's D statistics of the 210 simulation models do not need to be investigated. The last column is RSTUDENT. Of the 210 simulation models, 14 need to be investigated because their absolute values are larger than 2. These 14 models are Model 7 with RSTUDENT value of 2.2385, Model 22 with RSTUDENT value of 2.5458, Model 67 with RSTUDENT value of -2.2223, Model 68 with RSTUDENT value of -2.2224, Model 111 with RSTUDENT value of 3.6115, Model

143 with RSTUDENT value of 2.0394, Model 161 with RSTUDENT value of 6.6456, Model 170 with RSTUDENT value of 2.6951, Model 177 with RSTUDENT value of 2.3226, Model 179 with RSTUDENT value of 3.2175, Model 185 with RSTUDENT value of 2.3633, Model 187 with RSTUDENT value of -2.8220, Model 205 with RSTUDENT value of 2.0614, and Model 208 with RSTUDENT value of -2.0954.

Corresponding to Table 57, the 14 models that need to be investigated are as follows:

(1) Volume +20%, 4 lanes, SL 45 mph with Detectors (Model 7)

(2) Number of lanes on Major Road decrease from 6 to 4 (Model 22)

(3) N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 53th Street, Access Type 8→Access Type 7 (Model 67)

(4) N 46th Street, Access Type 4→Access Type 3, N 51st Street (South), Access Type 4→Access Type 3 & N 58th Street, Access Type 8→Access Type 7 (Model 68)

(5) Volume +10%, 4 lanes, SL 55 mph with Detectors (Model 111)

(6) Volume -5%, 4 lanes, SL 55 mph with Detectors (Model 143)

(7) Volume +35%, 4 lanes, SL 60 mph with Detectors, Remove Driveway 12,13,14,15 (Model 161)

(8) Volume +55%, 4 lanes, SL 60 mph with Detectors, Remove Driveway 10,11,12,13,14,15 (Model 170)

(9) Volume -55%, 8 lanes, SL 45 mph with Detectors, Remove Driveway 9,10,11,12,13,14,15 (Model 177)

(10) Volume +80%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 8,9,10,11,12,13,14,15 (Model 179)

(11) Volume -75%, 8 lanes, SL 55 mph with Detectors, Remove Access Points 7,8,9,10,11,12,13,14,15 (Model 185)

(12) Volume +95%, 4 lanes, SL 60 mph with Detectors, Remove Access Points 6, 7, 8, 9, 10, 11,12,13,14,15 (Model 187)

(13) Volume -50%, 8 lanes, SL 45 mph with Detectors, Remove Access Points 2, 3, 4, 6, 7, 8, 9, 10,11,12,13,14,15 (Model 205)

(14) Volume +60%, 4 lanes, SL 55 mph with Detectors, Remove Access Points 2, 3, 4, 6, 8, 9, 10,11,12,13,14,15 (Model 208)

Table 66 Testing for Outliers by Cook's D Statistics of 210 Simulation Models

<table>
<tr><th colspan="11">Output Statistics</th></tr>
<tr><th>Obs</th><th>Dependent Variable</th><th>Predicted Value</th><th>Std Error Mean Predict</th><th>Residual</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th></tr>
<tr><td>1</td><td>1.2884</td><td>1.5184</td><td>0.0524</td><td>-0.2300</td><td>0.696</td><td>-0.331</td><td>| | |</td><td>0.000</td><td>-0.3298</td></tr>
<tr><td>2</td><td>1.2426</td><td>1.6253</td><td>0.0545</td><td>-0.3826</td><td>0.696</td><td>-0.550</td><td>| *| |</td><td>0.000</td><td>-0.5491</td></tr>
<tr><td>3</td><td>0.9720</td><td>1.2789</td><td>0.0915</td><td>-0.3068</td><td>0.692</td><td>-0.444</td><td>| | |</td><td>0.001</td><td>-0.4427</td></tr>
<tr><td>4</td><td>1.7788</td><td>1.7321</td><td>0.0605</td><td>0.0467</td><td>0.695</td><td>0.0672</td><td>| | |</td><td>0.000</td><td>0.0670</td></tr>
<tr><td>5</td><td>1.2972</td><td>1.3857</td><td>0.0978</td><td>-0.0885</td><td>0.691</td><td>-0.128</td><td>| | |</td><td>0.000</td><td>-0.1278</td></tr>
<tr><td>6</td><td>3.4443</td><td>2.7016</td><td>0.1072</td><td>0.7427</td><td>0.689</td><td>1.077</td><td>| |** |</td><td>0.006</td><td>1.0776</td></tr>
<tr><td>7</td><td>3.8654</td><td>2.3460</td><td>0.1307</td><td>1.5194</td><td>0.685</td><td>2.217</td><td>| |**** |</td><td>0.036</td><td>2.2385</td></tr>
<tr><td>8</td><td>1.5350</td><td>1.8389</td><td>0.0694</td><td>-0.3040</td><td>0.694</td><td>-0.438</td><td>| | |</td><td>0.000</td><td>-0.4370</td></tr>
<tr><td>9</td><td>1.2069</td><td>1.5291</td><td>0.1069</td><td>-0.3222</td><td>0.690</td><td>-0.467</td><td>| | |</td><td>0.001</td><td>-0.4664</td></tr>
<tr><td>10</td><td>1.2247</td><td>1.4116</td><td>0.0546</td><td>-0.1869</td><td>0.696</td><td>-0.269</td><td>| | |</td><td>0.000</td><td>-0.2681</td></tr>
<tr><td>11</td><td>1.2481</td><td>1.0652</td><td>0.0857</td><td>0.1829</td><td>0.692</td><td>0.264</td><td>| | |</td><td>0.000</td><td>0.2636</td></tr>
<tr><td>12</td><td>1.1308</td><td>1.3047</td><td>0.0606</td><td>-0.1739</td><td>0.695</td><td>-0.250</td><td>| | |</td><td>0.000</td><td>-0.2496</td></tr>
<tr><td>13</td><td>1.0202</td><td>0.9584</td><td>0.0867</td><td>0.0619</td><td>0.692</td><td>0.0894</td><td>| | |</td><td>0.000</td><td>0.0892</td></tr>
<tr><td>14</td><td>1.1116</td><td>1.1979</td><td>0.0694</td><td>-0.0863</td><td>0.694</td><td>-0.124</td><td>| | |</td><td>0.000</td><td>-0.1240</td></tr>
<tr><td>15</td><td>0.9765</td><td>0.8515</td><td>0.0903</td><td>0.1250</td><td>0.692</td><td>0.181</td><td>| | |</td><td>0.000</td><td>0.1802</td></tr>
<tr><td>16</td><td>0.8952</td><td>0.0524</td><td>0.1175</td><td>0.8428</td><td>0.688</td><td>1.225</td><td>| |** |</td><td>0.009</td><td>1.2269</td></tr>
<tr><td>17</td><td>1.0103</td><td>1.0908</td><td>0.0802</td><td>-0.0806</td><td>0.693</td><td>-0.116</td><td>| | |</td><td>0.000</td><td>-0.1160</td></tr>
<tr><td>18</td><td>0.9473</td><td>0.7445</td><td>0.0962</td><td>0.2028</td><td>0.691</td><td>0.293</td><td>| | |</td><td>0.000</td><td>0.2928</td></tr>
<tr><td>19</td><td>1.2218</td><td>2.0604</td><td>0.1186</td><td>-0.8385</td><td>0.688</td><td>-1.220</td><td>| **| |</td><td>0.009</td><td>-1.2210</td></tr>
</table>

Table 66 (continued)

<table>
<tr><th colspan="11">Output Statistics</th></tr>
<tr><th>Obs</th><th>Dependent Variable</th><th>Predicted Value</th><th>Std Error Mean Predict</th><th>Residual</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th></tr>
<tr><td>**20**</td><td>0.9543</td><td>0.9840</td><td>0.0922</td><td>-0.0297</td><td>0.692</td><td>-0.0429</td><td>| | |</td><td>0.000</td><td>-0.0428</td></tr>
<tr><td>**21**</td><td>0.8513</td><td>0.6376</td><td>0.1039</td><td>0.2137</td><td>0.690</td><td>0.310</td><td>| | |</td><td>0.000</td><td>0.3090</td></tr>
<tr><td>**22**</td><td>4.2220</td><td>2.4879</td><td>0.1026</td><td>1.7340</td><td>0.690</td><td>2.512</td><td>| |***** |</td><td>0.028</td><td>2.5458</td></tr>
<tr><td>**23**</td><td>1.0226</td><td>0.8154</td><td>0.1000</td><td>0.2073</td><td>0.691</td><td>0.300</td><td>| | |</td><td>0.000</td><td>0.2995</td></tr>
<tr><td>**24**</td><td>1.2680</td><td>1.5221</td><td>0.0527</td><td>-0.2541</td><td>0.696</td><td>-0.365</td><td>| | |</td><td>0.000</td><td>-0.3645</td></tr>
<tr><td>**25**</td><td>1.2848</td><td>1.5304</td><td>0.0533</td><td>-0.2456</td><td>0.696</td><td>-0.353</td><td>| | |</td><td>0.000</td><td>-0.3523</td></tr>
<tr><td>**26**</td><td>1.3855</td><td>1.5221</td><td>0.0527</td><td>-0.1367</td><td>0.696</td><td>-0.196</td><td>| | |</td><td>0.000</td><td>-0.1959</td></tr>
<tr><td>**27**</td><td>1.2294</td><td>1.5278</td><td>0.0531</td><td>-0.2984</td><td>0.696</td><td>-0.429</td><td>| | |</td><td>0.000</td><td>-0.4280</td></tr>
<tr><td>**28**</td><td>1.2912</td><td>1.5278</td><td>0.0531</td><td>-0.2366</td><td>0.696</td><td>-0.340</td><td>| | |</td><td>0.000</td><td>-0.3393</td></tr>
<tr><td>**29**</td><td>1.2059</td><td>1.5278</td><td>0.0531</td><td>-0.3218</td><td>0.696</td><td>-0.463</td><td>| | |</td><td>0.000</td><td>-0.4617</td></tr>
<tr><td>**30**</td><td>1.2853</td><td>1.5090</td><td>0.0518</td><td>-0.2237</td><td>0.696</td><td>-0.321</td><td>| | |</td><td>0.000</td><td>-0.3208</td></tr>
<tr><td>**31**</td><td>1.2808</td><td>1.5146</td><td>0.0521</td><td>-0.2338</td><td>0.696</td><td>-0.336</td><td>| | |</td><td>0.000</td><td>-0.3353</td></tr>
<tr><td>**32**</td><td>1.2489</td><td>1.5342</td><td>0.0537</td><td>-0.2853</td><td>0.696</td><td>-0.410</td><td>| | |</td><td>0.000</td><td>-0.4092</td></tr>
<tr><td>**33**</td><td>1.2545</td><td>1.5259</td><td>0.0530</td><td>-0.2715</td><td>0.696</td><td>-0.390</td><td>| | |</td><td>0.000</td><td>-0.3894</td></tr>
<tr><td>**34**</td><td>1.3778</td><td>1.5316</td><td>0.0534</td><td>-0.1538</td><td>0.696</td><td>-0.221</td><td>| | |</td><td>0.000</td><td>-0.2205</td></tr>
<tr><td>**35**</td><td>1.2782</td><td>1.5316</td><td>0.0534</td><td>-0.2534</td><td>0.696</td><td>-0.364</td><td>| | |</td><td>0.000</td><td>-0.3635</td></tr>
<tr><td>**36**</td><td>1.2745</td><td>1.5316</td><td>0.0534</td><td>-0.2571</td><td>0.696</td><td>-0.370</td><td>| | |</td><td>0.000</td><td>-0.3688</td></tr>
<tr><td>**37**</td><td>1.2573</td><td>1.5128</td><td>0.0520</td><td>-0.2555</td><td>0.696</td><td>-0.367</td><td>| | |</td><td>0.000</td><td>-0.3664</td></tr>
<tr><td>**38**</td><td>1.3274</td><td>1.5184</td><td>0.0524</td><td>-0.1910</td><td>0.696</td><td>-0.275</td><td>| | |</td><td>0.000</td><td>-0.2739</td></tr>
</table>

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
39	1.2229	1.5342	0.0537	-0.3113	0.696	-0.447	| | |	0.000	-0.4466
40	1.3440	1.5398	0.0541	-0.1958	0.696	-0.281	| | |	0.000	-0.2808
41	1.2975	1.5398	0.0541	-0.2423	0.696	-0.348	| | |	0.000	-0.3476
42	1.3021	1.5398	0.0541	-0.2376	0.696	-0.342	| | |	0.000	-0.3409
43	1.1977	1.5210	0.0526	-0.3232	0.696	-0.465	| | |	0.000	-0.4637
44	1.3184	1.5266	0.0530	-0.2082	0.696	-0.299	| | |	0.000	-0.2986
45	1.3022	1.5316	0.0534	-0.2294	0.696	-0.330	| | |	0.000	-0.3290
46	1.3081	1.5316	0.0534	-0.2234	0.696	-0.321	| | |	0.000	-0.3205
47	1.2143	1.5316	0.0534	-0.3172	0.696	-0.456	| | |	0.000	-0.4551
48	1.2956	1.5128	0.0520	-0.2172	0.696	-0.312	| | |	0.000	-0.3115
49	1.2910	1.5184	0.0524	-0.2274	0.696	-0.327	| | |	0.000	-0.3261
50	1.2266	1.5371	0.0539	-0.3106	0.696	-0.446	| | |	0.000	-0.4455
51	1.2972	1.5371	0.0539	-0.2399	0.696	-0.345	| | |	0.000	-0.3442
52	1.3520	1.5184	0.0524	-0.1665	0.696	-0.239	| | |	0.000	-0.2387
53	1.3027	1.5240	0.0528	-0.2212	0.696	-0.318	| | |	0.000	-0.3173
54	1.2136	1.5371	0.0539	-0.3235	0.696	-0.465	| | |	0.000	-0.4641
55	1.2907	1.5184	0.0524	-0.2277	0.696	-0.327	| | |	0.000	-0.3265
56	1.3332	1.5240	0.0528	-0.1908	0.696	-0.274	| | |	0.000	-0.2736
57	1.2059	1.5184	0.0524	-0.3125	0.696	-0.449	| | |	0.000	-0.4483

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
58	1.2342	1.5240	0.0528	-0.2897	0.696	-0.416	| | |	0.000	-0.4156
59	1.2948	1.5052	0.0515	-0.2104	0.696	-0.302	| | |	0.000	-0.3017
60	1.2422	1.5379	0.0540	-0.2957	0.696	-0.425	| | |	0.000	-0.4243
61	1.2646	1.5436	0.0545	-0.2790	0.696	-0.401	| | |	0.000	-0.4002
62	1.2777	1.5436	0.0545	-0.2659	0.696	-0.382	| | |	0.000	-0.3814
63	1.4350	1.5436	0.0545	-0.1085	0.696	-0.156	| | |	0.000	-0.1556
64	1.3218	1.5248	0.0529	-0.2029	0.696	-0.292	| | |	0.000	-0.2910
65	1.1847	1.5304	0.0533	-0.3457	0.696	-0.497	| | |	0.000	-0.4960
66	1.3635	1.5354	0.0538	-0.1719	0.696	-0.247	| | |	0.000	-0.2465
67	0.004019	1.5354	0.0538	-1.5314	0.696	-2.201	| ****| |	0.006	-2.2223
68	0.003970	1.5354	0.0538	-1.5314	0.696	-2.201	| ****| |	0.006	-2.2224
69	1.3446	1.5166	0.0523	-0.1720	0.696	-0.247	| | |	0.000	-0.2466
70	1.2274	1.5221	0.0527	-0.2947	0.696	-0.424	| | |	0.000	-0.4227
71	1.3905	1.5409	0.0542	-0.1504	0.696	-0.216	| | |	0.000	-0.2157
72	1.3795	1.5409	0.0542	-0.1614	0.696	-0.232	| | |	0.000	-0.2315
73	1.3831	1.5221	0.0527	-0.1390	0.696	-0.200	| | |	0.000	-0.1994
74	1.3503	1.5278	0.0531	-0.1775	0.696	-0.255	| | |	0.000	-0.2546

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
75	1.3591	1.5409	0.0542	-0.1818	0.696	-0.261	| | |	0.000	-0.2607
76	1.2409	1.5221	0.0527	-0.2812	0.696	-0.404	| | |	0.000	-0.4034
77	1.3005	1.5278	0.0531	-0.2273	0.696	-0.327	| | |	0.000	-0.3260
78	1.3878	1.5221	0.0527	-0.1343	0.696	-0.193	| | |	0.000	-0.1926
79	1.3126	1.5278	0.0531	-0.2151	0.696	-0.309	| | |	0.000	-0.3085
80	1.2108	1.5090	0.0518	-0.2982	0.696	-0.429	| | |	0.000	-0.4277
81	1.3269	1.5436	0.0545	-0.2167	0.696	-0.311	| | |	0.000	-0.3108
82	1.2299	1.5436	0.0545	-0.3136	0.696	-0.451	| | |	0.000	-0.4500
83	1.2890	1.5436	0.0545	-0.2545	0.696	-0.366	| | |	0.000	-0.3651
84	1.2043	1.5248	0.0529	-0.3205	0.696	-0.461	| | |	0.000	-0.4597
85	1.2948	1.5304	0.0533	-0.2356	0.696	-0.339	| | |	0.000	-0.3380
86	1.2927	1.5409	0.0542	-0.2482	0.696	-0.357	| | |	0.000	-0.3560
87	1.3313	1.5409	0.0542	-0.2096	0.696	-0.301	| | |	0.000	-0.3007
88	1.3028	1.5221	0.0527	-0.2193	0.696	-0.315	| | |	0.000	-0.3145
89	1.3165	1.5278	0.0531	-0.2113	0.696	-0.304	| | |	0.000	-0.3030
90	1.3789	1.5466	0.0548	-0.1677	0.696	-0.241	| | |	0.000	-0.2405
91	1.2896	1.5278	0.0531	-0.2382	0.696	-0.342	| | |	0.000	-0.3416
92	1.2747	1.5333	0.0536	-0.2586	0.696	-0.372	| | |	0.000	-0.3710
93	1.3066	1.5278	0.0531	-0.2212	0.696	-0.318	| | |	0.000	-0.3172

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
94	1.2709	1.5333	0.0536	-0.2625	0.696	-0.377	| | |	0.000	-0.3765
95	1.2578	1.5146	0.0521	-0.2568	0.696	-0.369	| | |	0.000	-0.3683
96	1.3935	1.5474	0.0548	-0.1538	0.696	-0.221	| | |	0.000	-0.2207
97	1.3135	1.5474	0.0548	-0.2339	0.696	-0.336	| | |	0.000	-0.3355
98	1.3301	1.5474	0.0548	-0.2173	0.696	-0.312	| | |	0.000	-0.3117
99	1.3084	1.5286	0.0532	-0.2202	0.696	-0.316	| | |	0.000	-0.3158
100	1.1622	1.5342	0.0537	-0.3720	0.696	-0.535	| *| |	0.000	-0.5338
101	1.2633	1.5447	0.0546	-0.2815	0.696	-0.405	| | |	0.000	-0.4038
102	1.3202	1.5447	0.0546	-0.2245	0.696	-0.323	| | |	0.000	-0.3220
103	1.3141	1.5259	0.0530	-0.2118	0.696	-0.304	| | |	0.000	-0.3038
104	1.3638	1.5316	0.0534	-0.1678	0.696	-0.241	| | |	0.000	-0.2407
105	1.2589	1.5504	0.0551	-0.2914	0.696	-0.419	| | |	0.000	-0.4182
106	1.4011	1.5316	0.0534	-0.1305	0.696	-0.188	| | |	0.000	-0.1871
107	1.3853	1.5371	0.0539	-0.1518	0.696	-0.218	| | |	0.000	-0.2177
108	1.3592	1.5316	0.0534	-0.1724	0.696	-0.248	| | |	0.000	-0.2472
109	1.3739	1.5371	0.0539	-0.1632	0.696	-0.235	| | |	0.000	-0.2341
110	1.4519	1.5184	0.0524	-0.0665	0.696	-0.0956	| | |	0.000	-0.0953
111	5.2223	2.8008	0.1042	2.4215	0.690	3.510	| |******|	0.056	3.6115
112	1.2907	1.6131	0.1518	-0.3223	0.681	-0.473	| | |	0.002	-0.4724

Table 66 (continued)

Output Statistics										
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
113	0.8912	0.5866	0.1222	0.3046	0.687	0.443	| | |	0.001	0.4425
114	3.9275	2.7551	0.1097	1.1724	0.689	1.701	| |*** |	0.015	1.7093
115	1.0533	1.4598	0.1167	-0.4064	0.688	-0.591	| *| |	0.002	-0.5899
116	4.7766	3.5899	0.1583	1.1867	0.680	1.746	| |*** |	0.033	1.7551
117	1.0213	1.2429	0.1157	-0.2217	0.688	-0.322	| | |	0.001	-0.3214
118	3.4654	2.6132	0.1489	0.8522	0.682	1.250	| |** |	0.015	1.2519
119	1.2614	1.9871	0.1563	-0.7257	0.680	-1.067	| **| |	0.012	-1.0676
120	4.0824	3.0757	0.1328	1.0068	0.685	1.470	| |** |	0.016	1.4739
121	1.9690	2.5502	0.1071	-0.5812	0.689	-0.843	| *| |	0.003	-0.8423
122	0.9175	1.0677	0.1606	-0.1502	0.679	-0.221	| | |	0.001	-0.2207
123	4.8675	3.9642	0.1732	0.9033	0.676	1.336	| |** |	0.023	1.3390
124	1.6529	1.9406	0.1478	-0.2877	0.682	-0.422	| | |	0.002	-0.4211
125	3.9836	3.3429	0.1595	0.6407	0.679	0.943	| |* |	0.010	0.9430
126	2.4853	2.3609	0.1774	0.1244	0.675	0.184	| | |	0.000	0.1839
127	3.9058	3.6557	0.1598	0.2501	0.679	0.368	| | |	0.002	0.3675
128	1.5794	2.5337	0.1532	-0.9544	0.681	-1.402	| **| |	0.020	-1.4053
129	1.1662	1.0324	0.1188	0.1338	0.688	0.195	| | |	0.000	0.1941
130	2.5124	1.9719	0.1216	0.5405	0.687	0.787	| |* |	0.004	0.7859
131	1.1472	1.2390	0.1651	-0.0918	0.678	-0.135	| | |	0.000	-0.1351

Table 66 (continued)

<table>
<tr><th colspan="11">Output Statistics</th></tr>
<tr><th>Obs</th><th>Dependent Variable</th><th>Predicted Value</th><th>Std Error Mean Predict</th><th>Residual</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th></tr>
<tr><td>**132**</td><td>2.2728</td><td>2.4267</td><td>0.1170</td><td>-0.1540</td><td>0.688</td><td>-0.224</td><td>| | |</td><td>0.000</td><td>-0.2233</td></tr>
<tr><td>**133**</td><td>0.9044</td><td>0.4948</td><td>0.1108</td><td>0.4095</td><td>0.689</td><td>0.594</td><td>| |* |</td><td>0.002</td><td>0.5935</td></tr>
<tr><td>**134**</td><td>2.1590</td><td>2.8422</td><td>0.1791</td><td>-0.6833</td><td>0.674</td><td>-1.013</td><td>| **| |</td><td>0.014</td><td>-1.0133</td></tr>
<tr><td>**135**</td><td>0.9064</td><td>-0.0547</td><td>0.1223</td><td>0.9610</td><td>0.687</td><td>1.399</td><td>| |** |</td><td>0.012</td><td>1.4023</td></tr>
<tr><td>**136**</td><td>1.0759</td><td>2.0070</td><td>0.1226</td><td>-0.9311</td><td>0.687</td><td>-1.356</td><td>| **| |</td><td>0.012</td><td>-1.3584</td></tr>
<tr><td>**137**</td><td>1.1269</td><td>0.6050</td><td>0.1482</td><td>0.5218</td><td>0.682</td><td>0.765</td><td>| |* |</td><td>0.006</td><td>0.7646</td></tr>
<tr><td>**138**</td><td>1.3367</td><td>2.6284</td><td>0.1955</td><td>-1.2916</td><td>0.670</td><td>-1.928</td><td>| ***| |</td><td>0.063</td><td>-1.9414</td></tr>
<tr><td>**139**</td><td>0.9933</td><td>0.5310</td><td>0.1132</td><td>0.4623</td><td>0.689</td><td>0.671</td><td>| |* |</td><td>0.002</td><td>0.6705</td></tr>
<tr><td>**140**</td><td>1.2508</td><td>0.7579</td><td>0.2024</td><td>0.4929</td><td>0.668</td><td>0.738</td><td>| |* |</td><td>0.010</td><td>0.7373</td></tr>
<tr><td>**141**</td><td>1.1782</td><td>1.2641</td><td>0.1450</td><td>-0.0859</td><td>0.683</td><td>-0.126</td><td>| | |</td><td>0.000</td><td>-0.1255</td></tr>
<tr><td>**142**</td><td>1.3044</td><td>0.1026</td><td>0.1598</td><td>1.2018</td><td>0.679</td><td>1.769</td><td>| |*** |</td><td>0.035</td><td>1.7787</td></tr>
<tr><td>**143**</td><td>4.0362</td><td>2.6406</td><td>0.1067</td><td>1.3955</td><td>0.690</td><td>2.024</td><td>| |**** |</td><td>0.020</td><td>2.0394</td></tr>
<tr><td>**144**</td><td>1.2855</td><td>1.4700</td><td>0.0498</td><td>-0.1845</td><td>0.696</td><td>-0.265</td><td>| | |</td><td>0.000</td><td>-0.2645</td></tr>
<tr><td>**145**</td><td>3.4774</td><td>2.2959</td><td>0.1280</td><td>1.1815</td><td>0.686</td><td>1.723</td><td>| |*** |</td><td>0.021</td><td>1.7309</td></tr>
<tr><td>**146**</td><td>1.1646</td><td>1.4045</td><td>0.1127</td><td>-0.2400</td><td>0.689</td><td>-0.348</td><td>| | |</td><td>0.001</td><td>-0.3477</td></tr>
<tr><td>**147**</td><td>4.0938</td><td>3.0495</td><td>0.1590</td><td>1.0443</td><td>0.679</td><td>1.537</td><td>| |*** |</td><td>0.026</td><td>1.5422</td></tr>
<tr><td>**148**</td><td>0.9572</td><td>0.5539</td><td>0.1014</td><td>0.4032</td><td>0.690</td><td>0.584</td><td>| |* |</td><td>0.001</td><td>0.5831</td></tr>
<tr><td>**149**</td><td>1.0428</td><td>1.4064</td><td>0.0496</td><td>-0.3636</td><td>0.696</td><td>-0.522</td><td>| *| |</td><td>0.000</td><td>-0.5215</td></tr>
<tr><td>**150**</td><td>1.1399</td><td>1.8923</td><td>0.0698</td><td>-0.7524</td><td>0.694</td><td>-1.084</td><td>| **| |</td><td>0.002</td><td>-1.0843</td></tr>
</table>

Table 66 (continued)

<table>
<tr><th colspan="11">Output Statistics</th></tr>
<tr><th>Obs</th><th>Dependent Variable</th><th>Predicted Value</th><th>Std Error Mean Predict</th><th>Residual</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th></tr>
<tr><td>**151**</td><td>0.6861</td><td>0.7547</td><td>0.1404</td><td>-0.0686</td><td>0.683</td><td>-0.100</td><td>| | |</td><td>0.000</td><td>-0.1002</td></tr>
<tr><td>**152**</td><td>1.0840</td><td>2.1028</td><td>0.0998</td><td>-1.0188</td><td>0.691</td><td>-1.475</td><td>| **| |</td><td>0.009</td><td>-1.4796</td></tr>
<tr><td>**153**</td><td>1.2152</td><td>1.0065</td><td>0.1661</td><td>0.2087</td><td>0.678</td><td>0.308</td><td>| | |</td><td>0.001</td><td>0.3073</td></tr>
<tr><td>**154**</td><td>1.0394</td><td>1.3521</td><td>0.0522</td><td>-0.3127</td><td>0.696</td><td>-0.449</td><td>| | |</td><td>0.000</td><td>-0.4486</td></tr>
<tr><td>**155**</td><td>3.7645</td><td>2.7794</td><td>0.1038</td><td>0.9851</td><td>0.690</td><td>1.428</td><td>| |** |</td><td>0.009</td><td>1.4314</td></tr>
<tr><td>**156**</td><td>1.4063</td><td>2.4516</td><td>0.1230</td><td>-1.0453</td><td>0.687</td><td>-1.522</td><td>| ***| |</td><td>0.015</td><td>-1.5269</td></tr>
<tr><td>**157**</td><td>0.8514</td><td>0.5916</td><td>0.0910</td><td>0.2599</td><td>0.692</td><td>0.376</td><td>| | |</td><td>0.000</td><td>0.3748</td></tr>
<tr><td>**158**</td><td>1.1956</td><td>1.5835</td><td>0.1197</td><td>-0.3879</td><td>0.687</td><td>-0.564</td><td>| *| |</td><td>0.002</td><td>-0.5633</td></tr>
<tr><td>**159**</td><td>0.9613</td><td>1.2941</td><td>0.0576</td><td>-0.3328</td><td>0.695</td><td>-0.479</td><td>| | |</td><td>0.000</td><td>-0.4776</td></tr>
<tr><td>**160**</td><td>1.0154</td><td>1.0479</td><td>0.1044</td><td>-0.0325</td><td>0.690</td><td>-0.0471</td><td>| | |</td><td>0.000</td><td>-0.0470</td></tr>
<tr><td>**161**</td><td>7.4008</td><td>3.2730</td><td>0.1408</td><td>4.1278</td><td>0.683</td><td>6.040</td><td>| |******|</td><td>0.310</td><td>6.6456</td></tr>
<tr><td>**162**</td><td>0.7892</td><td>0.0150</td><td>0.1160</td><td>0.7742</td><td>0.688</td><td>1.125</td><td>| |** |</td><td>0.007</td><td>1.1259</td></tr>
<tr><td>**163**</td><td>1.0314</td><td>1.6701</td><td>0.1164</td><td>-0.6387</td><td>0.688</td><td>-0.928</td><td>| *| |</td><td>0.005</td><td>-0.9281</td></tr>
<tr><td>**164**</td><td>1.0345</td><td>1.2398</td><td>0.0644</td><td>-0.2053</td><td>0.695</td><td>-0.295</td><td>| | |</td><td>0.000</td><td>-0.2948</td></tr>
<tr><td>**165**</td><td>4.0881</td><td>2.9148</td><td>0.1244</td><td>1.1732</td><td>0.687</td><td>1.709</td><td>| |*** |</td><td>0.019</td><td>1.7169</td></tr>
<tr><td>**166**</td><td>1.5175</td><td>1.7895</td><td>0.1554</td><td>-0.2720</td><td>0.680</td><td>-0.400</td><td>| | |</td><td>0.002</td><td>-0.3990</td></tr>
<tr><td>**167**</td><td>1.0997</td><td>1.7110</td><td>0.1096</td><td>-0.6113</td><td>0.689</td><td>-0.887</td><td>| *| |</td><td>0.004</td><td>-0.8866</td></tr>
<tr><td>**168**</td><td>0.8343</td><td>-0.3483</td><td>0.1292</td><td>1.1826</td><td>0.686</td><td>1.725</td><td>| |*** |</td><td>0.021</td><td>1.7331</td></tr>
<tr><td>**169**</td><td>0.8531</td><td>1.1856</td><td>0.0723</td><td>-0.3325</td><td>0.694</td><td>-0.479</td><td>| | |</td><td>0.000</td><td>-0.4782</td></tr>
</table>

Table 66 (continued)

<table>
<tr><th colspan="11">Output Statistics</th></tr>
<tr><th>Obs</th><th>Dependent Variable</th><th>Predicted Value</th><th>Std Error Mean Predict</th><th>Residual</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th></tr>
<tr><td>170</td><td>5.1569</td><td>3.3482</td><td>0.1505</td><td>1.8088</td><td>0.681</td><td>2.655</td><td>| |***** |</td><td>0.069</td><td>2.6951</td></tr>
<tr><td>171</td><td>1.3319</td><td>1.2066</td><td>0.1427</td><td>0.1253</td><td>0.683</td><td>0.183</td><td>| | |</td><td>0.000</td><td>0.1830</td></tr>
<tr><td>172</td><td>1.1715</td><td>1.0957</td><td>0.1420</td><td>0.0758</td><td>0.683</td><td>0.111</td><td>| | |</td><td>0.000</td><td>0.1107</td></tr>
<tr><td>173</td><td>1.2982</td><td>0.7850</td><td>0.1504</td><td>0.5132</td><td>0.681</td><td>0.753</td><td>| |* |</td><td>0.006</td><td>0.7524</td></tr>
<tr><td>174</td><td>0.8570</td><td>1.1410</td><td>0.0796</td><td>-0.2840</td><td>0.693</td><td>-0.410</td><td>| | |</td><td>0.000</td><td>-0.4088</td></tr>
<tr><td>175</td><td>1.2678</td><td>1.4240</td><td>0.1383</td><td>-0.1561</td><td>0.684</td><td>-0.228</td><td>| | |</td><td>0.000</td><td>-0.2278</td></tr>
<tr><td>176</td><td>4.1770</td><td>2.8396</td><td>0.1543</td><td>1.3374</td><td>0.680</td><td>1.965</td><td>| |*** |</td><td>0.040</td><td>1.9793</td></tr>
<tr><td>177</td><td>1.0357</td><td>-0.5346</td><td>0.1413</td><td>1.5702</td><td>0.683</td><td>2.298</td><td>| |**** |</td><td>0.045</td><td>2.3226</td></tr>
<tr><td>178</td><td>0.8978</td><td>1.1069</td><td>0.0854</td><td>-0.2091</td><td>0.693</td><td>-0.302</td><td>| | |</td><td>0.000</td><td>-0.3013</td></tr>
<tr><td>179</td><td>5.6526</td><td>3.5246</td><td>0.1716</td><td>2.1280</td><td>0.676</td><td>3.146</td><td>| |******|</td><td>0.127</td><td>3.2175</td></tr>
<tr><td>180</td><td>1.6314</td><td>1.2845</td><td>0.1651</td><td>0.3469</td><td>0.678</td><td>0.512</td><td>| |* |</td><td>0.003</td><td>0.5107</td></tr>
<tr><td>181</td><td>1.5762</td><td>1.5501</td><td>0.1649</td><td>0.0260</td><td>0.678</td><td>0.0384</td><td>| | |</td><td>0.000</td><td>0.0383</td></tr>
<tr><td>182</td><td>0.8642</td><td>1.0488</td><td>0.0958</td><td>-0.1847</td><td>0.691</td><td>-0.267</td><td>| | |</td><td>0.000</td><td>-0.2666</td></tr>
<tr><td>183</td><td>2.4793</td><td>1.9056</td><td>0.1872</td><td>0.5736</td><td>0.672</td><td>0.853</td><td>| |* |</td><td>0.011</td><td>0.8528</td></tr>
<tr><td>184</td><td>1.1041</td><td>0.7762</td><td>0.1687</td><td>0.3279</td><td>0.677</td><td>0.484</td><td>| | |</td><td>0.003</td><td>0.4834</td></tr>
<tr><td>185</td><td>1.4607</td><td>-0.1183</td><td>0.1747</td><td>1.5790</td><td>0.676</td><td>2.337</td><td>| |**** |</td><td>0.073</td><td>2.3633</td></tr>
<tr><td>186</td><td>0.8100</td><td>0.9907</td><td>0.1066</td><td>-0.1807</td><td>0.690</td><td>-0.262</td><td>| | |</td><td>0.000</td><td>-0.2615</td></tr>
<tr><td>187</td><td>1.6058</td><td>3.4592</td><td>0.2021</td><td>-1.8534</td><td>0.668</td><td>-2.775</td><td>| *****| |</td><td>0.141</td><td>-2.8220</td></tr>
<tr><td>188</td><td>0.6661</td><td>-0.0382</td><td>0.1428</td><td>0.7043</td><td>0.683</td><td>1.031</td><td>| |** |</td><td>0.009</td><td>1.0314</td></tr>
</table>

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
189	1.3349	1.9867	0.1446	-0.6518	0.683	-0.955	| *| |	0.008	-0.9546
190	0.7532	0.1964	0.1193	0.5568	0.687	0.810	| |* |	0.004	0.8092
191	0.9584	0.9461	0.1151	0.0123	0.688	0.0179	| | |	0.000	0.0179
192	2.2078	1.6084	0.1622	0.5994	0.679	0.883	| |* |	0.009	0.8828
193	0.8327	0.7331	0.1357	0.0996	0.684	0.146	| | |	0.000	0.1452
194	0.8643	1.4948	0.1420	-0.6305	0.683	-0.923	| *| |	0.007	-0.9226
195	0.9839	0.5087	0.1850	0.4752	0.673	0.706	| |* |	0.008	0.7054
196	0.7585	0.8930	0.1255	-0.1345	0.686	-0.196	| | |	0.000	-0.1955
197	1.2980	2.0805	0.1610	-0.7825	0.679	-1.153	| **| |	0.015	-1.1535
198	0.6379	0.0996	0.1608	0.5383	0.679	0.793	| |* |	0.007	0.7921
199	1.2647	2.1545	0.1901	-0.8897	0.671	-1.325	| **| |	0.028	-1.3278
200	0.8182	-0.0612	0.1367	0.8794	0.684	1.285	| |** |	0.013	1.2873
201	0.5565	0.8348	0.1370	-0.2784	0.684	-0.407	| | |	0.001	-0.4060
202	0.5255	1.5955	0.1953	-1.0700	0.670	-1.597	| ***| |	0.043	-1.6035
203	0.5613	0.8327	0.1582	-0.2714	0.680	-0.399	| | |	0.002	-0.3986
204	1.0773	1.8281	0.2154	-0.7508	0.664	-1.131	| **| |	0.027	-1.1321
205	0.6269	-0.7576	0.1693	1.3845	0.677	2.045	| |**** |	0.052	2.0614
206	0.7543	0.8930	0.1255	-0.1387	0.686	-0.202	| | |	0.000	-0.2016
207	1.0213	1.1513	0.1746	-0.1300	0.676	-0.192	| | |	0.000	-0.1920

Table 66 (continued)

Output Statistics									
Obs	**Dependent Variable**	**Predicted Value**	**Std Error Mean Predict**	**Residual**	**Std Error Residual**	**Student Residual**	-2-1 0 1 2	**Cook's D**	**RStudent**
208	1.2134	2.6147	0.1794	-1.4014	0.674	-2.078	| ****| |	0.061	-2.0954
209	0.6939	-0.5952	0.1569	1.2891	0.680	1.896	| |*** |	0.038	1.9082
210	1.1735	0.9094	0.1856	0.2641	0.673	0.393	| | |	0.002	0.3918

5.5.4 Linear Regression Model (Remove 14 outliers)

Outliers are observations that exert a large influence on the overall outcome of a model or a parameter's estimate. Therefore, the 14 outlier sites were removed from the 210 simulation models, and 196 simulation models were investigated. Similarly, a linear regression model was developed for the 196 simulation models to determine the relationship between the dependent variable SSD and all the independent variables: access density, traffic volume, number of lanes and speed limit. The R^2 value of regression model is 0.6279, and the adjusted R^2 value is 0.6201. All simulation conditions were used to calculate coefficients in the predicted model. Table 67 shows the results by Generalized Linear Model (GLM). Column B is the coefficients for the intercept and all independent variables. Column E is the p value of T-statistics for the intercept and all independent variables. T-statistics indicated that the independent variables were statistically significant at a 95% level of confidence. Table 68 shows the Type III SS p-value by GLM method. The following shows the final developed regression equation:

$$Y = -0.5601 + 0.0941X_1 + 0.226X_2 - 0.3214X_3 + 0.4235X_4$$ **Equation 15**

Where,

Y = roadway SSD

X_1 = access density

X_2 = traffic volume

X_3 = number of lanes

X_4 = speed limit

In this study, X_3 is number of lanes, which includes three categories: 4, 6, and 8. So, X_3 is a continuous variable. Assumed X_3 is a dummy variable, and the number of lanes is divided into three groups: smaller than 6, equal to 6 and bigger than 6. The sign of X_3 may be changed from negative to positive. It indicates that roadway SSD increases with the increase in number of lanes.

Table 67 Coefficient Values by GLM Method of 196 Simulation Models

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-0.56	0.478	-1.17	0.243
Access Density	0.094	0.015	6.36	<.0001
Traffic Volume	0.226	0.022	10.27	<.0001
Number of Lanes	-0.321	0.028	-11.41	<.0001
Speed Limit	0.424	0.089	4.74	<.0001
R^2 = 0.6279, R^2_{adj} = 0.6201				

The coefficients for access density, traffic volume and speed limit are all positive, indicating that the SSD increases with the increase of access density, traffic volume, and speed limit. Conversely, the coefficient for number of lanes is negative, indicating that the SSD decreases with the increase in the number of lanes.

Table 68 Type III SS p-value by GLM Method of 196 Simulation Models

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Access Density	1	8.902	8.902	40.39	<.0001
Traffic Volume	1	23.241	23.241	105.45	<.0001
Number of Lanes	1	28.683	28.683	130.14	<.0001
Speed Limit	1	4.958	4.958	22.49	<.0001

The R^2 value of the 196 simulation models is 0.6279, which is larger than the R^2 value of the 210 simulation models, which is 0.5443. It indicates that the 196 simulation models have better goodness fit than the 210 simulation models, and it also verifies removing the 14 outliers makes regression model better.

Chapter 6 Conclusions

This study focuses on the impacts of access density on speed variation of roadway segments and relevant models. Analysis data were collected from 15 field sites in Florida. A simulation method was used to expand data sets to better acquire relationships between variables. The impacts of roadway access design factors were investigated, which could influence speed variation on multilane roadways, and impacts of obvious contributing factors were quantified. More specifically, conclusions and results are summarized as follows:

(1) It is proved that different access types have different impacts on speed variation on multilane roadways, even under the same prevailing conditions. And a new definition and calculation of access weight is presented to show the difference.

(2) New Access Density can represent a number of characteristics of access point, which could directly affect the roadway safety.

(3) Some factors are found have obvious contributions to roadway speed variation, according to field data collection and simulations, such as access density, traffic volume of main road, number of lanes of main road, speed limit. It is clear the access density, traffic volume, and speed limit have positive effects on roadway speed variation, while the number of lanes has negative effect.

Chapter 7 Future Work

Future work could include the following:

(1) Concentrate on signalized intersections in Florida State, get crash frequencies of signalized intersections of 10 years (2001–2010) from Florida State Crash Database, which is also called Crash Analysis Reporting System (CARs).

(2) Build a Negative-Binomial Model for the crash frequency, analyze the significance of the model, and verify the strong correlation between crash frequency and access weights.

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Appendices

Appendix A 468 Sample Access Weights by Access Type, Number of Lanes, Speed Limit, Level of Service, and Direction

Table 69 468 Sample Access Weights

No.	Access Type	Number of Lanes	Speed Limit	LOS	Direction	Access Weight
1	1	4	45	H	Eastbound	0.047
2	1	4	45	M	Eastbound	0.053
3	1	4	45	L	Eastbound	0.051
4	1	4	50	H	Eastbound	0.048
5	1	4	50	M	Eastbound	0.051
6	1	4	50	L	Eastbound	0.053
7	1	4	55	H	Eastbound	0.050
8	1	4	55	M	Eastbound	0.050
9	1	4	55	L	Eastbound	0.052
10	1	4	60	H	Eastbound	0.044
11	1	4	60	M	Eastbound	0.045
12	1	4	60	L	Eastbound	0.055
13	1	6	45	H	Eastbound	0.043
14	1	6	45	M	Eastbound	0.047
15	1	6	45	L	Eastbound	0.050
16	1	6	50	H	Eastbound	0.044
17	1	6	50	M	Eastbound	0.050
18	1	6	50	L	Eastbound	0.052
19	1	6	55	H	Eastbound	0.048
20	1	6	55	M	Eastbound	0.050
21	1	6	55	L	Eastbound	0.054
22	1	6	60	H	Eastbound	0.045
23	1	6	60	M	Eastbound	0.049
24	1	6	60	L	Eastbound	0.053
25	1	8	45	H	Eastbound	0.043
26	1	8	45	M	Eastbound	0.047
27	1	8	45	L	Eastbound	0.049
28	1	8	50	H	Eastbound	0.046
29	1	8	50	M	Eastbound	0.052
30	1	8	50	L	Eastbound	0.053
31	1	8	55	H	Eastbound	0.052
32	1	8	55	M	Eastbound	0.053
33	1	8	55	L	Eastbound	0.053
34	1	8	60	H	Eastbound	0.047
35	1	8	60	M	Eastbound	0.054
36	1	8	60	L	Eastbound	0.058
37	2	4	45	H	Eastbound	0.066
38	2	4	45	M	Eastbound	0.085
39	2	4	45	L	Eastbound	0.117

Table 69 (continued)

40	2	4	50	H	Eastbound	0.074
41	2	4	50	M	Eastbound	0.094
42	2	4	50	L	Eastbound	0.125
43	2	4	55	H	Eastbound	0.080
44	2	4	55	M	Eastbound	0.100
45	2	4	55	L	Eastbound	0.127
46	2	4	60	H	Eastbound	0.074
47	2	4	60	M	Eastbound	0.105
48	2	4	60	L	Eastbound	0.127
49	2	6	45	H	Eastbound	0.076
50	2	6	45	M	Eastbound	0.089
51	2	6	45	L	Eastbound	0.117
52	2	6	50	H	Eastbound	0.072
53	2	6	50	M	Eastbound	0.095
54	2	6	50	L	Eastbound	0.124
55	2	6	55	H	Eastbound	0.076
56	2	6	55	M	Eastbound	0.104
57	2	6	55	L	Eastbound	0.123
58	2	6	60	H	Eastbound	0.074
59	2	6	60	M	Eastbound	0.112
60	2	6	60	L	Eastbound	0.132
61	2	8	45	H	Eastbound	0.070
62	2	8	45	M	Eastbound	0.091
63	2	8	45	L	Eastbound	0.117
64	2	8	50	H	Eastbound	0.071
65	2	8	50	M	Eastbound	0.094
66	2	8	50	L	Eastbound	0.126
67	2	8	55	H	Eastbound	0.077
68	2	8	55	M	Eastbound	0.107
69	2	8	55	L	Eastbound	0.128
70	2	8	60	H	Eastbound	0.083
71	2	8	60	M	Eastbound	0.109
72	2	8	60	L	Eastbound	0.130
73	3	4	45	H	Eastbound	0.104
74	3	4	45	M	Eastbound	0.106
75	3	4	45	L	Eastbound	0.213
76	3	4	50	H	Eastbound	0.101
77	3	4	50	M	Eastbound	0.117
78	3	4	50	L	Eastbound	0.149
79	3	4	55	H	Eastbound	0.116
80	3	4	55	M	Eastbound	0.140
81	3	4	55	L	Eastbound	0.152
82	3	4	60	H	Eastbound	0.125
83	3	4	60	M	Eastbound	0.141

Table 69 (continued)

84	3	4	60	L	Eastbound	0.168
85	3	6	45	H	Eastbound	0.086
86	3	6	45	M	Eastbound	0.107
87	3	6	45	L	Eastbound	0.126
88	3	6	50	H	Eastbound	0.101
89	3	6	50	M	Eastbound	0.104
90	3	6	50	L	Eastbound	0.157
91	3	6	55	H	Eastbound	0.108
92	3	6	55	M	Eastbound	0.112
93	3	6	55	L	Eastbound	0.148
94	3	6	60	H	Eastbound	0.118
95	3	6	60	M	Eastbound	0.132
96	3	6	60	L	Eastbound	0.165
97	3	8	45	H	Eastbound	0.085
98	3	8	45	M	Eastbound	0.092
99	3	8	45	L	Eastbound	0.125
100	3	8	50	H	Eastbound	0.100
101	3	8	50	M	Eastbound	0.109
102	3	8	50	L	Eastbound	0.154
103	3	8	55	H	Eastbound	0.115
104	3	8	55	M	Eastbound	0.116
105	3	8	55	L	Eastbound	0.150
106	3	8	60	H	Eastbound	0.120
107	3	8	60	M	Eastbound	0.133
108	3	8	60	L	Eastbound	0.167
109	4	4	45	H	Eastbound	0.065
110	4	4	45	M	Eastbound	0.085
111	4	4	45	L	Eastbound	0.124
112	4	4	50	H	Eastbound	0.072
113	4	4	50	M	Eastbound	0.104
114	4	4	50	L	Eastbound	0.124
115	4	4	55	H	Eastbound	0.081
116	4	4	55	M	Eastbound	0.091
117	4	4	55	L	Eastbound	0.121
118	4	4	60	H	Eastbound	0.091
119	4	4	60	M	Eastbound	0.099
120	4	4	60	L	Eastbound	0.129
121	4	6	45	H	Eastbound	0.085
122	4	6	45	M	Eastbound	0.099
123	4	6	45	L	Eastbound	0.110
124	4	6	50	H	Eastbound	0.093
125	4	6	50	M	Eastbound	0.109
126	4	6	50	L	Eastbound	0.131
127	4	6	55	H	Eastbound	0.087

Table 69 (continued)

128	4	6	55	M	Eastbound	0.106
129	4	6	55	L	Eastbound	0.122
130	4	6	60	H	Eastbound	0.095
131	4	6	60	M	Eastbound	0.113
132	4	6	60	L	Eastbound	0.130
133	4	8	45	H	Eastbound	0.076
134	4	8	45	M	Eastbound	0.097
135	4	8	45	L	Eastbound	0.114
136	4	8	50	H	Eastbound	0.099
137	4	8	50	M	Eastbound	0.109
138	4	8	50	L	Eastbound	0.128
139	4	8	55	H	Eastbound	0.086
140	4	8	55	M	Eastbound	0.110
141	4	8	55	L	Eastbound	0.127
142	4	8	60	H	Eastbound	0.098
143	4	8	60	M	Eastbound	0.116
144	4	8	60	L	Eastbound	0.131
145	5	4	45	H	Eastbound	0.094
146	5	4	45	M	Eastbound	0.100
147	5	4	45	L	Eastbound	0.130
148	5	4	50	H	Eastbound	0.103
149	5	4	50	M	Eastbound	0.119
150	5	4	50	L	Eastbound	0.146
151	5	4	55	H	Eastbound	0.111
152	5	4	55	M	Eastbound	0.114
153	5	4	55	L	Eastbound	0.154
154	5	4	60	H	Eastbound	0.120
155	5	4	60	M	Eastbound	0.128
156	5	4	60	L	Eastbound	0.162
157	5	6	45	H	Eastbound	0.109
158	5	6	45	M	Eastbound	0.120
159	5	6	45	L	Eastbound	0.125
160	5	6	50	H	Eastbound	0.121
161	5	6	50	M	Eastbound	0.140
162	5	6	50	L	Eastbound	0.160
163	5	6	55	H	Eastbound	0.111
164	5	6	55	M	Eastbound	0.136
165	5	6	55	L	Eastbound	0.163
166	5	6	60	H	Eastbound	0.124
167	5	6	60	M	Eastbound	0.142
168	5	6	60	L	Eastbound	0.168
169	5	8	45	H	Eastbound	0.095
170	5	8	45	M	Eastbound	0.123
171	5	8	45	L	Eastbound	0.135

Table 69 (continued)

172	5	8	50	H	Eastbound	0.119
173	5	8	50	M	Eastbound	0.134
174	5	8	50	L	Eastbound	0.154
175	5	8	55	H	Eastbound	0.107
176	5	8	55	M	Eastbound	0.138
177	5	8	55	L	Eastbound	0.160
178	5	8	60	H	Eastbound	0.124
179	5	8	60	M	Eastbound	0.145
180	5	8	60	L	Eastbound	0.181
181	6	4	45	H	Eastbound	0.066
182	6	4	45	M	Eastbound	0.085
183	6	4	45	L	Eastbound	0.110
184	6	4	50	H	Eastbound	0.074
185	6	4	50	M	Eastbound	0.089
186	6	4	50	L	Eastbound	0.131
187	6	4	55	H	Eastbound	0.080
188	6	4	55	M	Eastbound	0.099
189	6	4	55	L	Eastbound	0.130
190	6	4	60	H	Eastbound	0.074
191	6	4	60	M	Eastbound	0.102
192	6	4	60	L	Eastbound	0.130
193	6	6	45	H	Eastbound	0.075
194	6	6	45	M	Eastbound	0.087
195	6	6	45	L	Eastbound	0.117
196	6	6	50	H	Eastbound	0.071
197	6	6	50	M	Eastbound	0.099
198	6	6	50	L	Eastbound	0.123
199	6	6	55	H	Eastbound	0.075
200	6	6	55	M	Eastbound	0.103
201	6	6	55	L	Eastbound	0.131
202	6	6	60	H	Eastbound	0.073
203	6	6	60	M	Eastbound	0.109
204	6	6	60	L	Eastbound	0.128
205	6	8	45	H	Eastbound	0.070
206	6	8	45	M	Eastbound	0.083
207	6	8	45	L	Eastbound	0.115
208	6	8	50	H	Eastbound	0.072
209	6	8	50	M	Eastbound	0.099
210	6	8	50	L	Eastbound	0.125
211	6	8	55	H	Eastbound	0.077
212	6	8	55	M	Eastbound	0.108
213	6	8	55	L	Eastbound	0.130
214	6	8	60	H	Eastbound	0.075
215	6	8	60	M	Eastbound	0.111

Table 69 (continued)

216	6	8	60	L	Eastbound	0.130
217	7	4	45	H	Eastbound	0.130
218	7	4	45	M	Eastbound	0.135
219	7	4	45	L	Eastbound	0.202
220	7	4	50	H	Eastbound	0.144
221	7	4	50	M	Eastbound	0.142
222	7	4	50	L	Eastbound	0.207
223	7	4	55	H	Eastbound	0.146
224	7	4	55	M	Eastbound	0.171
225	7	4	55	L	Eastbound	0.198
226	7	4	60	H	Eastbound	0.156
227	7	4	60	M	Eastbound	0.219
228	7	4	60	L	Eastbound	0.208
229	7	6	45	H	Eastbound	0.124
230	7	6	45	M	Eastbound	0.128
231	7	6	45	L	Eastbound	0.165
232	7	6	50	H	Eastbound	0.133
233	7	6	50	M	Eastbound	0.157
234	7	6	50	L	Eastbound	0.218
235	7	6	55	H	Eastbound	0.149
236	7	6	55	M	Eastbound	0.163
237	7	6	55	L	Eastbound	0.237
238	7	6	60	H	Eastbound	0.124
239	7	6	60	M	Eastbound	0.160
240	7	6	60	L	Eastbound	0.248
241	7	8	45	H	Eastbound	0.121
242	7	8	45	M	Eastbound	0.118
243	7	8	45	L	Eastbound	0.172
244	7	8	50	H	Eastbound	0.127
245	7	8	50	M	Eastbound	0.144
246	7	8	50	L	Eastbound	0.188
247	7	8	55	H	Eastbound	0.152
248	7	8	55	M	Eastbound	0.172
249	7	8	55	L	Eastbound	0.238
250	7	8	60	H	Eastbound	0.142
251	7	8	60	M	Eastbound	0.188
252	7	8	60	L	Eastbound	0.252
253	8	4	45	H	Eastbound	0.130
254	8	4	45	M	Eastbound	0.114
255	8	4	45	L	Eastbound	0.144
256	8	4	50	H	Eastbound	0.137
257	8	4	50	M	Eastbound	0.126
258	8	4	50	L	Eastbound	0.149
259	8	4	55	H	Eastbound	0.117

Table 69 (continued)

260	8	4	55	M	Eastbound	0.135
261	8	4	55	L	Eastbound	0.146
262	8	4	60	H	Eastbound	0.144
263	8	4	60	M	Eastbound	0.148
264	8	4	60	L	Eastbound	0.167
265	8	6	45	H	Eastbound	0.095
266	8	6	45	M	Eastbound	0.109
267	8	6	45	L	Eastbound	0.136
268	8	6	50	H	Eastbound	0.113
269	8	6	50	M	Eastbound	0.109
270	8	6	50	L	Eastbound	0.139
271	8	6	55	H	Eastbound	0.107
272	8	6	55	M	Eastbound	0.141
273	8	6	55	L	Eastbound	0.142
274	8	6	60	H	Eastbound	0.112
275	8	6	60	M	Eastbound	0.138
276	8	6	60	L	Eastbound	0.159
277	8	8	45	H	Eastbound	0.089
278	8	8	45	M	Eastbound	0.113
279	8	8	45	L	Eastbound	0.128
280	8	8	50	H	Eastbound	0.128
281	8	8	50	M	Eastbound	0.122
282	8	8	50	L	Eastbound	0.148
283	8	8	55	H	Eastbound	0.122
284	8	8	55	M	Eastbound	0.131
285	8	8	55	L	Eastbound	0.148
286	8	8	60	H	Eastbound	0.116
287	8	8	60	M	Eastbound	0.141
288	8	8	60	L	Eastbound	0.146
289	9	4	45	H	Eastbound	0.199
290	9	4	45	M	Eastbound	0.127
291	9	4	45	L	Eastbound	0.139
292	9	4	50	H	Eastbound	0.208
293	9	4	50	M	Eastbound	0.143
294	9	4	50	L	Eastbound	0.156
295	9	4	55	H	Eastbound	0.158
296	9	4	55	M	Eastbound	0.180
297	9	4	55	L	Eastbound	0.160
298	9	4	60	H	Eastbound	0.235
299	9	4	60	M	Eastbound	0.156
300	9	4	60	L	Eastbound	0.172
301	9	6	45	H	Eastbound	0.132
302	9	6	45	M	Eastbound	0.140
303	9	6	45	L	Eastbound	0.144

Table 69 (continued)

304	9	6	50	H	Eastbound	0.121
305	9	6	50	M	Eastbound	0.158
306	9	6	50	L	Eastbound	0.158
307	9	6	55	H	Eastbound	0.154
308	9	6	55	M	Eastbound	0.158
309	9	6	55	L	Eastbound	0.156
310	9	6	60	H	Eastbound	0.143
311	9	6	60	M	Eastbound	0.148
312	9	6	60	L	Eastbound	0.168
313	9	8	45	H	Eastbound	0.116
314	9	8	45	M	Eastbound	0.144
315	9	8	45	L	Eastbound	0.159
316	9	8	50	H	Eastbound	0.132
317	9	8	50	M	Eastbound	0.158
318	9	8	50	L	Eastbound	0.166
319	9	8	55	H	Eastbound	0.136
320	9	8	55	M	Eastbound	0.170
321	9	8	55	L	Eastbound	0.173
322	9	8	60	H	Eastbound	0.141
323	9	8	60	M	Eastbound	0.173
324	9	8	60	L	Eastbound	0.185
325	2	4	45	H	Westbound	0.026
326	2	4	45	M	Westbound	0.027
327	2	4	45	L	Westbound	0.029
328	2	4	50	H	Westbound	0.029
329	2	4	50	M	Westbound	0.030
330	2	4	50	L	Westbound	0.034
331	2	4	55	H	Westbound	0.034
332	2	4	55	M	Westbound	0.033
333	2	4	55	L	Westbound	0.039
334	2	4	60	H	Westbound	0.032
335	2	4	60	M	Westbound	0.036
336	2	4	60	L	Westbound	0.038
337	2	6	45	H	Westbound	0.026
338	2	6	45	M	Westbound	0.029
339	2	6	45	L	Westbound	0.029
340	2	6	50	H	Westbound	0.030
341	2	6	50	M	Westbound	0.033
342	2	6	50	L	Westbound	0.034
343	2	6	55	H	Westbound	0.034
344	2	6	55	M	Westbound	0.038
345	2	6	55	L	Westbound	0.039
346	2	6	60	H	Westbound	0.033
347	2	6	60	M	Westbound	0.037

Table 69 (continued)

348	2	6	60	L	Westbound	0.038
349	2	8	45	H	Westbound	0.026
350	2	8	45	M	Westbound	0.029
351	2	8	45	L	Westbound	0.029
352	2	8	50	H	Westbound	0.030
353	2	8	50	M	Westbound	0.033
354	2	8	50	L	Westbound	0.034
355	2	8	55	H	Westbound	0.034
356	2	8	55	M	Westbound	0.038
357	2	8	55	L	Westbound	0.039
358	2	8	60	H	Westbound	0.033
359	2	8	60	M	Westbound	0.037
360	2	8	60	L	Westbound	0.038
361	3	4	45	H	Westbound	0.082
362	3	4	45	M	Westbound	0.090
363	3	4	45	L	Westbound	0.104
364	3	4	50	H	Westbound	0.102
365	3	4	50	M	Westbound	0.109
366	3	4	50	L	Westbound	0.121
367	3	4	55	H	Westbound	0.099
368	3	4	55	M	Westbound	0.104
369	3	4	55	L	Westbound	0.123
370	3	4	60	H	Westbound	0.122
371	3	4	60	M	Westbound	0.121
372	3	4	60	L	Westbound	0.141
373	3	6	45	H	Westbound	0.077
374	3	6	45	M	Westbound	0.097
375	3	6	45	L	Westbound	0.100
376	3	6	50	H	Westbound	0.096
377	3	6	50	M	Westbound	0.106
378	3	6	50	L	Westbound	0.209
379	3	6	55	H	Westbound	0.096
380	3	6	55	M	Westbound	0.108
381	3	6	55	L	Westbound	0.117
382	3	6	60	H	Westbound	0.096
383	3	6	60	M	Westbound	0.124
384	3	6	60	L	Westbound	0.138
385	3	8	45	H	Westbound	0.078
386	3	8	45	M	Westbound	0.093
387	3	8	45	L	Westbound	0.100
388	3	8	50	H	Westbound	0.083
389	3	8	50	M	Westbound	0.102
390	3	8	50	L	Westbound	0.114
391	3	8	55	H	Westbound	0.087

Table 69 (continued)

392	3	8	55	M	Westbound	0.107
393	3	8	55	L	Westbound	0.120
394	3	8	60	H	Westbound	0.103
395	3	8	60	M	Westbound	0.117
396	3	8	60	L	Westbound	0.141
397	4	4	45	H	Westbound	0.072
398	4	4	45	M	Westbound	0.093
399	4	4	45	L	Westbound	0.110
400	4	4	50	H	Westbound	0.087
401	4	4	50	M	Westbound	0.096
402	4	4	50	L	Westbound	0.110
403	4	4	55	H	Westbound	0.085
404	4	4	55	M	Westbound	0.072
405	4	4	55	L	Westbound	0.122
406	4	4	60	H	Westbound	0.099
407	4	4	60	M	Westbound	0.108
408	4	4	60	L	Westbound	0.120
409	4	6	45	H	Westbound	0.059
410	4	6	45	M	Westbound	0.082
411	4	6	45	L	Westbound	0.110
412	4	6	50	H	Westbound	0.071
413	4	6	50	M	Westbound	0.084
414	4	6	50	L	Westbound	0.110
415	4	6	55	H	Westbound	0.085
416	4	6	55	M	Westbound	0.088
417	4	6	55	L	Westbound	0.128
418	4	6	60	H	Westbound	0.084
419	4	6	60	M	Westbound	0.101
420	4	6	60	L	Westbound	0.146
421	4	8	45	H	Westbound	0.069
422	4	8	45	M	Westbound	0.079
423	4	8	45	L	Westbound	0.107
424	4	8	50	H	Westbound	0.073
425	4	8	50	M	Westbound	0.083
426	4	8	50	L	Westbound	0.114
427	4	8	55	H	Westbound	0.080
428	4	8	55	M	Westbound	0.083
429	4	8	55	L	Westbound	0.110
430	4	8	60	H	Westbound	0.071
431	4	8	60	M	Westbound	0.090
432	4	8	60	L	Westbound	0.150
433	5	4	45	H	Westbound	0.161
434	5	4	45	M	Westbound	0.167
435	5	4	45	L	Westbound	0.124

Table 69 (continued)

436	5	4	50	H	Westbound	0.158
437	5	4	50	M	Westbound	0.173
438	5	4	50	L	Westbound	0.134
439	5	4	55	H	Westbound	0.169
440	5	4	55	M	Westbound	0.194
441	5	4	55	L	Westbound	0.149
442	5	4	60	H	Westbound	0.178
443	5	4	60	M	Westbound	0.158
444	5	4	60	L	Westbound	0.157
445	5	6	45	H	Westbound	0.096
446	5	6	45	M	Westbound	0.118
447	5	6	45	L	Westbound	0.105
448	5	6	50	H	Westbound	0.111
449	5	6	50	M	Westbound	0.130
450	5	6	50	L	Westbound	0.145
451	5	6	55	H	Westbound	0.133
452	5	6	55	M	Westbound	0.133
453	5	6	55	L	Westbound	0.144
454	5	6	60	H	Westbound	0.116
455	5	6	60	M	Westbound	0.127
456	5	6	60	L	Westbound	0.158
457	5	8	45	H	Westbound	0.082
458	5	8	45	M	Westbound	0.116
459	5	8	45	L	Westbound	0.109
460	5	8	50	H	Westbound	0.104
461	5	8	50	M	Westbound	0.136
462	5	8	50	L	Westbound	0.141
463	5	8	55	H	Westbound	0.102
464	5	8	55	M	Westbound	0.127
465	5	8	55	L	Westbound	0.146
466	5	8	60	H	Westbound	0.108
467	5	8	60	M	Westbound	0.128
468	5	8	60	L	Westbound	0.151

Appendix B SAS Codes to Build a Linear Regression Model (210 Simulation Models)

B.1 Creating new library

```
libname BING "C:\sas";

run;

proc import

datafile="c:\sas\Sample, Volume, Number of Lanes, Speed Limit, Access Density &
SSD of 210 models.csv"

out = BING.data

dbms = csv replace;

run;
```

B.2 Initial examination prior to modeling

```
ods rtf;

PROC PLOT DATA=BING.data;

PLOT SSD*SpeedLimit;

RUN;

PROC PLOT DATA=BING.data;

PLOT SSD*Volume;

RUN;

PROC PLOT DATA=BING.data;
```

```
PLOT SSD*numberoflanes;
RUN;
PROC PLOT DATA=BING.data;
PLOT SSD*accessdensity;
RUN;
ods rtf
close;
```

B.3 Correlations among independent variables

```
ods rtf;
PROC CORR DATA=BING.data;
VAR AccessDensity Volume Numberoflanes SpeedLimit;
RUN;
ods rtf
close;
```

B.4 Creating model—regression procedure

```
ods rtf;
PROC REG DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit;
RUN;
ods rtf
close;
```

B.5 Creating model—Generalized Linear Model (GLM) procedure

```
ods rtf;
```

```
PROC GLM DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit;
RUN;
 ods rtf
close;
```

B.6 Regression plot

```
ods rtf;
plot r.*p.;
run;
 ods rtf
close;
```

B.7 Choosing best model for adjusting R^2 value

```
ods rtf;
PROC REG DATA=BING.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/
SELECTION=ADJRSQ;
RUN;
 ods rtf
close;
```

B.8 Testing for assumption validation

```
ods rtf;
PROC REG DATA=BING.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/ DW SPEC;
```

```
OUTPUT OUT=RESIDS R=RES;
RUN;
PROC UNIVARIATE DATA=RESIDS
    NORMAL PLOT;
     VAR RES;
RUN;
 ods rtf
close;
```

B.9 Print out parameter estimates

```
ods rtf;
PROC GLM DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/ Solution;
RUN;
 ods rtf
close;
```

B.10 Testing for multicollinearity—all parameters

```
ods rtf;
PROC REG DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/ VIF;
RUN;
 ods rtf
close;
```

B.11 Testing for multicollinearity—all parameters excluding volume

```
ods rtf;
PROC REG DATA=Bing.data;
MODEL SSD=AccessDensity Numberoflanes SpeedLimit/ VIF;
RUN;
 ods rtf
close;
```

B.12 Testing for effects of outliers

```
ods rtf;
PROC REG DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/ INFLUENCE R;
RUN;
 ods rtf
close;
```

B.13 Testing fit of model

```
ods rtf;
PROC RSREG DATA=Bing.data;
MODEL SSD=AccessDensity Volume Numberoflanes SpeedLimit/ LACKFIT;
RUN;
 ods rtf
close;
```

About the Author

Mr. Bing Huang is currently a Ph.D. Candidate in the University of South Florida's (USF) Civil and Environmental Engineering Department with a concentration in transportation. He received his B.S. in computer science in 2005 at Nanjing University of Technology in China. In 2008, he received his M.S. in civil engineering from the University of Louisiana at Lafayette. He worked as a graduate research assistant at the Center for Urban Transportation Research (CUTR) for one year in 2009. His research interests focus on traffic safety and operations, traffic micro-simulation and calibration, Geographic Information Systems (GIS), Intelligent Transportation Systems (ITS), highway crash analysis, data management in transportation engineering, and statistical modeling in transportation. He served as the secretary of the USF Chinese Students and Scholars Association (CSSA) in 2009–2010, and he has been involved in several professional associations. His research work has been presented at national conferences and published in several transportation journals.