Evaluation of Free Flow Speeds on Interrupted Flow Facilities

Final Report

Project No. BDK83 977-18

by

Ren Moses & Enock Mtoi
Department of Civil Engineering
FAMU-FSU College of Engineering
2525 Pottsdamer Street, Room 129
Tallahassee, FL 32310

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

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16. Abstract

The efficacy of the Florida Department of Transportation (FDOT) simple model of predicting segment free flow speed by adding 5 miles per hour (mph) to the posted speed limit was compared to the performance of the new 2010 Highway Capacity Manual (HCM 2010) procedure which predicts free flow speed using posted speed limit and eight additional variables, i.e., the proportion of segment length with restrictive median, the proportion of segment with curb on the right-hand side, the number of access point approaches on the right side in the subject direction of travel, the number of access point approaches on the right side in the opposing direction of travel, the segment length, the width of the signalized intersection, the number of through lanes, and the distance between intersections. One-year speed data from 84 traffic monitoring sites located on interrupted flow facilities with speed limit ranging from 25 MPH to 55 MPH were used in the study. In addition, 3-day speed data were collected from 20 sites in the City of Tallahassee. Field mean free flow speed was determined for each analysis segment as well as the above geometric and traffic attributes required by HCM 2010 to predict free flow speed. The analyses were conducted separately for major arterial segments and for minor arterial segments. The comparison of the performance of the HCM 2010 and the FDOT free flow speed prediction models using root mean square error (RMSE) and coefficient of determination (R^2) showed that the FDOT simple formula of determining free flow speed performed better than HCM 2010 procedure which requires nine input variables to predict free flow speed. In both principal arterials and minor arterials, the HCM 2010 methodology under-predicted free flow speed when field estimated free-flow speed was higher than 40 mph. Consequently, the use of free flow speed predicted by the HCM 2010 model in LOS analysis in some cases produced lower levels of service compared to the use of field measured free flow speed.

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EXECUTIVE SUMMARY

Background

It is important that free flow speed be determined accurately in the field because this parameter plays an important role in models used in planning, operational analysis and performance evaluation of transportation systems. However, field determination of free flow speed is resource-intensive because it requires measuring sufficient sample size of vehicle speeds at the appropriate time of low vehicle interaction and at appropriate locations of comparable geometric, traffic, and signalization features. To overcome field data collection challenges most highway agencies use modeling techniques to predict free flow speed.

Because free flow speed is affected by many factors, it is obvious that an appropriate and robust model for predicting free flow speed has to take into account numerous independent variables related to geometrics, traffic, and signalization. In fact, such models have been proposed over the years, with the recent proposed model being the one that has been adopted in the 2010 Highway Capacity Manual (HCM 2010). The regression model contained in the HCM 2010 for predicting base free flow speed is

$$S_f = \left(25.6 + 0.47S_{pl} + f_{cs} + f_A\right) * f_L$$

where S_f is base free flow speed, S_{pl} is speed limit, f_{cs} is the adjustment for cross-section, f_A is the adjustment for access points, and f_L is the adjustment factor for segment length. However, the above equation is not as simple as it looks. Nested within the three adjustment factors – f_{cs}, f_A, and f_L – are other variables whose values must be determined and plugged into the equation. In fact, the total count of independent variables whose values need to be collected or specified in order to use the HCM 2010 free flow speed equation is nine.

The HCM 2010 equation is easy to apply if an agency or an analyst already has a database of these nine variables for all roadway segments within its jurisdiction. Without such complete dataset, the efficacy of the HCM 2010 free flow speed prediction model is questionable. So, the challenge facing FDOT and other agencies is either to develop a comprehensive database of all nine modeling variables or to evaluate other alternatives of modeling free flow speed, particularly for the purposes of systems planning and level of service analysis at the planning level.

Fortunately, prior to the inception of the 2010 Highway Capacity Manual and its speed prediction procedures, the Florida Department of Transportation, Planning Office had a simple model for predicting free flow speed on a highway segment. The model is given by

$$S_f = S_{pl} + 5$$

which is simply free flow speed, S_f, is equal to speed limit, S_{pl}, plus five miles per hour. As the FDOT Systems Planning Office transitions to 2010 Highway Capacity Manual (HCM 2010), concerns have been raised over the efficacy of the speed prediction methodology contained in the HCM 2010 "Urban Street Segments" level of service analysis procedures. To this end, the

Florida Department of Transportation initiated this research project to evaluate the efficacy of existing and alternative models.

Objectives

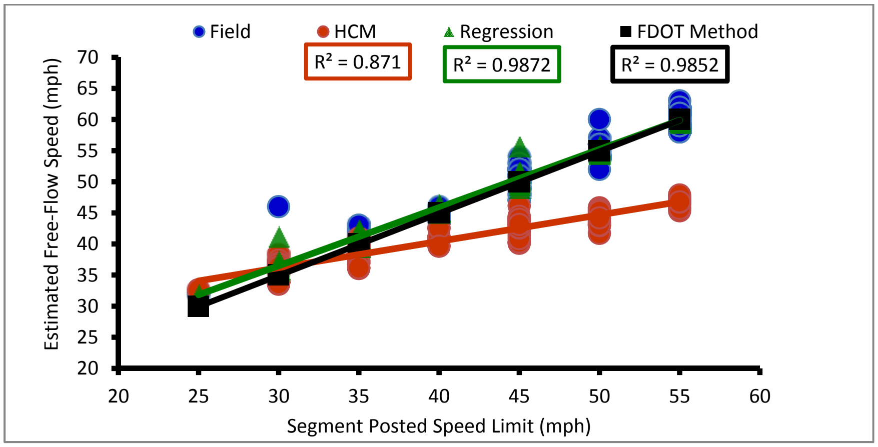
The overall goal of this project was to improve the systems planning process by establishing appropriate baseline free flow speeds on interrupted flow facilities that can be incorporated into FDOT quality and level of service analysis modules. Consistent with this goal, the objectives of this project were to:

- use empirical archived data collected from traffic monitoring sites on Florida highways to determine free flow speeds,
- supplement archived data with active data collection to ensure diversity of facility types operating in interrupted flow conditions,
- determine the efficacy of HCM 2010 and FDOT models described above in predicting free flow speed, and
- develop other simpler model(s) – preferably with fewer inputs – if possible.

Findings and Conclusions

One-year data from 84 traffic monitoring sites located on interrupted flow facilities with speed limit ranging from 25 MPH to 55 MPH were used in the study. In addition, 3-day speed data were collected from 20 sites in the City of Tallahassee. Mean free flow speeds were determined for the analysis segments as well as geometric and traffic attributes that the HCM 2010 uses to predict free flow speed. These attributes are the speed limit (S_{pl}), the proportion of segment length with restrictive median (p_{rm}), the proportion of segment with curb on the right-hand side (p_{curb}), the number of access point approaches on the right side in the subject direction of travel ($N_{ap,s}$), the number of access point approaches on the right side in the opposing direction of travel ($N_{ap,o}$), the segment length (L), the width of the signalized intersection (W_i), number of through lanes, (N_{th}), and the distance between intersections (L_s).

The relationship between posted speed limit and field estimated free flow speed is shown in the scatterplot. Also shown on the scatterplot are free flow speed data points predicted by the HCM 2010, FDOT, and a best fit model developed by the researchers.



The results show that the HCM 2010 model underpredicts free flow speed when field measured free flow speed is 40 mph or higher. Because of fewer segments with posted speed limit less than or equal to 35 MPH, the efficacy of the HCM 2010 prediction model cannot be ascertained in this speed range. The FDOT simple method of predicting free flow speed by adding 5 mph to the posted speed limit seem to perform well, judging by the high coefficient of determination, R^2, of 98.5%. Statistical analysis of the researchers' best fit model for these data showed that only a few independent variables were significant in predicting free flow speed. These variables were speed limit, the proportion of segment length with restrictive median, and the proportion of segment with curb on the right-hand side. However, it should be noted that the best fit model has not been validated using a different set of data due to resource limitations.

Benefits

This research study was aimed at determining the efficacy of the FDOT simple model of predicting free flow speed (using speed limit) in comparison with the HCM 2010 procedure which requires additional eight variables besides speed limit to predict free flow speed on a highway segment. The research shed light on the performance of the FDOT simple model on roadways with speed limit ranging from 25 MPH to 55 MPH. While the results of this study need to be validated with additional data, it is clear that the use of speed limit as a predictor of free flow speed does not require expensive collection of geometric and traffic variables and gives sufficiently reliable results for planning level analysis of urban principal and minor arterials.

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CHAPTER 1

INTRODUCTION

1.1 Background

Highway free flow speed is considered to be the speed a driver chooses under low volume conditions when the interaction between vehicles and the influence of traffic control devices is minimal. On interrupted flow highways – that is, highways characterized by intersections and roadside activity such as driveways – mean free flow speed is influenced by a number of geometric, traffic, and signalization factors. The literature shows that the major geometric attributes influencing driver's speed choice are the median type (restrictive or non-restrictive), curb type (raised or suppressed), access point density, number of lanes, lane width, and segment length. Major traffic factors influencing driver's speed choice are speed limit, composition of traffic, and car-following practices. The signalization factors that have influence on driver's speed choice on a signalized corridor include signal spacing, progression type, and signal timing parameters – such as effective green time and cycle length. In addition, history of speed enforcement and the level of enforcement activities have been found to affect drivers' choice of travel speed.

Free flow speed needs to be determined correctly as it plays an important role in planning, operational analysis, and performance evaluation of transportation systems. Transportation planners concerned with systems planning and highway performance evaluation use free flow speed as an input in travel forecasting, assessment of air quality, and determination of congestion indices. Traffic engineers use free flow speed in highway capacity and level of services evaluation, traffic modeling and simulation, as well as fuel consumption and emission studies.

Because of the level of importance of free flow speed in traffic analysis, accurate field determination of free flow speed is of paramount importance. However, field determination of free flow speed for use in analysis is resource-intensive because it requires measuring sufficient sample size of vehicle speeds at the appropriate time of low vehicle interaction and at appropriate locations with homogenous geometric, traffic, and signalization features. To overcome field data collection challenges, most highway agencies use modeling techniques to predict free flow speed.

1.2 Nature of the Problem

Because free flow speed is affected by many factors, it is obvious that an appropriate and robust model for predicting free flow speed has to take into account numerous independent variables related to geometries, traffic, and signalization. In fact, such models have been proposed over the years with recent proposed model being the one that has been incorporated into the 2010 Highway Capacity Manual (HCM 2010). The regression model contained in the HCM 2010 for predicting free flow speed is

$$S_f = (25.6 + 0.47 S_{pl} + f_{cs} + f_A) \times f_L \quad (1.1)$$

where S_f is free flow speed, S_{pl} is speed limit, f_{cs} is the adjustment for cross-section, f_A is the adjustment for access points, and f_L is the adjustment factor for segment length . However, Equation 1.1 is not as simple as it looks. Nested within the three adjustment factors – f_{cs}, f_A, and f_L – are other variables whose values must be determined and plugged into the equation. In fact, the total count of independent variables whose values need to be collected or specified in order to use the HCM 2010 free flow speed equation is nine.

The HCM 2010 equation is easy to apply if an agency or an analyst already has a database of these nine variables for all roadway segments within its jurisdiction. Without such complete dataset, the efficacy of the HCM 2010 free flow speed prediction model is questionable. So, one of the challenge facing FDOT and other agencies is either to develop a comprehensive database of all nine modeling variables or to evaluate other alternatives of modeling free flow speed, particularly for the purposes of systems planning and level of service analysis at the planning level.

Fortunately, prior to the inception of 2010 Highway Capacity Manual and its speed prediction procedure, the Florida Department of Transportation had a simple model for predicting free flow speed on a highway segment. The model is given by

$$S_f = S_{pl} + 5 \quad (1.2)$$

which is simply free flow speed, S_f, is equal to speed limit, S_{pl}, plus five miles per hour. The challenge facing the Florida Department of Transportation going forward is to decide whether to continue using this simple model, the HCM 2010 model, or another model for planning analysis. To this end, the Florida Department of Transportation, Systems Planning Office initiated this research project to evaluate the efficacy of existing models and other models.

1.3 Goal and Objectives

The overall goal of this project was to improve the systems planning process by establishing appropriate baseline free flow speeds on interrupted flow facilities that can be incorporated into FDOT quality and level of service analysis modules. Consistent with this goal, the objectives of this project were to:

- use empirical archived data collected from traffic monitoring sites on Florida highways to determine free flow speeds,
- supplement archived data with active data collection to ensure diversity of facility types operating in interrupted flow conditions,
- determine the efficacy of HCM 2010 and FDOT models described above in predicting free flow speed, and
- develop other simpler model(s) – preferably with fewer inputs – if possible.

1.4 Methodology

The sites to collect data from were randomly selected to ensure we had enough sample size and sufficient geographical distribution of the sites on interrupted flow facilities. Of importance was to ensure that the selected sites represented different area types, facility types, and facility sizes. The area types were categorized as CBD, suburban, and residential while facility types include divided arterials, undivided arterials, collector streets, and distributor streets. Facility size refers to the number of lanes in one direction of travel. A number of resources were used to verify the geometric, traffic characteristics, and signalization characteristics of the selected sites. Researchers relied on data from TRANSTAT at FDOT, site data collection, and Google Earth to verify independent variables that are known to influence free flow speed.

The statistical analysis of the free flow speed involved determining descriptive statistics and conducting regression modeling. First, the predictive power of the new HCM 2010 speed prediction equation was evaluated using the independent variables collected for each analysis segment. The independent variables were the speed limit, cross-sectional features, longitudinal features, access density and other variables. The predicted free flow speeds by the HCM 2010, FDOT model, and a best fit model were compared to the measured free flow speeds on different roadway segments. Statistical measures were computed for testing whether there were any significant differences in performance among the models tested.

1.5 Report Format

This report is organized as follows. Chapter 1 introduces the reader to the nature of the problem, the objectives of the research project together with the expected deliverables. In addition, the methodology used to accomplish various project tasks are detailed in this chapter. Chapter 2 reviews the relevant literature related to the proposed methodologies for predicting free-flow speed, the influences of posted speed limit on free flow speed, and the influence of geometric features on free-flow speed. Chapter 3 gives the overview of the variables of interest for modeling free flow speed on uninterrupted flow facilities. In addition, this chapter discusses the expected theoretical effects of each variable on the estimation of free flow speed. Chapter 4 discusses the acquisition of speed and volume data from sources maintained by the state agency, in this case the Florida Department of Transportation and the data collected by the research team using pneumatic tube counters. Detailed explanation of the strengths and weaknesses of the archived data and the statistical manipulation conducted to make the data amenable for model building is given in this chapter. Chapter 5 covers the process of modeling free flow speed using different mathematical models. The chapter also displays detailed results and the discussion thereof. Statistical analyses are then conducted to identify strengths and weaknesses of each model. In Chapter 6, sensitivity analysis is conducted to determine how sensitive the level of service designation (A, B, C, D, E, and F) is to free flow speed as an input. Chapter 7 gives summary of the project efforts and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1. Purpose and Scope

This chapter reports on the review of literature conducted with the purpose of revealing factors affecting free flow speed, proposed free flow speed models, and the use of free flow speed in operations and planning analyses. Comprehensive literature review was conducted using a number of sources including library databases, World Wide Web searches as well as direct contact with various practitioners around the country. The literature search concentrated on free flow speed studies on interrupted flow facilities particularly in urban areas. Free flow speed studies on uninterrupted flow facilities (i.e., freeways and limited access toll ways) were also reviewed but will be discussed only if the reported studies had bearing on the understanding free flow speed on interrupted flow corridors. In addition, the literature revealed that there were many factors that affect free flow speed. The review of literature reported herein will focus only on those factors that have been found to have a significant effect on free flow speed, particularly speed limit, area type, and facility size.

2.2. Factors Affecting Free Flow Speed

Free flow speed being a manifestation of driver's speed choice leads to the conjecture that factors affecting field-measured free flow speed are the same as those affecting driving behavior of a driver both spatially and temporally along a highway. It is worth noting that this literature review covers free flow speed on interrupted flow highways only. The influencing factors are generally divided into three categories – that is, geometric features, traffic features, and signalization features. There is a large body of literature discussing the influence of these factors in varying degrees of detail and significance. Table 2.1 shows a summary of these factors and their significance as revealed by various researchers.

2.3. Free Flow Speed Modeling

Following the review of the variables affecting free flow speed in Section 2.2, the literature review efforts were directed at determining how a combination of these variables and their interactions were used as independent variables by various researchers to produce models explaining free flow speed. Generally, the modeling process involves specifying the model with a large set predictor variables (including interactions) then using a number of regression techniques such as backward elimination, forward selection, or stepwise regression to fit a parsimonious model that explains the variation of free flow speed with a small set of independent variables. Therefore, while most modelers start with a large set of geometric, traffic, and signalization variables, most of the models they suggest end up with a small set of variables they consider significant in explaining the variation of free flow speed on a highway section.

Table 2.1. Summary of Literature Findings on Significance of Modeling Variables

Manuscript Title	Significant Variables	Author(s)
Capacity and Operational Effects of Midblock Left-Turn Lanes	Traffic demand, Access point density, Number of traffic lanes, and Land use	Bonneson, J.A. & P.T. McCoy (1997)
Running Time Prediction for Signalized Urban Streets	Speed limit, Median type, Access point density, Curb presence, and Number of lanes	Bonneson *et al.* (2011)
Estimating Free-Flow Speed for Rural Multilane Highways	Speed limit	Dixon *et al.* (1999)
Planning Techniques to Estimate Speeds and Service Volumes	Speed limit, Number of signals, Segment length	Dowling *et al.* (1996)
Design Speed, Operating Speed, and Posted Speed Practices	Speed limit	Fitzpatrick *et al.* (2003)
A Free-Flow Speed Model for Indiana Arterial Roads	Presence of trucks, Speed limit, Land use, Functional class, and Number of lanes	Ye *et al.* (2001)
Designing Roads that Guide Drivers to Choose Safer Speeds	Lane width, Shoulder width, Total pavement width, Parking width, Sidewalk width, Planting strips, Building setbacks, Access density , Land use types	Ivan *et al.* (2009)
Effects of Raising and Lowering Speed Limits on Selected Roadway Sections	Speed limit	Parker (1997)

Dowling *et al*. (1996) examined speed data from 10 speed measurement stations on four rural highways in three states. They developed the following relationship between free-flow speed (FFS) and speed limit:

$$FFS = 14 + 0.88 \times \text{speed limit} \quad (2.1)$$

Ye *et al.* (2001) modeled free-flow speed in Indiana using data from 116 monitoring stations. The speed data were categorized in 12 speed bins, the lowest of which is 0-35 mph, followed by 10 speed bins of 5 mph each, and the highest speed bin of 85-100 mph. The authors considered the average hourly speed was free flow speed if the volume of traffic was less than 1,000 vehicles per hour in two lanes and 1,500 vehicles per hour in three lanes. The authors produced four models to predict car speeds in daytime, car speeds in nighttime, truck speeds in daytime, and truck speeds in night time. The independent variables used in their four models were roadway class (freeway or non-freeway), land use type (0 if urban, 1 if rural), number of lanes (0 if four-lanes, 1 if six-lanes), and speed limit (0 if 55 mph, 1 if 65 mph). The resulting model predicting free flow speed in daytime is

$$FFS = 61.7 - 3.31 \times \text{truck percentage} + 5.8 \text{ x speed limit} + 1.18 \times \text{land use} + 6.8 \times \text{road class} - 8.3 \times \text{number of lanes} \quad (2.2)$$

The above model shows that trucks have a negative effect on free flow speed. Also, the higher the speed limit, the higher the free flow speed. In addition, rural roads had higher free flow speed than urban roads, and freeways had higher free flow speed than non-freeways. Finally, the model showed that the number of lanes had a negative effect with six-lane highways having lower free flow speed compared to 4-lane highways. The authors further reported that the coefficient of the determination, R^2, for the above model was 96.6%. Moreover, the authors reported that three other models had R^2 values of over 87%, and the magnitude of the coefficients and their signs (+/-) were similar to the above equation. One major finding of this research worthy noting in relation to our research is that Equation 2.2 shows that urban, four-lane, non-freeway roads with speed limits of 55 mph and 65 mph have free-flow speeds of 61.7 mph and 67.5 mph, respectively. This means that there is an average increase of free flow speed of 6 mph for the 10-mph increase in speed limit. Note that the simpler FDOT model assumes 5-mph increase in free flow speed for every 5-mph increase in speed limit.

Ivan *et al.* (2009) collected speed data on two-lane roads in rural, suburban, and urban areas. Data were collected from a total of 272 roads in Connecticut. The results of their analysis indicated that land use, posted speed limit, and the type of the roadway were very significant in predicting mean free flow speeds. Also, land use types, either by association with posted speed limit or roadway types had a very strong influence in predicting mean free flow speeds. Roadside parking was significant in reducing mean free flow speeds especially on the "street" roadway type. The results also indicated that for streets, drivers do not make much distinction between the 30 MPH and 35 MPH posted speed limits. This lack of distinction also extended to roadways with 40 MPH and 45 MPH posted speed limits.

CHAPTER 3

EXPLANATION OF DATA COLLECTED

3.1 HCM 2010 Factors Affecting Free-flow Speed

Assessment of the efficacy of the HCM 2010 procedure of estimating free flow speed is tied to the ability to reasonably collect field geometric and traffic data for use in the regression analysis. The plan was to build a regression model in which free flow speed is the response variable influenced by a number of geometric, traffic variables, and signalization variables – that is, independent variables existing in the field. Some of these independent variables are used in the HCM 2010 procedure of predicting free flow speed. The free flow speed predicted by our regression model will be compared to free flow speed predicted by the HCM 2010 model and to the FDOT methodology of determining free flow speed by adding 5 mph to the speed limit. The following sections discuss in detail the nature of data that were collected for the purpose of comparing different models of free-flow speed prediction.

3.2 Geometric Variables

A number of geometric variables affect driver speed choice on a roadway. Thus, to a reasonable extent, collection of these data types is important in the whole modeling exercise. The geometric variables of interest are as follows.

3.2.1 Presence of Restrictive Median

A median functions to prevent or discourage vehicles from crossing opposing traffic lanes. A wide median with raised curb is restrictive and provides a measure of protection against lane departure thus enabling choice of higher free flow speeds. Thus, free flow speed on a segment with restrictive median is expected to be higher than on the segment with nonrestrictive median. The HCM 2010 free flow speed equation uses percent of restrictive median in a highway segment being analyzed as one of the input variables. In this research, these data were extracted as a digital vector data from Transportation Statistics Office (TRANSTAT) which maintains the official FDOT base map of all roads in the Roadway Characteristics Inventory (RCI) database. TRANSTAT is also responsible for the production and maintenance of numerous maps, GIS data layers (shapefiles and geodatabases) as well as custom GIS tools. The shape files contained in the TRANSTAT had information about median type and median width of different road segments. The research team developed a procedure of using Google Earth® to verify the median type and width information.

3.2.2 Presence of Raised Curb

A curb is a raised vertical element that separates the road from the roadside and plays important function of discouraging vehicles from driving on sidewalks or lawns. The type and location of curbs affects driver behavior and in turn free flow speed on a highway. Curbs are used extensively on all types of low-speed urban roads. Although curbs are not considered fixed objects in the context of clear zone considerations, they have an effect of reducing free flow speed. The effects of curb and restrictive median have been combined in the HCM 2010 procedure to form a single adjustment factor for segment cross-section attributes as shown in Equation 3.1:

$$f_{cs} = 1.5p_{rm} - 0.47p_{curb} - 3.7p_{curb}p_{rm} \quad (3.1)$$

where p_{rm} is the proportion of link length (segment) with restrictive median, and p_{curb} is the proportion of segment with curb on the right-hand side. The research team used FDOT video logs to extract information on the presence of curb along the analysis segments. The FDOT video logs are available online at http://www3.dot.state.fl.us/videolog/default.asp. The research team also used Google Earth® to verify the accuracy of information in the video logs.

3.2.3 Access Point Density

A Policy on Geometric Design of Highways and Streets (2011) defines an access point as an intersection, driveway, or an opening on either side of a roadway. The primary function of an access point is to provide a point of entrance and exit along a highway for vehicles coming from or going to a roadside development, i.e., commercial or residential establishment. The HCM 2010 considers an access point to be "active" and "inactive" depending on hourly volume using the access point approach. An access point approach is classified as "active" if it has an entering demand flow rate of 10 vehicles per hour or more during the analysis period. The access point flow rate is expressed in hourly volume but the analysis period may be shorter than one hour. There are some cases in which a segment has many access intersections that are considered inactive but collectively have some impact on traffic flow. The HCM 2010 procedure requires those points to be combined into one equivalent active access point approach.

The total number of access points on both sides of the roadway, divided by the length of the segment, is referred to as access point density. According to HCM 2010 methodology, access point density (in points per mile) is computed using the following equation:

$$D_a = \frac{5{,}280(N_{ap,s} + N_{ap,o})}{(L - W_i)} \quad (3.2)$$

where, $N_{ap,s}$ is the number of access point approaches on the right side in the subject direction of travel, $N_{ap,o}$ is the number of access point approaches on the right side in the opposing direction of travel, L is the segment length, and W_i is the width of the signalized intersection.

The practice of regulating access by limiting the number of accesses and location of these accesses along highway is termed "access management". On streets or highways where there is no access management and roadside business entrances are allowed to develop haphazardly, interference from the roadside can become a major factor in reducing the capacity, reducing speed, and eroding the mobility function of the segment. In this study, an access point was defined as an active driveway, intersection, or median cut allowing direct access to the direction of travel studied. Engineering judgment was used to determine whether a driveway influences the operations of the mainline traffic. Access points to active businesses such convenience stores were considered "active" while those leading to single unit residences were treated as "inactive".

In the HCM 2010 methodology, the adjustment factor quantifying the effects of access points along the segment of length, *L,* the number of through lanes N_{th}, and access point density D_a, is negatively related to free flow speed and is given by Equation 3.3:

$$f_A = \frac{-0.078 D_a}{N_{th}} \quad \ldots\ldots 3.3$$

The information on access type and access management was extracted from TRANSTAT shape files in the form of digital vector data. The access point information was verified using video logs and Google Earth®. As seen in HCM 2010 Equation 3.3 above, the number of through lanes has influence on free flow speed. The higher the number of through lanes on the segment, the lower the effect of access point density on the free flow speed.

3.2.4 Signal Spacing

Segment length has influence on driver's choice of operating speed. Shorter segments result in lower mean free flow speed as most vehicles are caught in the stop-and-go process associated with red and green lights. The value of adjustment factor, f_L accounting for signal spacing is given by the HCM 2010 equation:

$$f_L = 1.02 - 4.7 \frac{S_{fo} - 19.5}{\max(L_s, 400)} \leq 1.0 \quad \ldots\ldots 3.4$$

where, S_{fo} is base free flow speed (mph), and L_s is the distance between adjacent signalized intersections in feet.

Equation 3.4 presumes that L_s is equal to the distance between the two intersections that (a) each has a type of control that can impose restrictions on the subject segment and (b) each have a type of control that can be imposed on the subject through movement a legal requirement to stop or yield. Intersection information, access management, and access control type were extracted from digital vector data contained in the RCI database. Additional data were collected using video logs and Google Earth®.

CHAPTER 4

ACQUISITION OF SPEED DATA

4.1 Overview

At the onset of this research project, the plan was to use archived data, from the Transportation Statistics Office of the Florida Department of Transportation, for free flow speed analysis. This office is a central source for highway and traffic data. The office operates temporary and permanent count stations strategically placed at various locations on the state highway system. The data that were analyzed covered the period from July 1, 2010, to June 30, 2011[1]. Figure 4.1 shows the distribution of the telemetered traffic monitoring sites by functional class and speed limit. A total of 89 sites were located on non-freeway urban arterials and are therefore relevant for use in analyzing free flow speed on interrupted flow facilities. However, analysis of speed data from five sites – two in residential collectors and three in minor arterials – showed irregularities that were deemed inappropriate for further analysis. Therefore, only 84 TTMS segments were used in this study. The segments were divided by functional class – i.e., principal arterials and minor arterials. AASHO (1964) defined principal arterials as "a system of streets and highways carrying major portion of trips entering and leaving the urban area, as well as the majority of through movements desiring to bypass the central city. In addition, significant intra-area travels, such as between central business districts and outlying residential areas, between major inner city communities, or between major suburban centers should be served by this system". AASHO (1964) also defines minor arterials as "a street system including all arterials not classified as a principal and contains facilities that place more emphasis on land access than the higher system, and offer a lower level of traffic mobility. Such facilities may carry local bus routes and provide intra-community continuity, but ideally should not penetrate identifiable neighborhoods." Applying this functional classification to the 84 analysis sites resulted in 60 (71%) monitoring being located on principal arterials and 24 (29%) being located on minor arterials as shown in Figure 4.1a. Figure 4.1b shows the speed limit distribution of the sites.

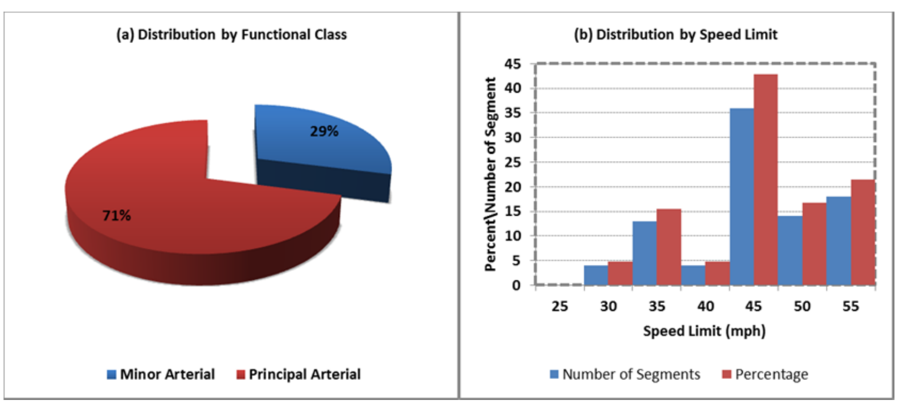

FIGURE 4.1. **Distribution of Sites by Functional Class and Speed Limit**

[1] This period was chosen because the data were already readily available for another project.

Figure 4.1b shows that only 4 sites (5%) were located in segments with 30 MPH speed limit; 13 (15%) on 35 MPH; 4 (5%) on 40 MPH; and 36 (43%) on 45 MPH. Figure 4.1a shows that the majority of the traffic monitoring sites (i.e., 71%) is located on major arterials. Therefore, it was important to select additional sites to make up for the shortfall in minor arterials functional class. The additional sites that were selected and the procedure used to collect speed data will be discussed later in this chapter.

4.2 Processing of TTMS Data

To improve usability of the TTMS data, it was important to conduct a rigorous preprocessing to put data in a structured format, to remove bad data and outliers, and to extract data relevant for free flow speed analysis.

4.2.1 File Format and Data Structure

The data used for this study covered the period from July 1, 2010 to June 30, 2011. Two sets of data were thus provided to the research team in ASCII format. One file set consisting of 96,553 speed count data files and 86,891 vehicle classification count data files contained traffic data recorded from January 1, 2010 to December 31, 2010 and another file set comprising 47,525 speed count data files and 42,153 vehicle classification count data files covered the period beginning January 1, 2011 and ending June 30, 2011. Each TTMS hourly speed and vehicle classification count data file contained records for a particular count unit at a particular TTMS site for a particular date for each travel lane. In the hourly speed count data files each record is organized into twenty-six fields as shown in Table 4.2.

TABLE 4.1. Data Structure of Speed Count Data File

Description	Position	Start Column	End Column
Record Type	1	1	3
County	2	4	5
Site ID	3	6	9
ATR Lane	4	10	11
Year	5	12	14
Month	6	15	16
Day	7	17	18
Hour	8	19	20
Minute	9	21	22
Source	10	23	26
1 to 20 mph	11	27	31
21 to 25 mph	12	32	35
26 to 30 mph	13	36	39
31 to 35 mph	14	40	43

Description	Position	Start Column	End Column
36 to 40 mph	15	44	47
41 to 45 mph	16	48	51
46 to 50 mph	17	52	55
51 to 55 mph	18	56	59
56 to 60 mph	19	60	63
61 to 65 mph	20	64	67
66 to 70 mph	21	68	71
71 to 75 mph	22	72	75
76 to 80 mph	23	76	79
81 to 85 mph	24	80	83
85+ mph	25	84	87
Total	26	88	93

The vehicle counts for each record are contained in 15 speed bins according to the speed of the vehicle. One speed bin is used for all vehicles traveling at or below 20 miles per hour (mph), one bin for vehicles traveling at speeds greater than 85 mph, and 13 speed bins at 5 mph intervals for vehicles traveling at speed greater than 20 mph to 85 mph. Each record in the hourly speed count data file represents a single lane at the TTMS site. Table 4.3 above shows the data structure of the file while Figure 4.3 below shows an extract from a typical TTMS hourly speed count data file.

```
SPD930010 1 1001010100 060    0    0    1    4   32   68   54   17    5    1    0    0    0    0    0   182
SPD930010 2 1001010100 060    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
SPD930010 3 1001010100 060    0    0    0    5   35   67   17   10    2    0    0    0    0    0    0   136
SPD930010 4 1001010100 060    0    1    6   28   92  101   51   16    1    0    0    0    0    0    0   296
SPD930010 1 1001010200 060    0    0    1    4   39   85   52   15    3    0    0    0    0    0    0   199
SPD930010 2 1001010200 060    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
SPD930010 3 1001010200 060    0    0    0    4    6   52   30   12    1    0    0    0    0    0    0   105
SPD930010 4 1001010200 060    0    0    1    7   45  131   50   16    2    0    0    0    0    0    0   252
SPD930010 1 1001010300 060    0    0    1    3   15   45   39   17    4    0    0    0    0    0    0   124
SPD930010 2 1001010300 060    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
SPD930010 3 1001010300 060    0    0    0    2    5   23   19    4    2    0    0    0    0    0    0    55
SPD930010 4 1001010300 060    0    2    1    6   15   63   36   14    5    1    0    0    0    0    0   143
SPD930010 1 1001010400 060    0    0    0    0    6   11   24   11    2    2    0    0    0    0    1    57
```

FIGURE 4.2. **Extract from Typical TTMS Hourly Speed Count Data File**

4.2.2 Data Augmentation, Cleaning and Validation

Other data files were acquired and merged into the main dataset to augment the TTMS count data and to aid in the data cleaning process. The files that were acquired are described below.

- *Lane Relationship data file (LaneRel.csv).* This file contains information for all lanes at all TTMS sites and each record in the file provides information about a single lane. The information in each record includes TTMS Site ID, Unit No., ATR Lane number and direction of travel for the lane.

- *Florida State 2010 and 2011 Holidays*. Traffic flow on holidays is atypical and thus there was a need to identify, flag, and discard counts that were recorded on holidays. A list of dates for 2011 holidays was obtained from the Florida Department of Management Services (DMS) website. The dates for 2010 holidays were generated by adjusting the dates from the 2011 list of State holidays. These were added to a list containing each Day of Week for 2010 and 2011 by date. Weekdays on which a holiday was observed were flagged as holidays. The 2010 and 2011 holiday and day of week information were merged into the main data set using a merge key created from data in the year, month, and day fields. All weekday (Monday to Friday) records in the main data set are for non-holiday weekdays. Each record in the main data set is associated with one of eight "Day of Week" types – namely, Monday; Tuesday; Wednesday; Thursday; Friday; Saturday; Sunday; and Holiday.
- *2010 and 2011 TTMS "Bad Counts" data files.* These files listed the dates when counts at a particular TTMS was deemed as bad data based on data audits conducted by the Florida Department of Transportation data analysts. This information was merged into the main data set – using a merge key created form the Site ID, year, month, day, and direction of travel fields – and used to flag corresponding records as bad counts. These "bad" records were excluded from the main dataset during the data cleaning process.
- *TTMS Site Description data file.* This file provided several details about each TTMS site including: number of lanes by direction; location by road section, road name and coordinates; active status of the site; and whether or not the site counts vehicles by classes.
- *Florida Statewide Model Facility Type and Area Type Data file*. Files in the highway network of the Florida Statewide model (version 5.1.2 Release 1) were used to obtain the facility type and area type of the roadway on which the TTMS site was located. The highway network was visually compared to a GIS map of the Florida highway system to relate each TTMS site to a link in the statewide model highway network. This relationship was used to assign the facility type and area type attributes to each TTMS site based on the attributes of its associated statewide model highway network link. This information was added to each record of the main dataset using a merge key created from the data in the Site ID field.
- *Posted Speed Limits at TTMS sites file.* This file contained information on the posted speed limits at TTMS sites. This information was merged into the main data set using a merge key created from data in the Site ID and Direction fields.
- *Special Events file.* This file contained information about the dates on which the counts at TTMS sites were affected by special event traffic. This information was merged into the main data set using a merge key created from data in the TTMS Site ID, year, month and date key.

The data check process revealed that 2,784 records from 29 of the TTMS hourly speed count data files were found to have a data structure that was different from the other TTMS hourly speed count data files. The records in those 29 files included unit number and direction of travel while the other speed data count files did not. The data structure of the records in the 29 files was made consistent with the other TTMS hourly speed data files before the records were added to the main data set. In addition, 288 records in the TTMS hourly speed count data had a 2-digit year of 20 (implying year 2020). These include 108 records with 0 lane volumes between the hours of midnight and 7:00 p.m. All 288 hourly records were excluded from the main dataset.

The records in the TTMS hourly count data files (for all except the 29 files mentioned above) did not include information about direction of travel and also did not include enough information to enable deduction of the direction data from other sources. However, the name of each count data file included a unit number that when combined with values from the "SITE_ID" and "ATRLane" fields in each record provided enough information to determine the direction of travel for each lane using data from the Lane Relationship file. It was therefore necessary to add the Unit Number value contained in each TTMS count data file name to each record of the associated count data file. This information was subsequently used to add the direction of travel to each count record. The lane direction information in the lane relationship file was merged into the main dataset using a merge key created from data in the TTMS Site ID, Unit No and ATR Lane number fields.

Upon completion of data processing and cleaning, the number of records in the main dataset was reduced from 9,182,224 to 8,580,315. Each record contained one hour counts for each lane at each TTMS site and descriptive information about each lane and the TTMS site.

4.2.3 Data Variables of Interest

Following data validation process, the following variables were synthesized – County, Lane Number, Month, Day, Hour, Minute, Speed Bins (15 bins in 5-mph increments including < 20 mph and > 85 mph), Total Volume by Speed, Total Volume by Classification, Light Vehicles, Heavy Vehicles, %Heavy Vehicles, Direction of Travel, TTMS Location, Urban Size, Functional Classification, AADT, K-Factor, Facility Type, Area Type, Posted Speed Limit, and Day of the Week. Figure 4.4 shows a spreadsheet extract from the main dataset with a view of some of the column titles. Each record represents one hour counts for a lane.

	Cnty	Site_ID	Unit	Direction	ATR_Lane	Year	Month	Day	Hour	Minute	Source	mph_1_20	mph_21_25	mph_26_30	mph_31_35	mp
1	93	0010	1	N	1	10	7	1	1	0	60	0	0	0	2	
2	93	0010	1	N	1	10	7	1	2	0	60	0	0	1	0	
3	93	0010	1	N	1	10	7	1	3	0	60	0	0	0	0	
4	93	0010	1	N	1	10	7	1	4	0	60	0	0	0	0	
5	93	0010	1	N	1	10	7	1	5	0	60	0	0	0	0	
6	93	0010	1	N	1	10	7	1	6	0	60	0	0	0	4	
7	93	0010	1	N	1	10	7	1	7	0	60	0	0	0	1	
8	93	0010	1	N	1	10	7	1	8	0	60	0	0	1	7	
9	93	0010	1	N	1	10	7	1	9	0	60	1	0	5	15	
10	93	0010	1	N	1	10	7	1	10	0	60	6	2	7	12	
11	93	0010	1	N	1	10	7	1	11	0	60	5	0	0	0	
12	93	0010	1	N	1	10	7	1	12	0	60	0	0	0	0	
13	93	0010	1	N	1	10	7	1	13	0	60	0	0	0	0	

FIGURE 4.3. **Spreadsheet Display of the Main Dataset**

4.3 Field Speed Data Collection

To fill the TTMS data gap in which minor arterial roadways were not sufficiently represented in the pool of sites to be analyzed, speed data had to be collected on a selected number of roadway segments. Due to lack of sufficient resources, only 20 sites were selected and all were located in the City of Tallahassee. The sites were selected based on speed limit and traffic volume to ensure that roadways of lower functional class particularly close to CBD areas were well represented in the dataset. Table 4.2 shows the geometric and traffic characteristics of the roadway segments.

TABLE 4.2. Selected Roadway Segments for Speed Data Collection

ROAD NAME	INTERSECTION 1	INTERSECTION 2	CLASS	Speed Limit, S_{pl}	No. of through lanes N_{th}
N Macomb St	W Pensacola St	W Tennessee St	Collector	30	2
Lake Bradford	Jackson Bluff Rd	Gamble St	Minor Arterial	35	2
Thomasville Rd	South Ride	Waverly Rd	Principal Arterial	35	2
Thomasville Rd	E Bradford Rd	South Ride	Principal Arterial	35	3
Tennessee St	Monroe St	Meridian St	Minor Arterial	35	2
Blair Stone Rd	Old St Augustine Rd	Apalachee Pkwy	Minor Arterial	30	2
Blair Stone Rd	Apalachee Pkwy	Park Ave	Minor Arterial	35	2
Orange Ave	Wahnish Way	Adams St	Minor Arterial	35	2
Apalachee Pkwy	Franklin Blvd	Magnolia Dr	Principal Arterial	45	2
Tharpe St	High Rd	Ocala Rd	Minor Arterial	30	2
Tennessee St	N Copeland St	Woodward Ave	Minor Arterial	30	3
W Pensacola St	Ausley Rd	White Dr	Principal Arterial	40	2
S Adams	W Orange Ave	Paul Russell Rd	Principal Arterial	45	2
N Monroe St	Park Ave	Tennessee St	Principal Arterial	25	2
S Monroe St	Oakland Ave	Palmer Ave	Principal Arterial	35	2
Paul Russell Rd	S Adams St	S Monroe St	Minor Arterial	30	2
Capital Circle NE	Centerville	Hermitage Blvd	Principal Arterial	45	3
Capital Circle NE	Hermitage Blvd	Raymond Diehl Rd	Principal Arterial	45	3
Miccosukee Rd	Blair Stone Rd	Capital Circle Ne	Minor Arterial	35	2
Miccosukee Rd	Magnolia Dr	Hillcrest	Minor Arterial	30	1

The information in Table 4.2 shows that one segment had speed limit of 25 MPH, six segments had speed limit of 30 MPH, 8 segments had speed limit of 35 MPH, one segment had speed limit of 40 MPH, and 4 segments had speed limit of 45 MPH. The review of traffic volume data published by the City of Tallahassee showed that nine segments had an average daily traffic (ADT) volume of between 7,000 and 23,000 vehicles per day (vpd) while 11 segments had ADT volume of between 24,000 and 50,000 vpd. Appendix Table A.1 shows additional attributes of these segments.

Data on the 20 Tallahassee roadway segments were collected using pneumatic tube counters made by Jamar Technologies, TRAX Apollyon model. The Jamar tube counters time-stamps each vehicle, records its speed, and records the number of axles it has. The collection of individual vehicle speeds was important since it enables analysts to determine which vehicle was free flowing. The time stamp information was used to determine headways between vehicles. The HCM 2010 procedure (page 30-35) requires that only vehicles whose lead headway is 8 seconds or more and lag headway is 5 seconds or more be included in the determination of mean free flow speed. Figure 4.4 illustrates this requirement.

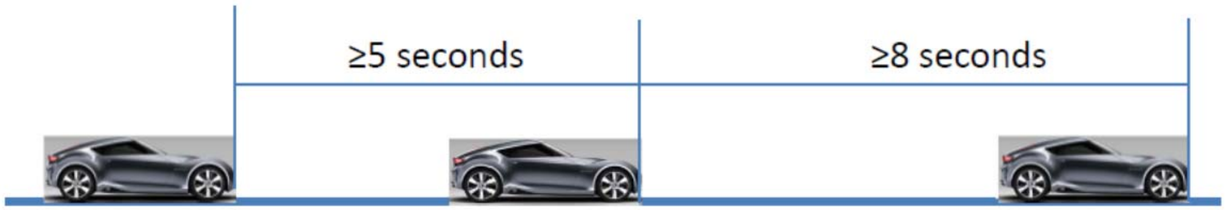

FIGURE 4.4. Illustration of HCM 2010 Procedure of Determining Free Flow Vehicles.

CHAPTER 5

FREE FLOW SPEED MODELING

5.1 Approach

The main objective of this study was to determine the efficacy of HCM 2010 methodology of predicting free flow speeds in the relation to the simple FDOT methodology particularly on uninterrupted flow highways in urban areas. As we had readily available data, we found it prudent to investigate an alternative simple model that, if viable, FDOT could use for free flow speed prediction, should their current model prove less accurate. The alternative model we developed used the same input variables as the HCM 2010 model in order to avoid bias when comparing all three models. The aim of this comparative study was to ensure that the level of service analysis based on HCM 2010 procedure is as robust as practically possible.

5.2 Data Preparation

Prior to undertaking the modeling exercise, a number of data preparation tasks were performed. The tasks included screening the TTMS data, acquiring segment geometric variables, estimating free flow speed from the field data, and building database for modeling. These tasks are explained in detail below.

5.2.1 Screening of TTMS Data

TTMS data screening involved filtering out observations which did not meet the quality check criteria. This had to be done in order to establish a reliable dataset for estimation of field free flow speed. Data collected during peak hours and at night were segregated from those recorded during off-peak hours. The data recorded during off-peak hours were assumed to comprise free flowing vehicles. In addition, the data were checked for consistency resulting in observations with missing fields being removed from the dataset.

5.2.2 Converting Time Mean Speed into Space Mean Speed

It is well known that time mean speed overestimates the influence of faster vehicles and consequently overestimates the mean speed. However, if the sample size collected is significantly large enough, speed variance becomes small, and hence, space mean speed approaches time mean speed as seen in Figure 5.1. Since the raw data acquired from FDOT had vehicle speeds aggregated in 5-mph speed bins on an hourly basis, it was necessary to convert the speed bins into time mean speeds and space mean speeds using the following formulas:

$$Time\ Mean\ Speed = \frac{\sum_{b=1}^{b=15}(Count_b^i \times Speed_b)}{\sum_{b=1}^{b=15}(Count_b^i)} \quad \text{......} 5.1$$

$$Harmonic\ Mean\ Speed = \frac{\sum_{b=1}^{b=15} Count_b^i)}{\sum_{b=1}^{b=15}\left(\frac{Count_b^i}{Speed_b}\right)} \quad \ldots\ldots\ldots\ldots 5.2$$

where b is the speed bin index (1 to 15), $Count_b^i$ is the number of vehicles in speed bin "b" recorded in hour "i', and $Speed_b$ is mid-point of the speed range in bin "b".

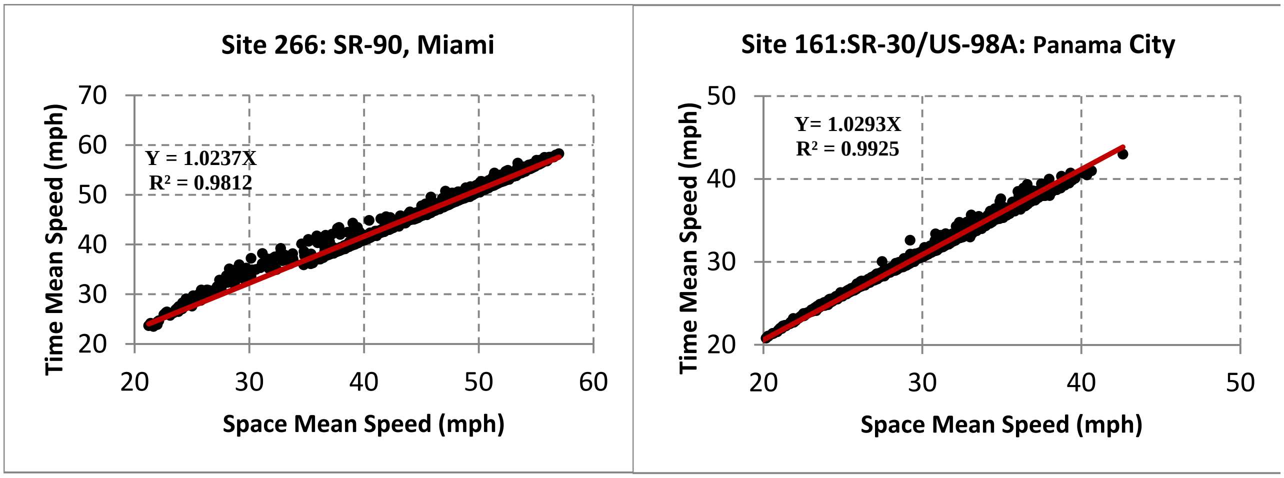

FIGURE 5.1. Comparison of Time and Space Mean Speeds

The statistical comparison between time mean speed and the space mean speed was then performed using paired *t*-test as shown in an abbreviated Table 5.1. It can be observed that, *t*-values are extremely large due to convergence of the distribution to normal when sample size is large enough. With large sample size, time mean speed and space mean speed gravitates towards being equal.

TABLE 5.1. Comparison of Time to Space Mean Speed

Site ID	Roadway Name	County	Speed Limit, mph	Sample Size	R-squared	|t|	Pr>|t|
266	SR 90	Dade	45	5,814	0.9812	1.000E+23	<0.000
151	SR 20/US 27	Leon	35	4,867	0.9759	1.161E+48	<0.000
166	SR 30/US 98A	Bay	35	5,682	0.9925	1.324E+12	<0.000
96	SR 9	Dade	50	4,981	0.9711	4.000E+131	<0.000

The results in Table 5.1 show that the two speed measures are not significantly different. This result suggests that when the sample size is large enough, there is insignificant difference between time mean speed and space mean speed calculated using the arithmetic mean formula and harmonic mean formula, respectively.

5.2.3 Determining Free Flow Speed from the TTMS Data

After screening and checking for consistency of the Telemetered Traffic Monitoring Sites (TTMS) data, the next step was to filter out the outliers from the dataset by plotting speed-volume curves for each hour. Figure 5.2 shows that as hourly volume increases, the average speed decreases. Any pair of hourly speed and volume that did not follow the trend in Figure 5.2 was discarded.

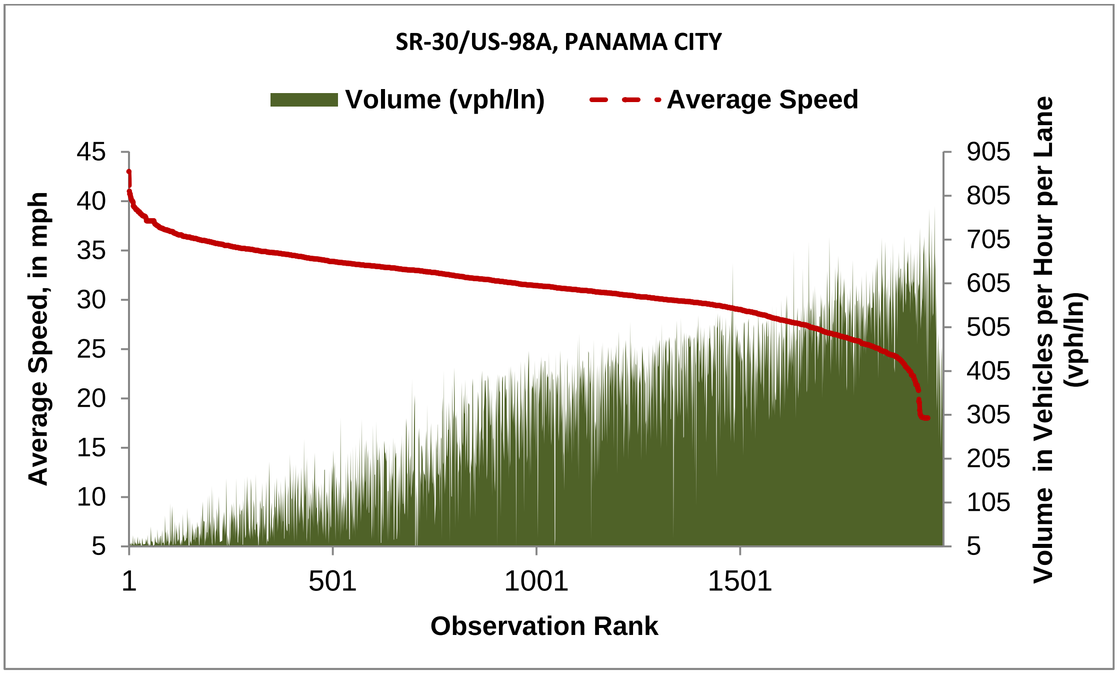

FIGURE 5.2. Speed-Volume Curve of a TTMS in Panama City, Florida

5.2.4 Determining Free Flow Speed from Tallahassee Data

The collection of 3-day speed data on 20 roadway segments in the City of Tallahassee using pneumatic tube counters provided an the opportunity to determine free flow speed in accordance with HCM 2010 procedure as specified in Chapter 30 of the HCM 2010 publication. The HCM 2010 procedure has three main steps:

Step 1. Conduct a spot-speed study at a midsegment location during low volume conditions. Record the speed of 100 or more free-flowing passenger cars. A car is free-flowing when it has a headway of 8 seconds or more to the vehicle ahead and 5 seconds or more to the vehicle behind in the same traffic lane.

Step 2. Compute the average of the spot speeds S_{spot} and their standard deviation σ_{spot}.

Step 3. Compute the segment free-flow speed S_f as a space mean speed using equation

$$S_f = S_{spot} - \frac{{\sigma_{spot}}^2}{S_{spot}} \quad \text{.......} \quad 5.3$$

where S_f is free-flow speed (mph), S_{spot} is the average spot speed (mph), and σ_{spot} is the standard deviation of spot speeds (mph).

These three steps were applied to the speed data collected by the pneumatic tube counters. The format of the raw data collected by the counters is shown in Table 5.2. A computer program was written to extract vehicles whose leading and following gap were more than 8 seconds and more than 5 seconds, respectively. The speeds of these vehicles were then summed up and averaged. The final step was the calculation of the space mean speed using Equation 5.3. It should be noted that only daytime speeds of passenger cars (i.e., two-axle vehicles) were used in the analysis.

TABLE 5.2. Raw Data from a Pneumatic Tube Counter

File Name: C:\DOCUME~1\Geofrey\LOCALS~1\Temp\trx37D2.tmp
Start Date: 1/31/2013
Start Time: 12:00:00 PM
Site Code:
Station ID Paul Russel
Location 1:
Location 2:
Longitude: 0' 0.000 South
Latidude: 0' 0.000 East

Veh. No.	Date	Time	Lane	Axles	Spec	Class	Length (In Inches)	Speed (In MPH)	Gap (In Seconds)	Follow (In Inches)	Axle 1-2	Axle 2-3	Axle 3-4	Axle 4-5
1	1/31/2013	12:30:32 PM	1	2	3	3	128	23	33	9999	128			
2	1/31/2013	12:30:40 PM	1	5	25	9	666	21	8	2957	183	51	383	49
3	1/31/2013	12:31:09 PM	1	2	3	3	141	26	27	9999	141			
4	1/31/2013	12:31:17 PM	1	2	2	2	106	21	8	2957	106			
5	1/31/2013	12:31:45 PM	1	2	2	2	104	26	28	9999	104			
6	1/31/2013	12:32:40 PM	1	2	2	2	104	28	55	9999	104			
7	1/31/2013	12:32:51 PM	1	2	2	2	109	34	11	6582	109			
8	1/31/2013	12:32:57 PM	1	2	2	2	105	29	5	2552	105			
9	1/31/2013	12:33:00 PM	1	2	2	2	360	28	3	1478	118			
10	1/31/2013	12:33:00 PM	1	2	2	2	360	28	3	1478	118			
11	1/31/2013	12:33:02 PM	1	2	2	2	110	25	1	440	110			
12	1/31/2013	12:33:05 PM	1	2	2	2	108	25	3	1320	108			
13	1/31/2013	12:34:25 PM	1	2	2	2	106	26	80	9999	106			
14	1/31/2013	12:34:41 PM	1	2	4	5	154	25	16	7040	154			
15	1/31/2013	12:34:51 PM	1	2	2	2	105	24	9	3802	105			
16	1/31/2013	12:34:58 PM	1	2	2	2	105	22	7	2710	105			
17	1/31/2013	12:35:00 PM	1	2	2	2	109	25	1	440	109			
18	1/31/2013	12:35:29 PM	1	2	2	2	117	26	29	9999	117			
19	1/31/2013	12:35:30 PM	1	2	3	3	121	32	1	563	121			
20	1/31/2013	12:36:02 PM	1	2	2	2	111	19	31	9999	111			
21	1/31/2013	12:36:32 PM	1	2	2	2	109	27	30	9999	109			
22	1/31/2013	12:36:44 PM	1	2	2	2	101	35	12	7392	101			
23	1/31/2013	12:36:53 PM	1	2	2	2	112	31	9	4910	112			
24	1/31/2013	12:36:59 PM	1	2	2	2	113	29	5	2552	113			
25	1/31/2013	12:37:03 PM	1	2	2	2	97	25	5	2200	97			

5.2.5 Building of Modeling Dataset

A dataset of independent and dependent variables was created. The variables were segment traffic, geometric, and signal attributes. Traffic attributes were segment's speed and volume. These were extracted from the TTMS data source and from field data collected in Tallahassee using pneumatic tube counters. The geometrics of the analysis segments were collected using the ArcGIS Explore, Google Earth, and the digital vector data acquired from various FDOT databases. Through these databases, we acquired posted speed limit (S_{pl}), number of through lanes (N_{th}), proportion of a segment with raised curb (P_{curb}), proportion of a segment with restrictive median (P_{rm}), access point density (D_a), segment length (L_{seg}), and lane width (L_{width}).

5.3 Modeling

After building the dataset of independent and dependent variables, the next step towards development of predictive models was the selection of the functional form of the alternative model to fit the data. Normally, the function form is determined after several runs of different variable combinations which correlate the dependent variable to the covariates of the model. Since the objective of this study was to assess the differences between FDOT simple equation and the HCM 2010 procedure, the alternative regression model had to use the covariates similar to the HCM 2010 covariates. The models fitted were divided into four categories to capture the influence of all variables in different functional classes. The categories were: (1) models for principal arterial roads only; (2) models for minor arterial roads only; (3) aggregate model comprising principal and minor arterials; and (4) models fitted to Tallahassee data only.

5.3.1 Graphical Analyses

Scatter plots of a dependent variable vis-à-vis various independent variables can be virtually examined to determine which variable(s) have a noticeable influence on speed. Appendix B shows scatter plots of free flow speed versus independent variables. The scatter plot of free flow speed versus speed limit shows that there is a strong positive correlation. Other scatter plots revealing correlation are those of access density versus estimated free-flow speed and the segment length versus free-flow speed plots.

5.3.2 Model Fitting

Three models were fitted to the data – the FDOT model, HCM 2010 model, and our own regression best-fit model. The developed regression model relate the field estimated free-flow speed with segment posted speed limit (S_{pl}), number of through lanes (N_{th}), proportion of a segment with raised curb (P_{curb}), proportion of a segment with restrictive median (P_{rm}), access point density (D_a), segment length (L_{seg}), and lane width (L_{width}). The model was specified using the following regression equation:

$$FFS = \beta_0 + \sum_{i=1}^{N} \beta_i X_i + INTER + \varepsilon_i, \qquad \varepsilon_i \sim N(0, \sigma^2) \qquad 5.3$$

where β_0 is an intercept of the model, β_i are the coefficients of a predictor variables $X_i's$, $\boldsymbol{\varepsilon_i}$ are error terms and $INTER$ are the interaction terms between the variables.

Both the FDOT and the HCM 2010 models were coded in the spreadsheet containing the dependent and independent variables' data. These models already have empirical mathematical forms. Therefore, segment geometric and traffic variables were plugged into the model equations for each segment to determine the expected free-flow speed. The outputs from these models were compared to field data to assess the goodness of fit graphically and by the use of coefficient of determination, R^2 and root mean square error *(RMSE)*. Concurrently, our regression model was fitted using the regression procedure contained in the SAS statistical software. The analysis was conducted for the two functional classes and for the aggregate dataset. Also, as indicated earlier, analysis was conducted for TTMS data only (84 segments), for Tallahassee data only (20 segments), and for combined dataset (104 segments).

5.4 Discussion of Results

5.4.1 Regression Models Parameter Estimates

Table 5.2 shows the results of the model fitting efforts. The influence of speed limit on free flow speed is quite significant in all datasets – urban principal arterial dataset, urban minor arterial dataset, and the combined principal and minor arterials dataset. Test of the significance of the speed limit parameter resulted in *p*-value < 0.0001 in all three datasets. Similarly, proportion of segment with curb and proportion with restrictive median are also significant in the all three dataset.

TABLE 5.3. Regression Modeling Results

Parameter	**Estimate**	**Standard Error**	***p*-value**	**Comment**
Urban Principal Arterials				
Intercept	5.1371	6.0668	0.4006	**Insignificant**
Speed Limit (mph)	1.0210	0.0503	<.0001	Significant
Number of Lanes	0.0798	0.4956	0.8727	**Insignificant**
Proportion with Curb	-6.4055	1.7553	0.0006	Significant
Proportion with Restrictive Median	0.0002	0.0001	0.0400	Significant
Access Point Density (per mile)	0.0123	0.0257	0.6348	**Insignificant**
Length of Segment (ft)	0.0001	0.0003	0.8442	**Insignificant**
Lane Width (ft)	0.4153	0.5228	0.4302	**Insignificant**
Adjusted R-Square :		0.9028		
Root MSE:		2.1649		
Urban Minor Arterials				
Intercept	-0.6235	5.7715	0.9148	**Insignificant**
Speed Limit (mph)	0.8583	0.0328	<.0001	Significant
Number of Lanes	0.0133	0.3612	0.9709	**Insignificant**
Proportion with Curb	5.4752	1.6738	0.0272	Significant
Proportion with Restrictive Median	0.0000	0.0000	0.0399	Significant
Access Point Density (per mile)	0.0236	0.0164	0.1630	**Insignificant**
Length of Segment (ft)	0.0001	0.0002	0.4573	**Insignificant**
Lane Width (ft)	0.50529	0.3189	0.1248	**Insignificant**
Adjusted R-Square :		0.9810		
Root MSE:		1.0665		
Aggregate model (Principal + Minor)				
Intercept	6.8008	1.7944	0.0200	Significant
Speed Limit (mph)	0.9661	0.0322	<.0001	Significant
Number of Lanes	-0.0492	0.3371	0.3117	**Insignificant**
Proportion with Curb	-5.6238	1.4396	0.0196	Significant
Proportion with Restrictive Median	0.0003	0.0001	0.0406	Significant
Access Point Density (per mile)	0.0144	0.0057	0.0424	Significant
Length of Segment (ft)	0.0001	0.0000	0.0121	Significant
Lane Width (ft)	0.4394	0.3325	0.1159	**Insignificant**
Speed Limit by Number of lanes	-0.1890	0.0840	0.0280	Significant
Prop. with curb by Prop. Restrictive Median	-61.9620	19.7800	0.0030	Significant
Speed Limit by Access Point Density	-0.0010	0.0040	0.8030	**Insignificant**
Adjusted R-Square :		0.9427		
Root MSE:		1.8547		

In addition to significance check on individual variables, the interactions between the variables were also tested for additive effects of the free-flow speed response function. Only two level interaction terms, speed limit by number of lanes, and proportion with curb by proportion with restrictive median have a significant interaction effect on the mean free-flow speed. This implies that the effect of the speed limit on the mean free-flow speed is associated with the number of lanes.

The urban principal arterial model indicates that only speed limit, proportion of segment with curb, and the proportion of segment with restrictive median are significant predictors of free-flow speed. Access point density and length of segment, which showed significant influence in the prediction of free-flow speed in the aggregate model are insignificant in the urban principal arterial model. Factors which were insignificant in the aggregate model (number of lanes and lane width) remained insignificant in the urban principal arterial model.

In the urban minor arterial model, similar characteristics among predictors were observed. Segment posted speed limit, proportion of segment with curb, and proportion of segment with restrictive median have strong influence in predicting free-flow speed. In this model and the urban principal arterial model, interaction terms were insignificant, and they were consequently eliminated from the models.

5.4.2 Comparison of HCM 2010, FDOT, and Best Fit Models

The performance of the three models were compared using data classified as urban principal arterials, urban minor arterial, and aggregated dataset. The free flow speeds predicted by the three models were subsequently compared to the values estimated from field data. The root mean square error (RMSE), the coefficient of determination (R^2), and graphical check were used to compare the degree of agreement between the model output and the field data. All three models – HCM 2010, FDOT and best-fit – were analyzed and compared. The results of this comparative analysis are displayed in Table 5.3.

TABLE 5.4. Comparative Analysis of Three Models

Model	**Formulation**	**RMSE**	**R^2**
Principal arterials	HCM 2010	5.2	0.7285
	FDOT	2.2	0.8984
	Regression	2.8	0.8856
Minor arterials	HCM 2010	4.3	0.7944
	FDOT	2.1	0.9723
	Regression	2.0	0.9882
Aggregate	HCM 2010	4.5	0.7532
	FDOT	2.7	0.8573
	Regression	2.4	0.9145

The results in Table 5.3 show that the HCM 2010 model has lower R^2 and higher RMSE values compared to FDOT and the developed regression model for all three datasets (aggregate, principal arterials and minor arterials). The FDOT method and the regression model shows reasonable prediction of free flow speed based on high coefficient of determination, R^2, and low root mean square error, RMSE.

In addition to statistical analysis, the predictive power of these models were visually examined using a number of plots including a plot shown in Figure 5.3. The figure shows that the developed regression model and FDOT models trace the field data well when the field estimated free-flow speeds across the whole spectrum of measured field free flow speed. In contrast, the HCM 2010 model seems to under-predict free-flow speeds when the field estimated free-flow speed is 40 mph or higher. Similar trends were seen when the data were divided into urban principal arterials only and urban minor arterial only. Plots of the urban principal and urban minor arterial models are shown in Appendix C.

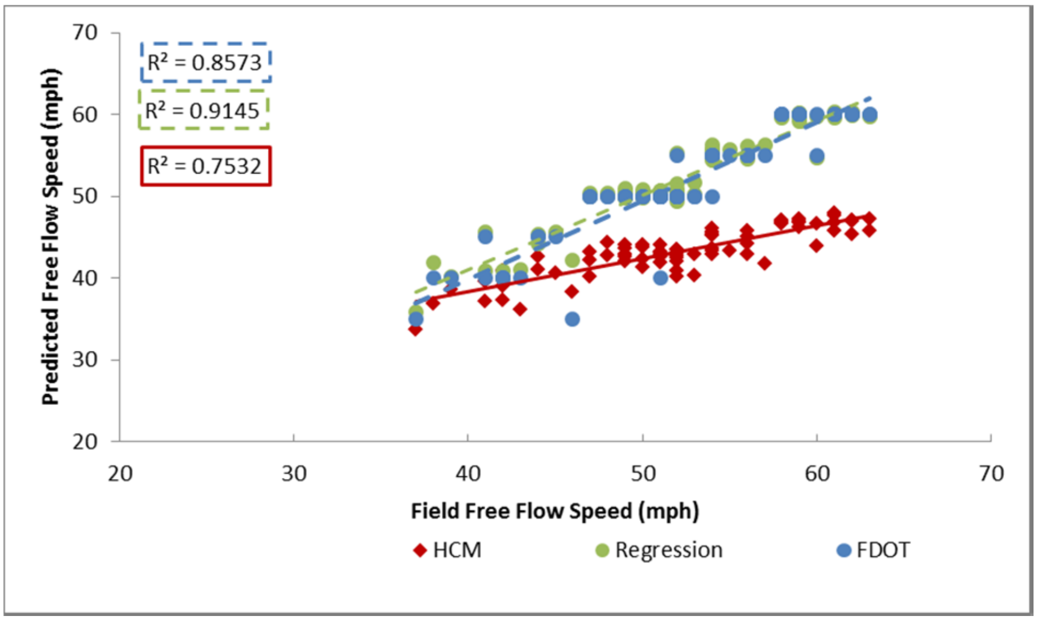

FIGURE 5.3. Scatterplot of Field vs. Predicted Free-Flow Speed

CHAPTER 6

SENSITIVITY ANALYSIS

6.1 Model Response Behavior at Different Speed Limits

In the previous chapter it was noted that free flow speed on a roadway segment is strongly positively correlated to the posted segment speed limit. It is prudent to compare predictive behaviors of the three models at different speed limits. The previous chapter indicated that the developed regression model and the FDOT model seemed to fit the data well while the HCM 2010 model tended to under-predict free-flow speeds when the field estimated free-flow speed was higher than 40 mph.

To check how any one model changes its response at different speed limits, other variables were held constant and the free-flow speeds were predicted with the speed limit as the only varying predictor. The speed limit was varied from 20 mph to 45 mph at an increment of 2.5 mph. The slope at which the model's response changes was observed for all three models. The results are plotted in Figure 6.1.

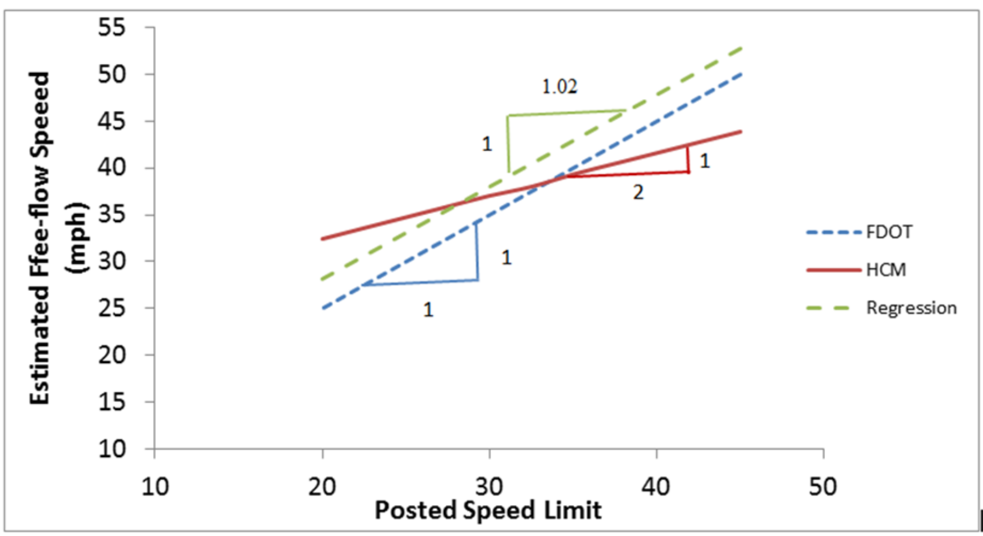

FIGURE 6.1. Sensitivity to Changes in Posted Speed Limit

The results in Figure 6.1 indicate that the HCM 2010 model over-predicts segment free-flow speed at lower speed limits while at higher speed limits the model under-predicts free-flow speed. The slope at which this model changes its responses towards changes in speed limit is 1 to 2 which is gentler than the rate at which FDOT and regression models change (slopes of 1 to 1 and 1 to 1.02, respectively). The FDOT and regression models suggest lower free-flow speed when speed limit is lower and higher free-flow speed in segments with higher posted speed limits. The main differences between the HCM 2010 model and the FDOT model are observed when speed limit is below 30 mph and higher than 35 mph. Similar differences are noted between the HCM 2010 model and the regression model. The FDOT and regression models show similar responsive characteristics at all speed limits with an average difference of 2.8 mph.

6.2 Effects of Speed Limit on Field and Predicted Free Flow Speed

The development of reliable and robust predictive models requires an understanding of both the system being modeled and the statistical techniques available for model building. If this understanding is not applied in model development, then the resulting model is not likely to be reliable or robust and, at best, will describe only the statistical association between the dependent and independent variables in the database used for calibration. In order to assess the consistency of field estimated free-flow speed and model predicted speeds on segments with different speed limits, correlation coefficients were analyzed.

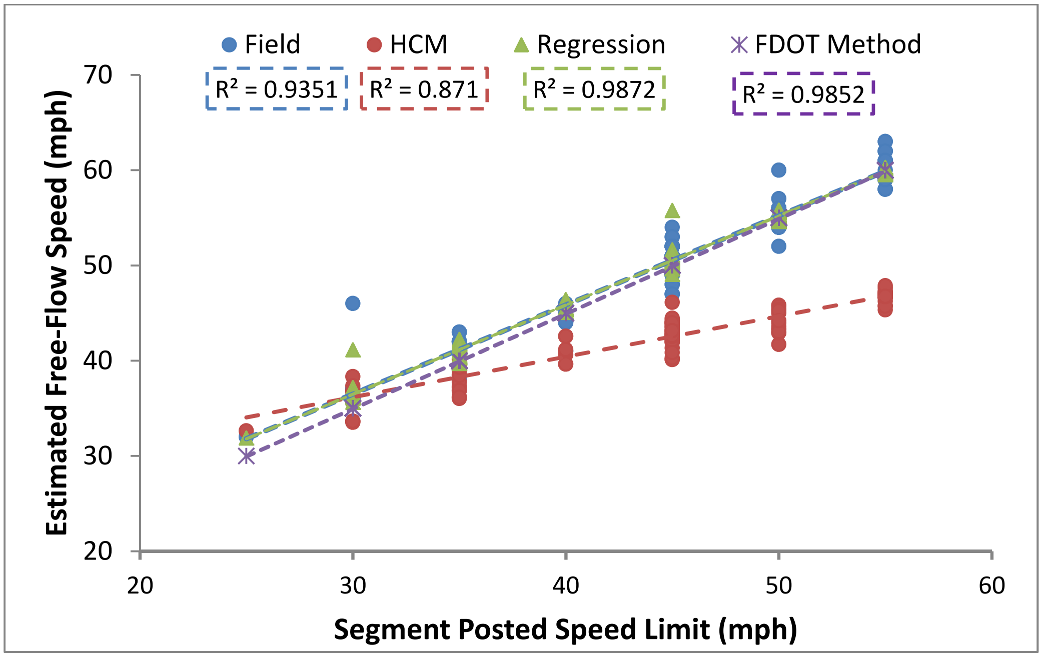

FIGURE 6.2. Influence of Speed Limit on Free Flow Speed

The results in Figure 6.2 show consistent increase in field estimated free-flow speed as the speed limit increases. There is a strong relationship between field estimated free-flow speed and the speed limit as indicated by the R^2 value (0.9351). The predicted free-flow speeds from FDOT and regression models are closely related to the field estimated values. Also, the predicted free-flow speeds from FDOT and regression models are strongly related to segment posted speed limit. The FDOT model resulted in an R^2 of 0.9852 and for the regression model is 0.9872. The HCM 2010 model shows similar characteristics as those observed as Figure 6.1. The model over-predicts the free-flow speed at lower speed limits and under-predicts at higher speed limits. Likewise, the model deviates from field observed data at speeds below 30 mph and speeds higher than 35 mph. When the speed limit is higher than 40 mph, the HCM 2010 model shows that it is possible to have free-flow speed lower than the posted speed limit. For instance, at speed limit of 45 mph field estimated free-flow was in the range of 47 mph to 54 mph, the HCM 2010 would give free-flow speed as low as 40. At a speed limit of 55 mph the observed free flow speed was between 58 mph and 62 mph while the HCM 2010 methodology estimated the speed to be 47 mph. Similar patterns have been observed in the analyses of urban principal arterials and urban minor arterials as shown in plots attached as Appendix D.

6.3 Effect of Free Flow Speed on Segment Level of Service

The FDOT Planning Office procedure for determining level of service (LOS) as contained in the 2012 Arterial Planning Software has a number of inputs including free flow speed. The computational methodologies in ARTPLAN 2012 were revised to reflect the 2010 Highway Capacity Manual. More information about FDOT's LOSPLAN programs, including ARTPLAN can be accessed at http://www.losplan.net/. In this analysis, only automobile LOS was considered. Signal timing data were acquired from City of Tallahassee, Traffic Signal Systems Office. In this section, we examine what would be the resulting level of service if free flow speed was input as predicted by the three models or as field measured. In all cases, all other variables were held constant except for free flow speed. The LOS analysis was conducted only on 20 segments located in the City of Tallahassee. Table 6.1 shows an abbreviated table of the results of the analysis of four roadway segments. Appendix Table E.1 shows the results for all 20 segments.

TABLE 6.1. Analysis of Level of Service

Segment	Prediction Method	Speed Limit, *mph*	Free Flow Speed, *mph*	Cycle Length, *sec*	g/C ratio	Control Delay, *sec*	Segment LOS
Apalachee Parkway	FDOT	45	50	150	0.40	35.65	B
	Best fit	45	52	150	0.40	35.65	B
	HCM	45	44	150	0.40	35.65	C
	Field measured	45	51	150	0.40	35.65	B
South Adams Street	FDOT	45	50	150	0.45	36.58	C
	Best fit	45	50	150	0.45	36.58	C
	HCM	45	44	150	0.45	36.58	D
	Field measured	45	52	150	0.45	36.58	C
North Macomb Street	FDOT	30	35	130	0.45	35.75	C
	Best fit	30	36	130	0.45	35.75	C
	HCM	30	36	130	0.45	35.75	C
	Field measured	30	37	130	0.45	35.75	C
Thomasville Road	FDOT	35	40	160	0.50	35.50	B
	Best fit	35	41	160	0.50	35.50	B
	HCM	35	38	160	0.50	35.50	C
	Field measured	35	42	160	0.50	35.50	B

The results in Appendix Table E.1 show that out of the 20 segments, using the HCM 2010 predicted speed results into one level of service lower than the LOS gotten by the field measured value for ten segments. This results mainly because the LOS procedure is very sensitive to input free flow speed and since as indicated earlier HCM 2010 model underpredicts free flow speed when field free flow is about 40 mph or higher. The use of free flow speed predicted by the FDOT model results in level of service designation close to those obtained by the use of field measured free flow speed. It is only in two cases where the use of the FDOT predicted free flow speed resulted in level of service that was lower than field measured. The good performance of FDOT and best fit model is mainly due to the fact that they do predict free flow speeds that correlate well with field measure free flow speed as revealed by very high coefficients of determination, i.e., R^2 higher than 98% for both models.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

One-year data from traffic monitoring sites located on interrupted flow facilities with speed limit ranging from 25 MPH to 60 MPH were used in the study. In addition, 3-day speed data were collected from 20 sites in the City of Tallahassee. Mean free flow speeds were determined for the analysis segments as well as geometric and traffic attributes that the HCM 2010 uses to predict free flow speed. These attributes were the speed limit (S_{pl}); the proportion of segment length with restrictive median (p_{rm}); the proportion of segment with curb on the right-hand side (p_{curb}); the number of access point approaches on the right side in the subject direction of travel ($N_{ap,s}$); the number of access point approaches on the right side in the opposing direction of travel ($N_{ap,o}$); the segment length (L); the width of the signalized intersection (W_i); number of through lanes, (N_{th}); and the distance between intersections (L_s).

The analyses were conducted separately for principal arterial segments and for minor arterial segments as well as for the combined dataset. The comparison of the performance of the HCM210 free flow speed prediction model to FDOT free flow speed prediction model using root mean square error (RMSE) and coefficient of determination (R^2) as measures of performance showed that the FDOT simple formula of determining free flow speed performs better than HCM 2010 procedure which requires nine input variables to predict free flow speed. In both principal arterials and minor arterials, the HCM 2010 methodology underpredicts when field free flow speed is 40 mph or higher. Because of fewer segments with posted speed limit less than or equal to 35 MPH, the efficacy of the HCM 2010 prediction model cannot be ascertained in this speed range.

The best fit regression model that was developed shows that it fits the data better than the HCM 2010 and FDOT models. In addition, statistical analysis of this model showed that only a few independent variables were significant in predicting free flow speed. These variables were speed limit (S_{pl}); the proportion of segment length (segment) with restrictive median (p_{rm}); and the proportion of segment with curb on the right-hand side (p_{curb}). However, it should be noted that the model has not been validated using a different set of data due to resource limitations.

7.2 Recommendations

The performance of both HCM 2010 and FDOT speed prediction models were evaluated. It is safe to say that the HCM 2010 speed prediction procedure is more involved as it requires nine input variables while the FDOT speed prediction model is simple and more appealing to an analyst as it requires only knowledge of the posted speed limit to determine free flow speed. Although the results from 104 roadway segments seem to confirm that the FDOT model, despite its simplicity, predicts free flow speed reasonably well. It is recommended that further data collection is needed to increase the level of confidence in its predictive power versus the predictive power of HCM 2010 model. Most researchers use a guideline of 30 samples in order for the central limit theorem to be applicable in inferential statistics. Therefore, 30 samples per speed limit will result in a minimum of 210 roadway segments considering that there are 7 speed limit values between 25 MPH and 55 MPH. In our study, a few speed limits were overrepresented while roadway segments with speed limit less than 35 MPH were underrepresented.

Additional qualifications of this study are in order. Only interrupted flow facilities were covered in this study mainly involving signalized corridors. The study did not analyze free flow speeds on uninterrupted or limited access facilities. In addition, the signalized corridors analyzed were mainly located on urban principal and minor arterials. Urban collector and distributor roads as well as rural roadways of all functional classification were not analyzed. Thus, the efficacy of both HCM 2010 and FDOT model in predicting free flow speeds on these other types of roadways cannot be ascertained. Since the results point to improved performance when models are built for specific area type and functional class combination, collection of additional data by area type and functional class should be considered in future research.

It should also be noted that the HCM 2010 speed prediction model may be tweaked to increase its predictive power without removing variables from the model. The predictive power of our best fit model was improved when only three original HCM 2010 independent variables were left in the model, i.e., the speed limit (S_{pl}), the proportion of segment length with restrictive median (p_{rm}), and the proportion of segment with curb on the right-hand side (p_{curb}). But, instead of removing variables, a different intercept and/or different coefficients of the same variables can be evaluated. Different HCM 2010-type models can be produced for different functional classes – i.e., collector, distributor, arterial, etc. – and different area types – i.e., CBD, urban, residential, rural, etc. Such analysis could also lead to evaluating other variables for inclusion in the model such as parking in CBD areas, if warranted by field conditions.

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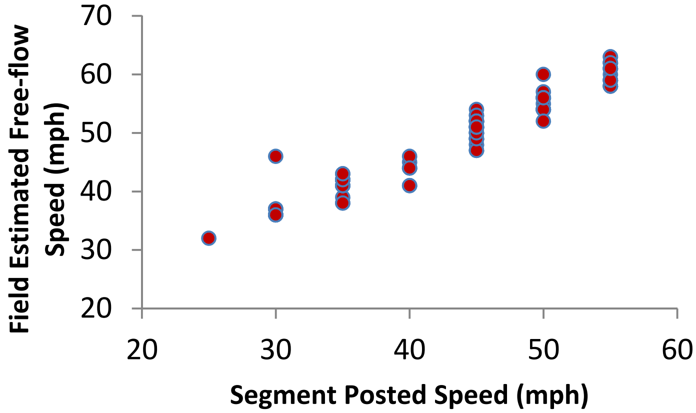
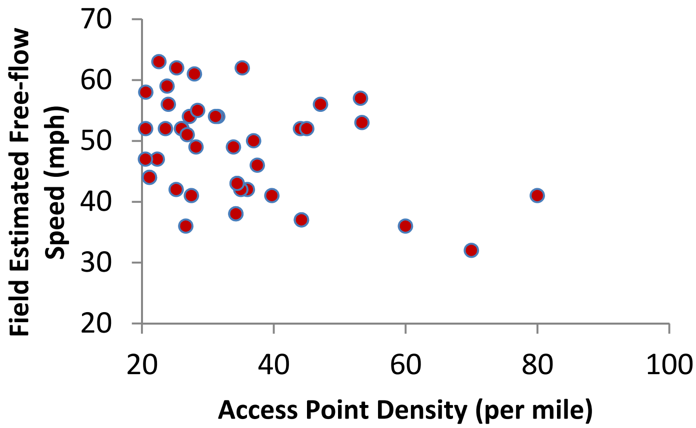
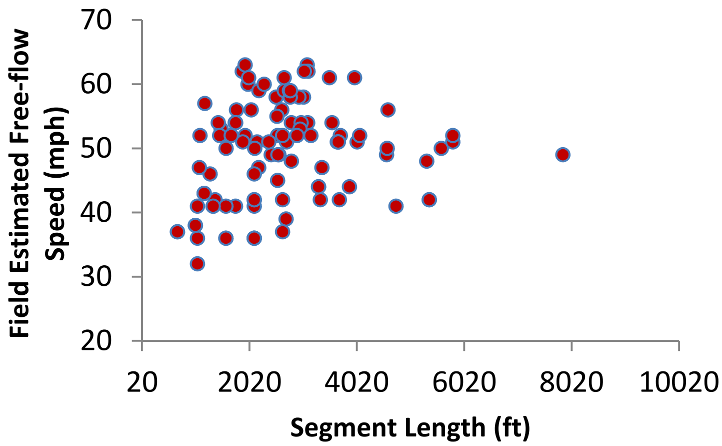
APPENDIX A – DESCRIPTION OF TALLAHASSEE SEGMENTS

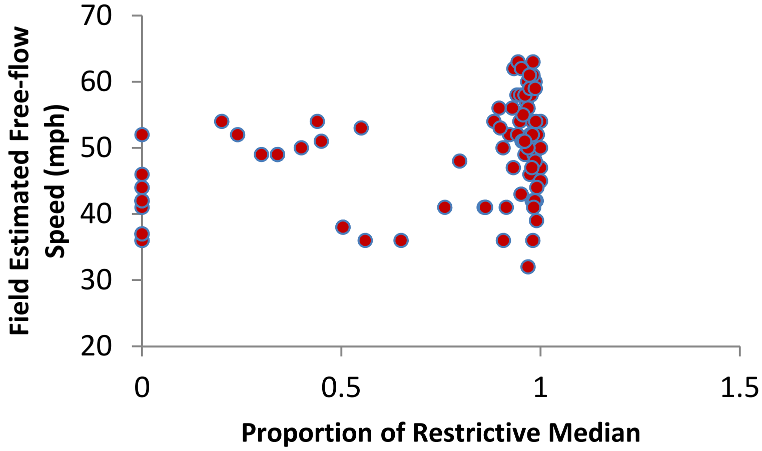
TABLE A.1. Attributes of the 20 Roadway Segments in the City of Tallahassee

ROAD NAME	INTERSECTION 1	INTERSECTION 2	CLASS	Speed Limit, S_{pl}	Adjusted Volume (vpd)	No. of through lanes N_{th}
N Macomb St	W Pensacola St	W Tennessee St	Collector	30	17,903	2
Lake Bradford	Jackson Bluff Rd	Gamble St	Minor Arterial	35	28,690	2
Thomasville Rd	South Ride	Waverly Rd	Principal Arterial	35	30,484	2
Thomasville Rd	E Bradford Rd	South Ride	Principal Arterial	35	30,484	3
Tennessee St	Monroe St	Meridian St	Minor Arterial	35	29,696	2
Blair Stone Rd	Old St Augustine Rd	Apalachee Pkwy	Minor Arterial	30	20,715	2
Blair Stone Rd	Apalachee Pkwy	Park Ave	Minor Arterial	35	23,073	2
Orange Ave	Wahnish Way	Adams St	Minor Arterial	35	22,929	2
Apalachee Pkwy	Franklin Blvd	Magnolia Dr	Principal Arterial	45	38,439	2
Tharpe St	High Rd	Ocala Rd	Minor Arterial	30	27,626	2
Tennessee St	N Copeland St	Woodward Ave	Minor Arterial	30	39,753	3
W Pensacola St	Ausley Rd	White Dr	Principal Arterial	40	30,431	2
S Adams	W Orange Ave	Paul Russell Rd	Principal Arterial	45	21,964	2
N Monroe St	Park Ave	Tennessee St	Principal Arterial	25	30,852	2
S Monroe St	Oakland Ave	Palmer Ave	Principal Arterial	35	19,890	2
Paul Russell Rd	S Adams St	S Monroe St	Minor Arterial	30	7,427	2
Capital Circle NE	Centerville	Hermitage Blvd	Principal Arterial	45	50,000	3
Capital Circle NE	Hermitage Blvd	Raymond Diehl Rd	Principal Arterial	45	47,032	3
Miccosukee Rd	Blair Stone Rd	Capital Circle Ne	Minor Arterial	35	19,494	2
Miccosukee Rd	Magnolia Dr	Hillcrest	Minor Arterial	30	8,553	1

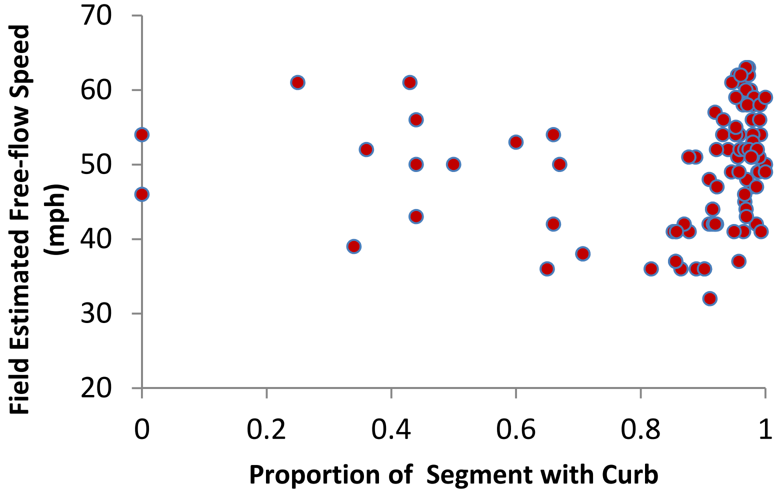
APPENDIX B – SCATTER PLOTS OF RESPONSE VS. PREDICTORS

Table B.1. Scatter Plots of Free Flow Speed versus Various Independent Variables

<table>
<tr><th>PLOT</th><th>OBSERVATIONS</th></tr>
<tr><td>
</td><td>Posted speed limit seems to be linearly correlated with field measured free flow speed. The correlation is positive.</td></tr>
<tr><td>
</td><td>Access density shows a somewhat negative correlation with field free flow speed. Increase in access density per mile results in virtual reduction in free flow speed.</td></tr>
<tr><td>
</td><td>Although it is difficult to ascertain a trend in this scatterplot, it is generally accepted that longer segments (i.e., longer distances between traffic signals) have higher free flow speeds.</td></tr>
</table>



This plot doesn't show any discernible relationship between proportion of restrictive median and the field free-flow speed.



Similarly, this plot doesn't show any discernible relationship between proportion with curb and the field free-flow speed. It is difficulty to infer the sign and significance of proportion of restrictive median in the prediction of free-flow speed from this plot.

APPENDIX C – PRINCIPAL AND MINOR ARTERIAL MODELS

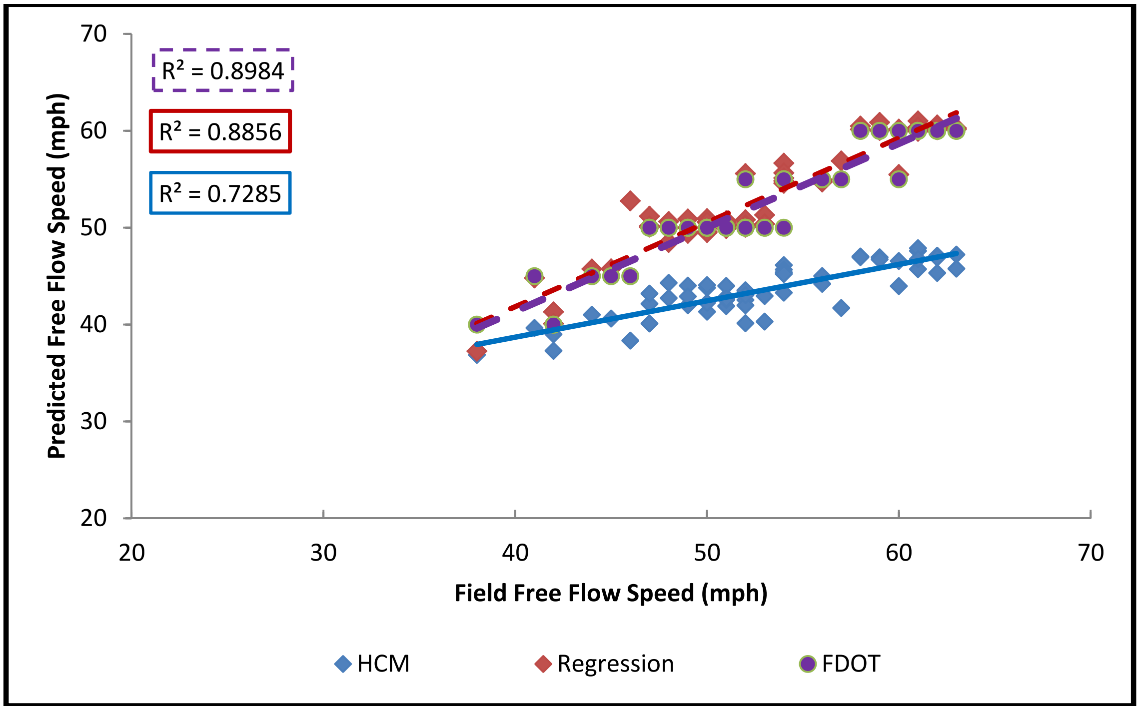


FIGURE C. 1. Urban Principal Arterial Models

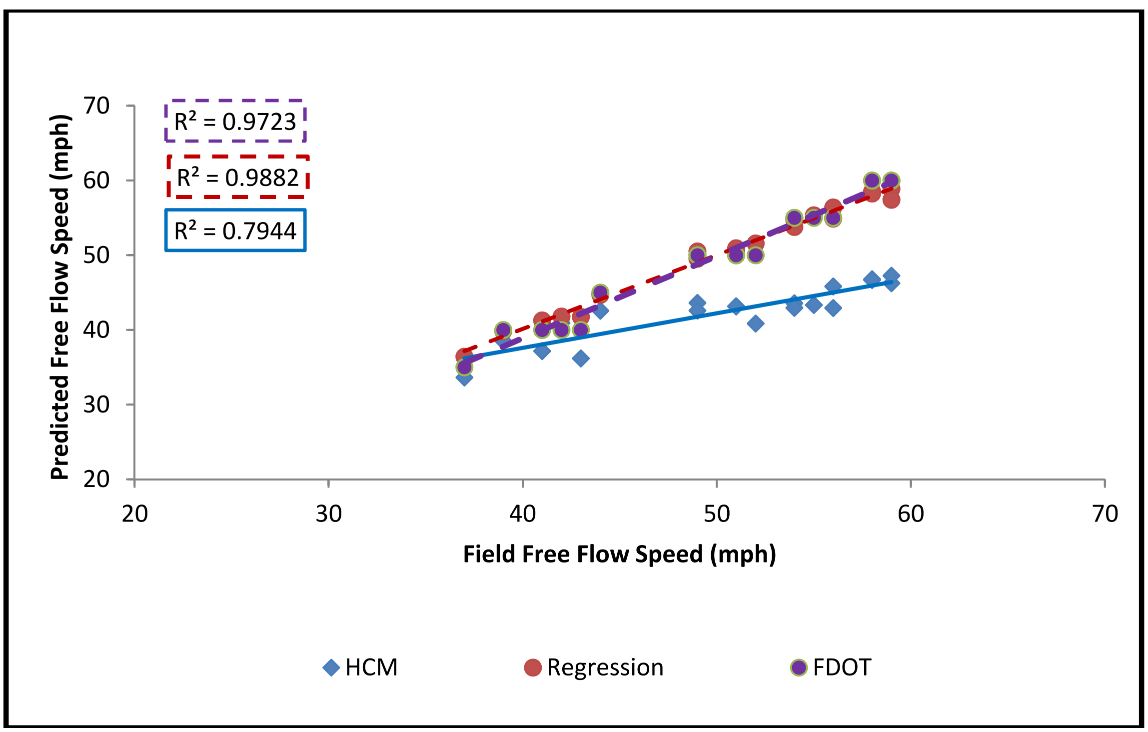


FIGURE C. 2. Urban Minor Arterial Models

APPENDIX D – SENSITIVITY ANALYSIS BY FUNCTIONAL CLASS

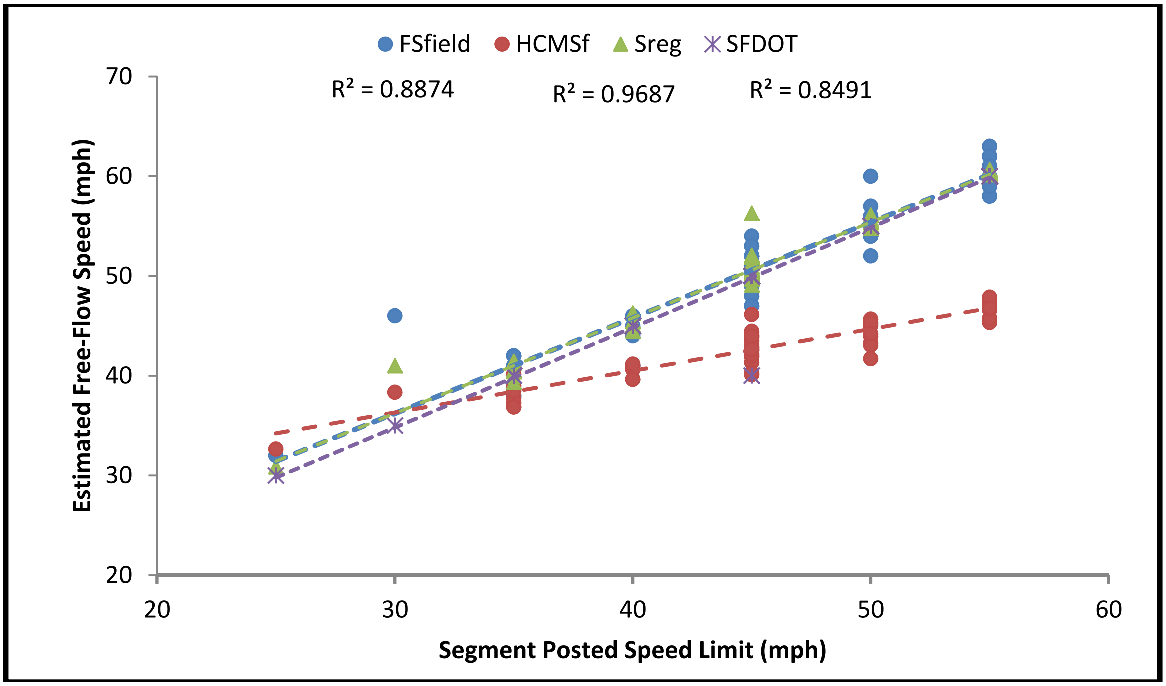


FIGURE D.1. Speed Limit against Field and Predicted Free Flow Speed on Urban Principal Arterial Models

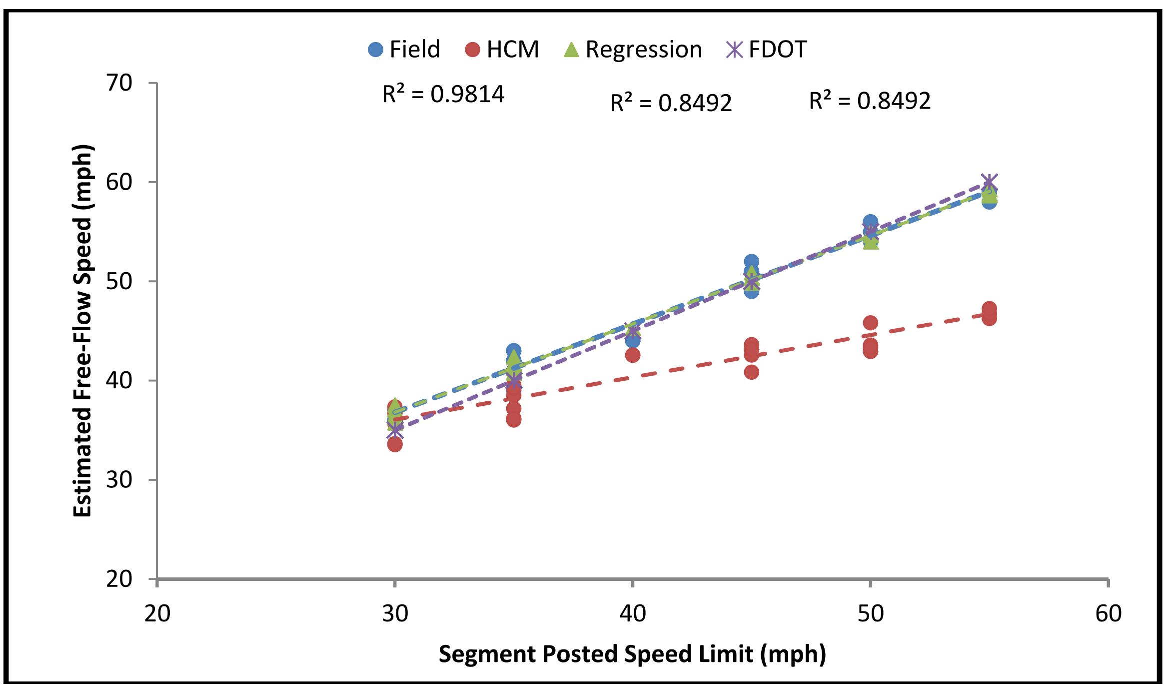


FIGURE D.2. Speed Limit against Field and Predicted Free Flow Speed on Urban Minor Arterial Models

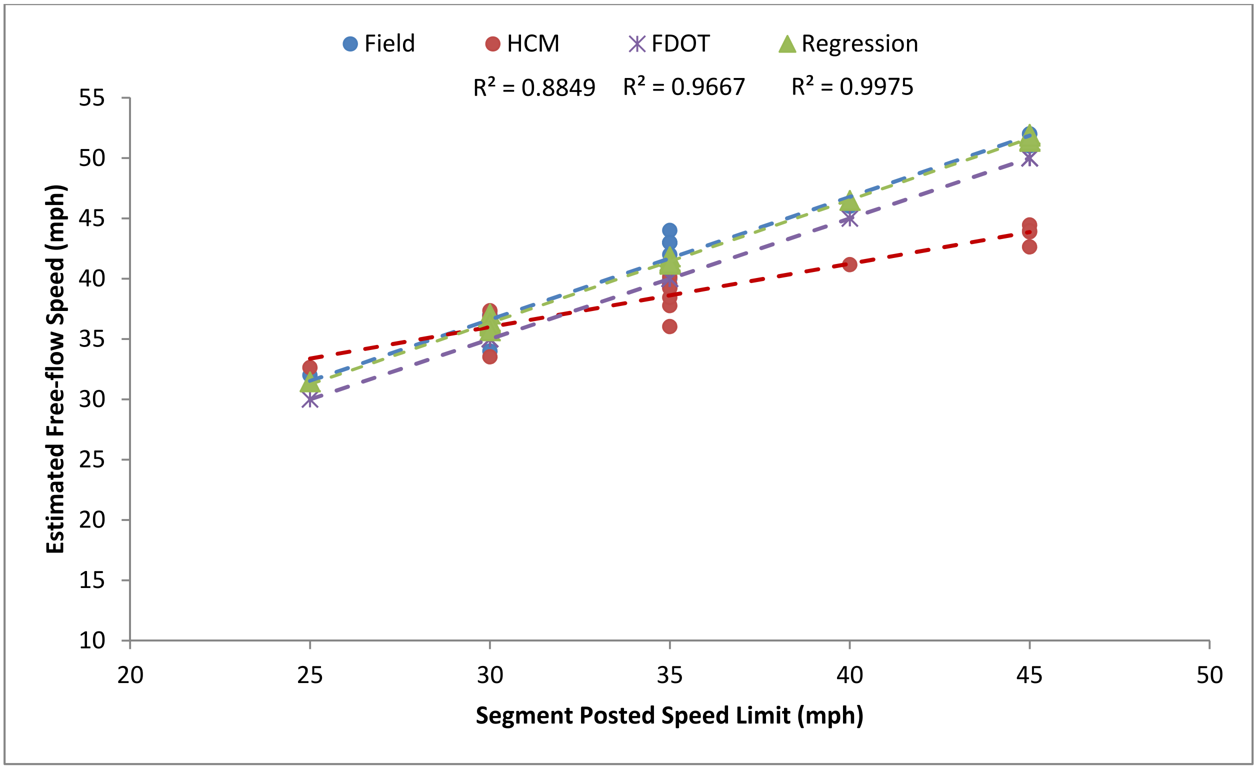


FIGURE D.3. Speed Limit against Field and Predicted Free Flow Speed for Aggregate Models using Data from Tallahassee only

TABLE D.1. Parameter Estimates and Fit Statistics

Aggregate Model Using Data from Tallahassee only				
Parameter	**Estimate**	**Standard Error**	***p*-values**	**Comment**
Intercept	3.61481	3.61849	0.3393	**Insignificant**
Speed Limit (mph)	0.98425	0.03684	<.0001	**Significant**
Number of Lanes	0.57101	0.26635	0.05	**Significant**
Proportion with Curb	0.63728	3.77101	0.8689	**Insignificant**
Proportion with Restrictive Median	-0.00018247	0.00019485	0.3691	**Insignificant**
Access Point Density (per mile)	-0.00164	0.00774	0.8362	**Insignificant**
Length of Segment (ft)	0.0002001	0.0002373	0.4171	**Insignificant**
Lane Width (ft)	0.16708	0.24246	0.505	**Insignificant**
R-Square:		0.9958		
Adjusted R-Square :		0.9928		
Root MSE:		0.51709		
Dependent Mean:		41.7		
Coefficient Variation:		1.24002		

APPENDIX E – LEVEL OF SERVICE ANALYSIS

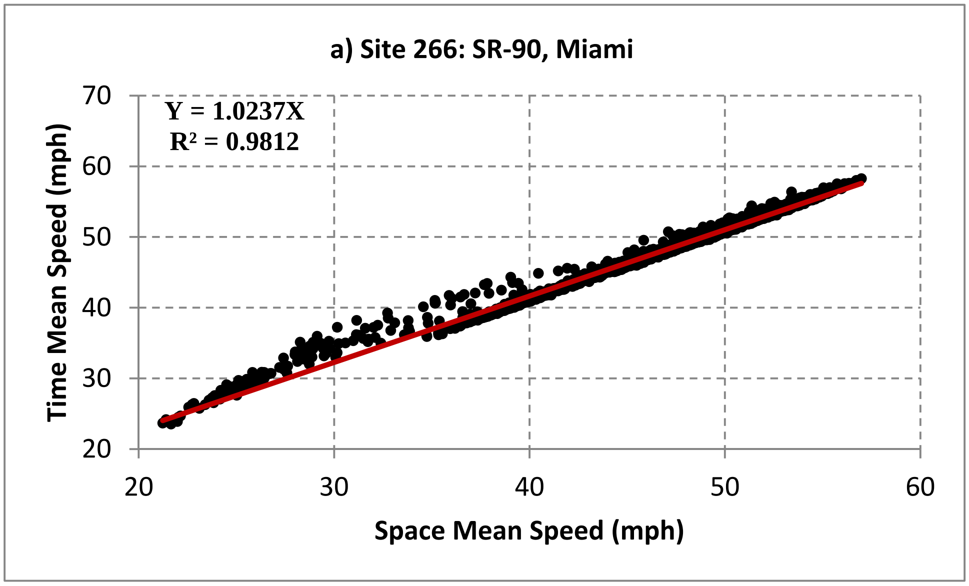
TABLE E.1. Analysis of Level of Service on Tallahassee Roadway Segments

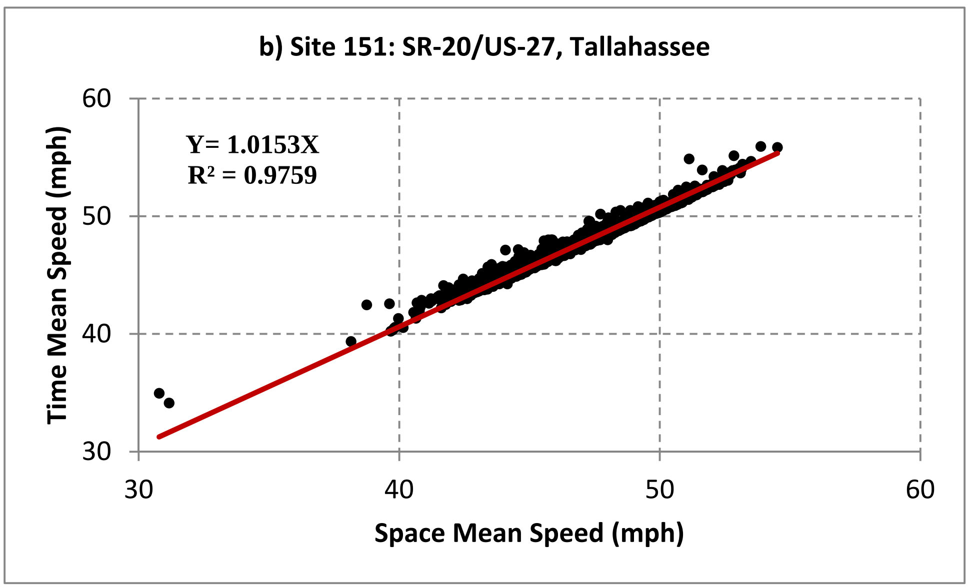
Prediction Method	Segment	Speed Limit, *mph*	Free Flow Speed, *mph*	Cycle Length, *sec*	g/C ratio	Control Delay, *sec*	Intersection Approach LOS	Speed, *mph*	Segment LOS
FDOT		45	50	150	0.40	35.65	D	33.28	B
Best fit		45	52	150	0.40	35.65	D	33.28	B
HCM		45	44	150	0.40	35.65	D	30.8	C
Field FFS	Apalachee Pkwy	45	51	150	0.40	35.65	D	33.28	B
FDOT		45	50	150	0.45	36.58	D	24.19	C
Best fit		45	50	150	0.45	36.58	D	24.19	C
HCM		45	44	150	0.45	36.58	D	22.86	D
Field FFS	S Adams	45	52	150	0.45	36.58	D	24.20	C
FDOT		40	45	140	0.50	38.42	D	21.03	D
Best fit		40	46	140	0.50	38.42	D	21.03	D
HCM		40	41	140	0.50	38.42	D	19.73	D
Field FFS	W. Pensacola	40	47	140	0.50	38.42	D	21.24	D
FDOT		30	35	130	0.45	35.75	D	23.15	C
Best fit		30	36	130	0.45	35.75	D	25.85	C
HCM		30	36	130	0.45	35.75	D	25.85	C
Field FFS	N Macomb St	30	37	130	0.45	35.75	D	26.45	C
FDOT		35	40	140	0.55	37.30	D	30.78	C
Best fit		35	42	140	0.55	37.30	D	34.12	B
HCM		35	40	140	0.55	37.30	D	30.48	C
Field FFS	Lake Bradford	35	43	140	0.55	37.30	D	34.78	B
FDOT		35	40	160	0.50	35.50	D	33.42	B
Best fit		35	41	160	0.50	35.50	D	34.62	B
HCM		35	38	160	0.50	35.50	D	28.72	C
Field FFS	Thomasville Rd	35	42	160	0.50	35.50	D	35.92	B
FDOT		35	40	160	0.55	36.30	D	28.35	C
Best fit		35	42	160	0.55	36.30	D	29.85	C
HCM		35	40	160	0.55	36.30	D	28.35	C
Field FFS	Thomasville Rd	35	40	160	0.55	36.30	D	28.35	C
FDOT		35	40	160	0.45	34.10	C	28.10	C
Best fit		35	41	160	0.45	34.10	C	29.70	C
HCM		35	36	160	0.45	34.10	C	24.90	D
Field FFS	Tennessee St	35	43	160	0.45	34.10	C	31.10	C

FDOT	Blair Stone Rd	30	35	148	0.45	36.20	D	18.60	D
Best fit		30	36	148	0.45	36.10	D	19.70	D
HCM		30	37	148	0.45	36.10	D	19.90	D
Field FFS		30	37	148	0.45	36.10	D	19.90	D
FDOT	Blair Stone Rd	35	40	148	0.50	36.60	D	30.90	C
Best fit		35	41	148	0.50	36.60	D	30.70	C
HCM		35	39	148	0.50	36.60	D	29.40	C
Field FFS		35	44	148	0.50	36.60	D	34.50	B
FDOT	Orange Ave	35	40	130	0.35	37.10	D	30.60	C
Best fit		35	41	130	0.35	37.10	D	31.70	C
HCM		35	39	130	0.35	37.10	D	30.30	C
Field FFS		35	43	130	0.35	37.10	D	23.50	C
FDOT	Tharpe St	30	35	150	0.45	38.50	D	18.00	D
Best fit		30	36	150	0.45	38.50	D	19.80	D
HCM		30	37	150	0.45	38.50	D	18.90	D
Field FFS		30	34	150	0.45	38.50	D	17.30	D
FDOT	Tennessee St	30	35	160	0.41	35.00	C	21.60	B
Best fit		30	37	160	0.41	35.00	C	25.70	B
HCM		30	37	160	0.41	35.00	C	25.70	C
Field FFS		30	37	160	0.41	35.00	C	25.70	B
FDOT	N Monroe St	25	30	150	0.41	34.20	C	17.80	D
Best fit		25	31	150	0.40	34.20	C	17.70	D
HCM		25	33	150	0.40	34.20	C	18.70	D
Field FFS		25	32	150	0.40	34.20	C	18.20	D
FDOT	S Monroe St	35	40	150	0.40	38.30	D	25.20	C
Best fit		35	41	150	0.40	38.30	D	25.90	C
HCM		35	38	150	0.40	38.30	D	20.50	D
Field FFS		35	41	150	0.40	38.10	D	25.90	C
FDOT	Paul Russel Rd	30	35	150	0.44	32.10	C	22.10	D
Best fit		30	36	150	0.44	32.10	C	22.30	D
HCM		30	34	150	0.44	32.10	C	21.30	D
Field FFS		30	36	150	0.44	32.10	C	22.30	D
FDOT	Capital Circle NE	45	50	160	0.41	33.50	C	37.20	B
Best fit		45	52	160	0.41	33.50	C	38.70	B

HCM		45	44	160	0.41	33.50	C	32.00	C
Field FFS		45	52	160	0.41	33.50	C	38.70	B
FDOT	Capital Circle NE	45	50	160	0.41	34.40	C	35.40	C
Best fit		45	52	160	0.41	34.40	C	36.50	C
HCM		45	43	160	0.41	34.40	C	29.60	D
Field FFS		45	52	160	0.41	34.40	C	36.50	C
FDOT	Miccosukee Rd	35	40	130	0.45	33.50	C	24.20	C
Best fit		35	41	130	0.45	33.50	C	24.60	C
HCM		35	39	130	0.45	33.50	C	23.40	C
Field FFS		35	41	130	0.45	33.50	C	24.60	C
FDOT	Miccosukee Rd	30	35	130	0.48	34.30	C	17.70	D
Best fit		30	36	130	0.48	34.30	C	19.90	D
HCM		30	36	130	0.48	34.30	C	19.90	D
Field FFS		30	36	130	0.48	34.30	C	19.90	D

APPENDIX F – SMS VS. TMS PLOTS


a) Site 266: SR-90, Miami
Y = 1.0237X
R² = 0.9812
Time Mean Speed (mph)
Space Mean Speed (mph)
20
30
40
50
60
70


b) Site 151: SR-20/US-27, Tallahassee
Y= 1.0153X
R² = 0.9759
Time Mean Speed (mph)
Space Mean Speed (mph)
30
40
50
60

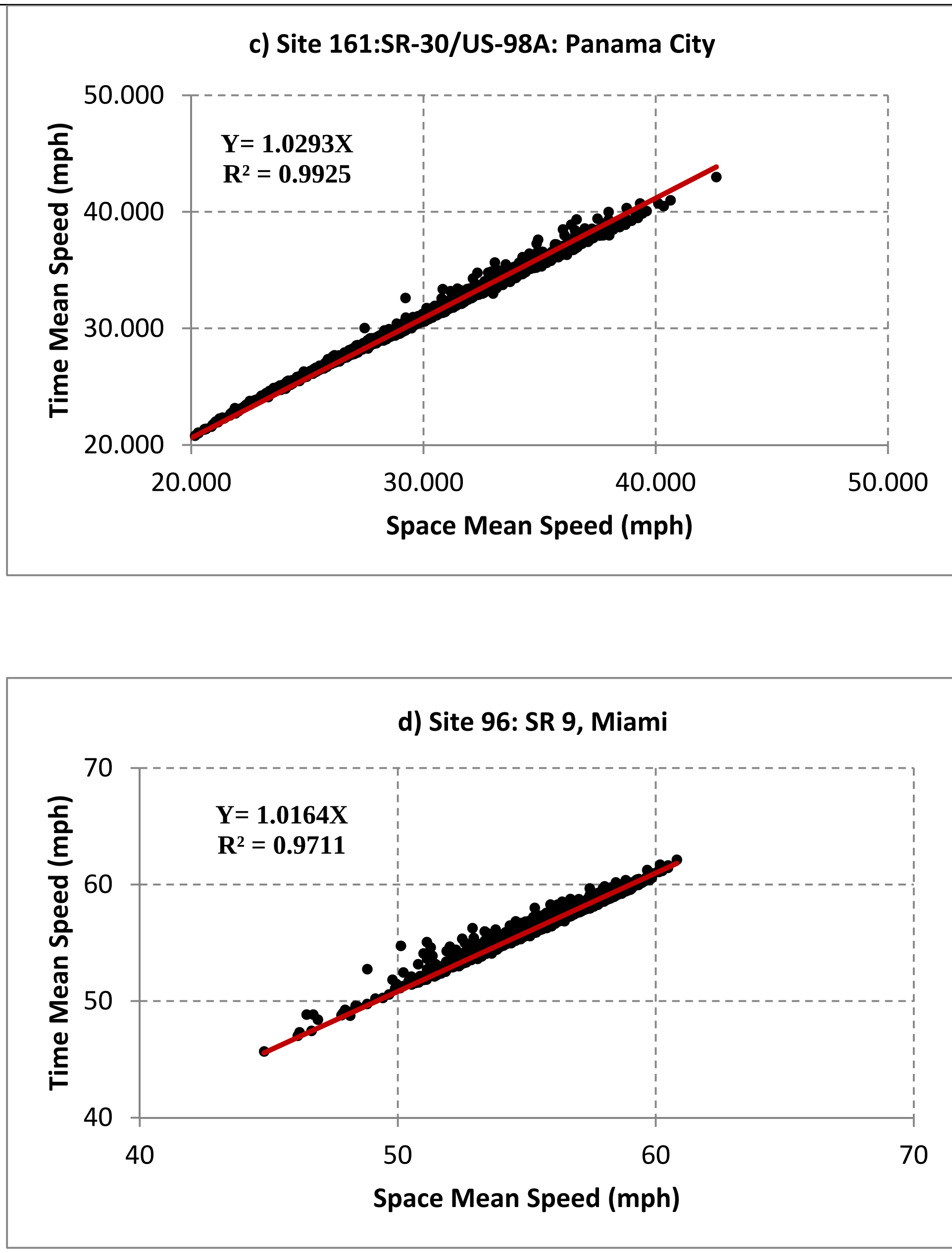
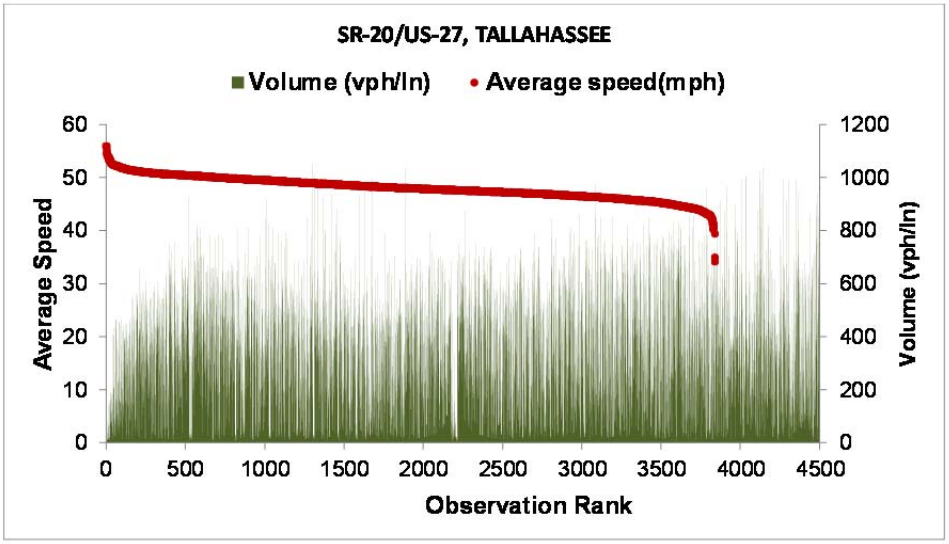


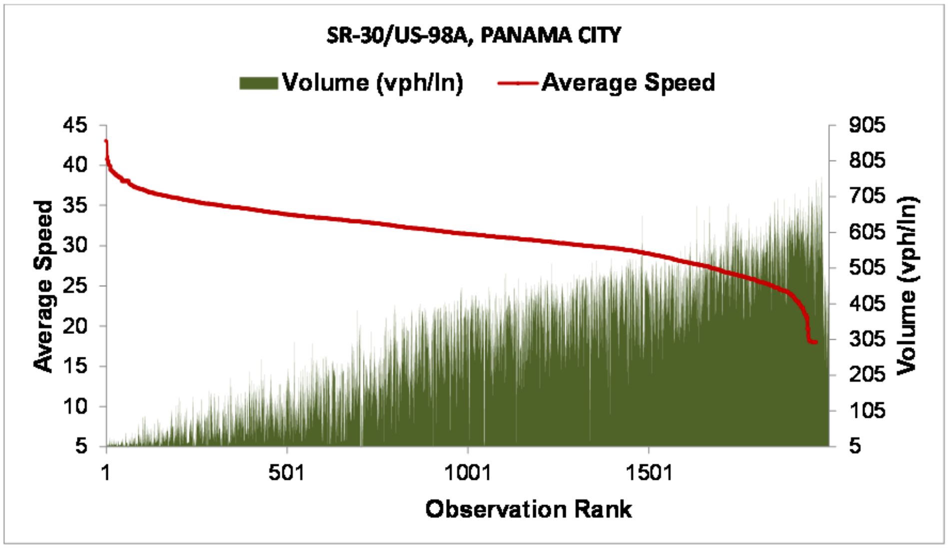
FIGURE F.1. Plots of Space Mean Speed against Time Mean Speed

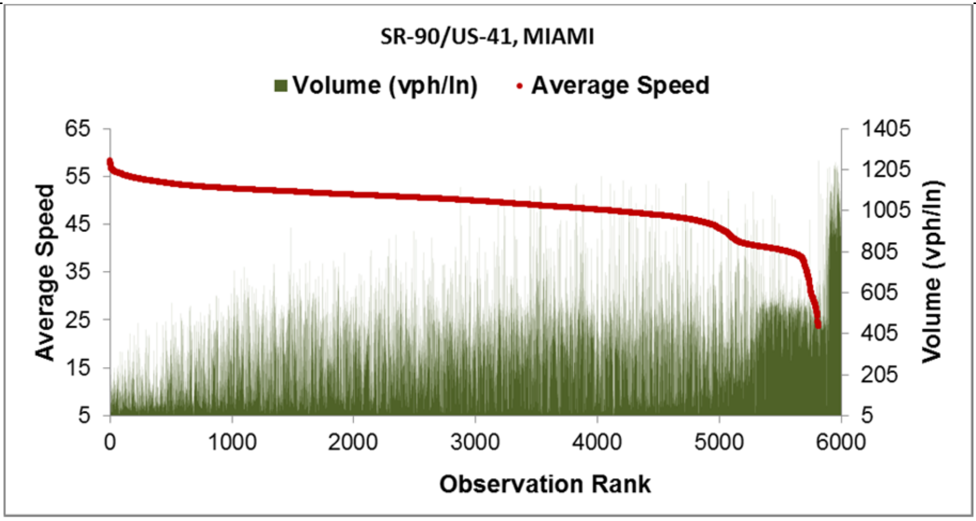
APPENDIX G – TTMS FREE FLOW SPEED EXTRACTION

Extraction of segment Free-flow Speed from TTMS data set

1. Go to FTYPE column. Filter out FTYPE 2, 3, and 4 (Non-freeway facilities).
2. Separate information for each segment by creating workbook/worksheet for every segment
3. Take out Saturdays, Sundays, and Holidays and night time observations.
4. Sort the data in increasing order of speed.
5. Create another column for observation rank.
6. Plot both speed and volume versus observation rank on the same graph. Put speed on primary vertical axis and volume on secondary vertical axis.
7. Speed should be decreasing with increasing volume, and observation rank for well behaving segments.
8. The observed free – flow speed should the maximum speed when volume is minimal.


SR-20/US-27, TALLAHASSEE
Volume (vph/ln)
Average speed(mph)
Average Speed
Volume (vph/ln)
Observation Rank
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
0
500
1000
1500
2000
2500
3000
3500
4000
4500


SR-30/US-98A, PANAMA CITY
Volume (vph/ln)
Average Speed
Average Speed
Volume (vph/ln)
Observation Rank
5
10
15
20
25
30
35
40
45
5
105
205
305
405
505
605
705
805
905
1
501
1001
1501



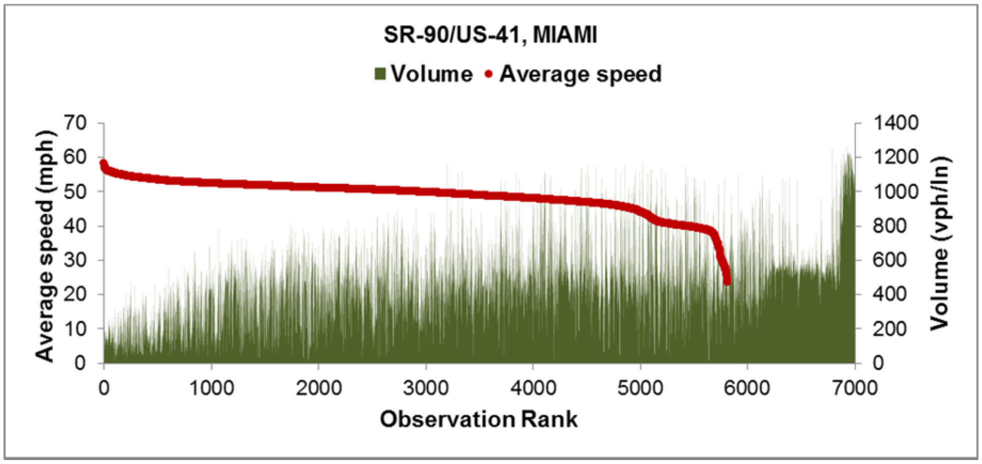


FIGURE G.1. Plots of Speed-Volume Relationship from a selected TTMS