Twenty-Four Hour Peaking Relationship to Level of Service and Other Measures of Effectiveness

Final Report

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by

Ren Moses, Ph.D., P.E.
Department of Civil Engineering
FAMU-FSU College of Engineering
2525 Pottsdamer Street, Room 129
Tallahassee, FL 32310

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16. Abstract

Transportation planners and traffic engineers are increasingly interested in traffic analysis tools that analyze demand profiles and performance that go beyond analysis of the traditional peak hours and extend the analysis to other hours of the day. The primary objective of this research was to utilize historical traffic data from telemetered traffic monitoring sites (TTMS) to analyze 24-hour peaking relationship to various performance measures. Data from 26 TTMS sites located in large urbanized areas showed that the 99th percentile hourly volume was close to 2,000 vehicles per hour per lane on limited access facilities, i.e., freeways, toll roads, and HOV lanes. The 99th percentile hourly volume did not reach 1,000 vehicles per hour per lane on divided and undivided arterial roads. Congestion levels in a 24-hour period were analyzed using methodology contained in the 2012 Urban Mobility Report by Texas A&M Transportation Institute in which speed reduction factor (SRF) is calculated by dividing the average combined peak period speed by the free-flow speed. The results of congestion level analysis using permanent count stations data showed that on limited access facilities, severe congestion occurs in only 4 hours of the day, moderate congestion in 10 hours of the day, and relatively free flowing conditions in 10 hours of the day. For divided and undivided arterial roads, severe congestion occurs in 5 hours of the day, moderate congestion in 11 hours and relatively free flowing operations in 8 hours of the day. The results of the linear models for the peak volumes developed from the hourly data analyzed by lane showed that area type was not a significant predicting variable. Gaussian models developed for weekday hourly volumes were able to reasonably replicate the peaking profiles with R-squared values higher than 0.95 for all facility types. The Gaussian hourly volume models can also be used to predict future traffic volumes if the characteristics of future trip making are known. Such characteristics may be used to modify the amplitude, centroid, width and number of peak periods. Estimates of future change in traffic volumes can be obtained by multiplying the average function of the hourly volume by elasticity parameter and the fraction of the change in cost of travel. Estimation of future change in traffic volume can be used by transportation planners to determine if the peak period is expected to spread.

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EXECUTIVE SUMMARY

Background

There is a paradigm shift in modeling of travel patterns and evaluation of performance of the surface transportation system. Transportation planners and traffic engineers are increasingly interested in traffic analysis tools that analyze demand profiles and performance that go beyond analysis of the traditional peak hours and extend the analysis to other hours of the day. The need for improved travel modeling techniques is brought about by the continued growth of congestion in urban areas that is resulting in spreading of peak commuting hours. Transportation planners have traditionally been concerned with travel characteristics occurring during the peak hours of the day (i.e., 7-9 a.m. morning peak and 4-6 p.m. evening peak). Traffic volumes and speeds for level of service analysis are determined for the peak periods only. New projects are then hatched for the purpose of improving level of service during the traditional peak commuting hours.

While a transportation facility – intersection, freeway, tollway, arterial, collector, etc. – might be showing distress during peak analysis periods based on a limited set of performance measures, the facility might be serving the public well during non-peak hours, particularly if the facility has multimodal functions. Thus, there is a need to investigate methodologies for evaluating peaking characteristics and travel conditions in all 24 hours of the day. Such methods may include peak hour to total volume ratios, link-based volume-to-capacity (v/c) ratios, and models that predicts hourly volumes based of prevailing ADTs. There is abundancy of historical data of hourly volumes and speeds which can be used for these purposes. Most departments of transportation around the country generally collects and archives such data.

Objectives

The primary objective of the research was to utilize historical traffic data from permanent traffic count stations or telemetered traffic monitoring sites (TTMS) to analyze 24-hour peaking relationship to various performance measures. The benefit of analyzing 24-hour period traffic characteristics is substantial. Understanding of the 24-hour peaking characteristics could support planning and engineering applications such as estimating reasonable operating conditions, calculating roadway throughput, determining the number of lanes, and other planning functions. Development of models to characterize 24-hour volume variation is important for planners because of insufficient resources to collect data on all possible combinations of facility types, area types, and speed limits.

Findings and Conclusions

The analysis of 24-hour variation of volume and speeds was conducted by area type, facility type, and speed limit of the roadway. The area types were rural, urban, urbanized, and large urbanized. The facility types were freeways & expressways; divided arterials; undivided arterials; collectors; one-way facilities; ramps; toll roads; and HOV lanes. The speed limit ranged from 30 mph to 70 mph in increments of 5 mph. Data collected by the TTMS from 1996 to 2012 were used to determine 24-hour variation and peaking characteristics on roadways categorized by area type, facility type, and prevailing speed limit at the TTMS site. Because peak spreading is largely a phenomenon occurring in large urbanized areas, the research effort concentrated in these areas.

Data from 26 TTMS sites located in large urbanized areas showed that the 99th percentile hourly volume was close to 2,000 vehicles per hour per lane on limited access facilities, i.e., freeways; toll roads, and HOV lanes. The 99th percentile hourly volume did not reach 1,000 vehicles per hour per lane on divided and undivided arterial roads.

Congestion levels in a 24-hour period were analyzed using methodology used by 2012 Urban Mobility Report in which speed reduction factor (SRF) is calculated by dividing the average combined speed of a particular period by the prevailing free-flow speed of the facility. Based on SRF, three congestion levels were determined: Level 1- relatively free flowing conditions; Level 2 – moderate congestion; and Level 3 – severe congestion with significant reduction of speed within the hour. The results in Table 1 show the number of hours (in a 24-hour period) experiencing a particular congestion level and the number of vehicles per lane that are caught in each congestion level. The results show that in most facilities severe congestion occurs less than 50% of the 24-hour period although the number of vehicles per lane experiencing severe congestion tend to be higher. The reliability of the facility can be related to SRFs and intensity of traffic congestion. For instance, the results of the congestion levels on different facilities can be used by transportation professionals to understand the reliability of the trips that are made on similar facilities.

TABLE 1. Congestion Level Prevalence in Urbanized Facilities

Facility Type	Speed Limit	% (Average Number of Hours in a Day)			Number of Vehicles per lane*		
		1	2	3	1	2	3
Undivided	30	16.7% (4)	45.8% (11)	37.5% (9)	40	1,098	1,393
Undivided	35	4.2% (1)	37.5% (9)	58.3% (14)	33	947	4,171
Undivided	45	29.2% (7)	50.0% (12)	20.8% (5)	545	2,830	1,714
Undivided	50	16.7% (4)	54.2% (13)	29.2% (7)	175	3,343	2,936
Divided	35	16.7% (4)	41.7% (10)	41.7% (10)	109	1,956	4,699
Divided	40	33.3% (8)	37.5% (9)	29.2% (7)	420	2,509	2,555
Divided	45	16.7% (4)	50.0% (12)	33.3% (8)	512	3,925	4,861
Divided	50	29.2% (7)	41.7% (10)	29.2% (7)	846	4,295	4,485
Divided	55	29.2% (7)	37.5% (9)	33.3% (8)	279	1,974	2,458
Freeway	55	8.3% (2)	37.5% (9)	54.2% (13)	195	5,771	12,977
Freeway	65	12.5% (3)	37.5% (9)	50.0% (12)	523	8,507	13,188
HOV/HOT	65	25.0% (6)	41.7% (10)	33.3% (8)	676	6,860	7,933
Toll	60	29.2% (7)	50.0% (12)	20.8% (5)	1,073	3,245	2,404
Toll	65	0.0% (0)	50.0% (12)	50.0% (12)	0	7,863	12,280

*These are the total number of vehicles that were caught in the corresponding congestion level.

Analysis of the 2010 National Household Travel Survey (NHTS) database provided information on the most recent travel patterns and trip-making behavior for residents in Florida's large urbanized metropolitan areas which are Jacksonville, Miami-Fort Lauderdale-Pompano Beach, Orlando-Kissimmee and Tampa-St. Petersburg-Clearwater. Table 2 shows the peaking characteristics for work trip (summation of only home-based work trips and nonhome-based work trips) and all trips (summation of all trip types) in Florida large urbanized areas. The data in Table 2 reveal that the highest proportion of work trips occur during the critical morning peak. The evening critical peak has lower proportion of work related trips compared to morning peak but the post peak shoulder is broader than the morning post peak shoulder. This is an indication of a more extended peak period during the evening compared to morning peak period. Shoulder peak times are included in this analysis due to their importance in the quantification of the peak spreading phenomenon.

TABLE 2. Peak and Peak-Shoulders Analysis

Time Period	Peak Position	Duration	All Trips	Work Trips
AM	Pre-peak Shoulder	6:00-7:00	5%	9%
	Critical Peak	**7:00-9:00**	**13%**	**32%**
	Post-peak Shoulder	9:00-10:00	6%	4%
Mid-Day	Inter Peak	10:00-14:00	25%	8%
PM	Pre-peak Shoulder	14:00-15:00	8%	4%
	Critical Peak	**15:00-18:00**	**24%**	**20%**
	Post-peak Shoulder	18:00-19:00	8%	8%
Night	Off Peak	19:00-6:00	11%	15%

Knowledge of the variations of traffic trips before and after the peak hour can help to determine the length of analysis periods on urban roads. The shoulder hour volumes has a tremendous effect on the peak operations of the facilities as they occur on the congestion build up period. This is the period where the roadway may operate at near capacity or a bottleneck may be activated. Inclusion of the shoulder hours in the analysis periods would help the transportation practitioners to realistically plan for operational improvement strategies. Users of the NHTS analysis results should be aware of the limitations of the data used. The NHTS data do not represent all sample households and all person within the sampled households, a phenomenon called under-coverage. NHTS is aware of this under-coverage in the data.

The results of the linear models for the peak volumes developed from the hourly data collected by lane showed that area type was not a significant predicting variable. Similarity between 24-hour peaking profiles in urban, urbanized and large urbanized areas might have explained the cause of statistical insignificance.

The observed 24-hour peaking profiles were modeled using probabilistic (Gaussian) functions. Gaussian models were found to model the weekday hourly volumes by reasonably replicating the peaking profiles with R-squared values higher than 0.95 for all facility types. The Gaussian hourly volume model can be used to predict future traffic volumes if the characteristics of future trip making are known. Such characteristics may be used to modify or calibrate the amplitude, centroid, width and number of peak periods.

The Gaussian models were also related to the demand elasticity to determine future traffic. Estimates of future change in traffic volumes can be obtained by multiplying the average function of the hourly volume by elasticity parameter and the fraction of the change in cost of travel. Estimation of future change in traffic volume can be used by transportation planners to determine if the peak period is expected to spread in the future.

The hourly volumes models developed in this study have some limitations. These models do not represent actual travel demand on the facility during peak periods because they are based on traffic counts. Experience shows that when demand to use a transportation facility exceeds the capacity of the facility, some trips may divert to other routes, modes or destinations. TTMS data do not incorporate such trip diversions.

Benefits

The benefit of analyzing 24-hour period traffic characteristics is substantial. Understanding of the 24-hour peaking characteristics could support planning and engineering applications such as estimating reasonable operation conditions, calculating roadway throughput, and determining the number of lanes. The 2010 National Household Travel Survey (NHTS) analysis results can help transportation practitioners to plan for operational improvement strategies not only during the peak hour but also during shoulder hours. The results of traffic congestion level prevalence can inform practitioners and road users about trip reliabilities made on similar facilities in urban areas. The hourly volumes models developed in this research may be used by practitioners to effectively reconstruct traffic volume profiles on similar new roadways planned on urban areas or where existing data are missing on similar facilities.

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CHAPTER 1

INTRODUCTION

1.1 Background

There is a paradigm shift in modeling of travel patterns and evaluation of performance of the surface transportation system. Transportation planners and traffic engineers are increasingly interested in traffic analysis tools that analyze demand profiles and performance that go beyond analysis of the traditional peak hours and extend the analysis to other hours of the day. The need for improved travel modeling techniques is brought about by the continued growth of congestion in urban areas that is resulting in spreading of peak commuting hours. Transportation planners have traditionally been concerned with travel characteristics occurring during the peak hours of the day (i.e., 7-9 a.m. morning peak and 4-6 p.m. evening peak). Traffic volumes and speeds for level of service analysis are determined for the peak periods only. New projects are then hatched for the purpose of improving level of service during the traditional peak commuting hours.

While a transportation facility – intersection, freeway, tollway, arterial, collector, etc. – might be showing distress during peak analysis periods based on a limited set of performance measures, the facility might be serving the public well during non-peak hours, particularly if the facility has multimodal functions. Thus, there is a need to investigate methodologies for evaluating peaking characteristics and travel conditions in all 24 hours of the day. Such methods may include peak hour to total volume ratios, link-based volume-to-capacity (v/c) ratios, and models that predicts hourly volumes based of prevailing ADTs. There is abundancy of historical data of hourly volumes and speeds which can be used for these purposes. Most departments of transportation around the country generally collects and archives such data.

1.2 Nature of the Problem

Traditional peak period analysis measures of performance such as level of service (LOS) and annual average daily traffic (AADT) are widely used to analyze the performance of transportation facilities. However, these measures are not sufficient to capture hourly variation of traffic beyond the peak hour of analysis. For instance, the measures do not indicate the performance of the facility during shoulder and off-peak hours of operations. Furthermore, measures such as LOS do not show the distance, duration and depth of congestion which are important congestion dimensions in planning, designing, operating, and management of transportation systems. Traditional measures also do not answer questions regarding implications of peak spreading in travel forecasting and highway performance evaluation.

In order to capture the profile of traffic characteristics, historical data should be synthesized and analyzed. Enormous amount of traffic data is archived by transportation data agencies and traffic management centers. Analysis of archived data would help traffic analysts, transportation planners and decision makers answer questions such as hours of the day that are congested, extent of congestion on different facilities, and facilities that operate with similar traffic operating characteristics (from a macroscopic perspective). To answer such questions, there is a need to develop traffic characteristics models that can replicate existing traffic peaking characteristics and predict future peaking profiles.

1.3 Goal and Objectives

The overall goal of this project is to improve the systems planning process by developing traffic characteristic models for evaluating performance of highway systems on 24-hour basis. Consistent with this goal, the primary objective of the research is to analyze archival traffic data from telemetered traffic monitoring sites for the purpose of determining 24-hour peaking relationship to various performance measures. Understanding of the 24-hour peaking characteristics could support transportation planning and engineering applications such as estimating reasonable operating conditions, calculating roadway throughput, determining the number of lanes, etc. Development of models to characterize 24-hour volume variation is important for planners because of insufficient resources to collect data on all possible combinations of facility types, area types, and speed limits. Such models can be used to effectively reconstruct characteristics on similar facilities during planning of transportation investments.

1.4 Methodology

A comprehensive literature search was performed to uncover published and unpublished information related to methodologies for analyzing temporal and spatial variations of traffic flow and the measures of effectiveness used to assess highway performance. Special attention in the literature review process was directed at determining proposed mobility and reliability measures that are used by highway agencies in project analysis to establish appropriate policy actions, programs, and highway projects.

Historical traffic data used in this research project were obtained from the Statistics Office of the Florida Department of Transportation. The Statistics Office installs and maintains temporary and permanent count stations strategically placed at various locations on the state highway system. The data collected by electronic equipment installed at these stations include individual vehicle records composed of number of axles per vehicle, axle spacing, overall vehicle length, and operating speed. For our research purposes, the data that were acquired included distribution of operating speeds, hourly volumes, the annual average daily traffic (AADT), and classification of vehicles.

The analysis of data involved data reductions to check for completeness and consistency. Data with complete and consistent attributes were used to calculate descriptive statistics of multi-year by area type, facility type and facility size. Additionally, 24-hour volume profiles were developed to understand the daily variation of the traffic. A multi-year data was used to develop models for predicting the distribution of hourly volumes in future years. Traffic volume models were compared with data from the National Household Travel Survey (NHTS) and Highway Economics Requirement System (HERS) model.

1.5 Report Format

This report is organized as follows:

Chapter 1—Introduction: This chapter discusses the project background, need for research, research goals, and methodology used.

Chapter 2—Literature review: This chapter provides an overview of the studies and reports that were published related to volume variation and peaking characteristics. The chapter gives an overview of commuting trends in the United States and the resulting daily travel patterns. Additionally, the chapter summarizes the results of literature search on performance measures, peak spreading characteristics, peak models and techniques used to describe peak spreading.

Chapter 3—Acquisition and Analysis of TTMS Data: This chapter discusses data collection process and data reduction process. The chapter presents the results of descriptive analysis of volume and speed data by facility type and area type. Also included in the chapter is the summary of daily variations of traffic characteristics for different facility types and area types.

Chapter 4—Prediction of Hourly Volume Variation: This chapter analyzes and models traffic peaking characteristics in urbanized areas. Rural areas were excluded in the analysis based on the results from Chapter 4 that show minimal to no congestion on facilities located in these areas. The development of linear peak volume model and Gaussian weekday hourly volume models is covered in this chapter. The chapter further discusses trip timing behavior based on data collected from the National Household Travel Survey (NHTS) and relationship with Highway Economics Requirement System (HERS) model.

Chapter 5—Conclusions and Recommendations: This chapter concludes the research study and highlights recommendations for enhancement of the models developed in Chapter 4.

Appendices: Appendices are attached to expand upon the results discussed in Chapter 3 and Chapter 4.

CHAPTER 2

LITERATURE REVIEW

2.1. Overview

As demand on transportation networks continues to grow and the expansion of transportation infrastructure lags behind, it is expected that congestion will continue to grow as well. This is particularly noticeable in urban areas where highway traffic is dominated by regular commuters who tend to use highways for home-to-work and work-to-home trips during preferred times in the mornings and afternoons. Figure 2.1 which is adapted from NCHRP 187 (1978) illustrates this phenomenon. Transportation planners continue to grapple with a number of issues depicted in Figure 2.1:

- how long are the morning and afternoon peak periods?
- what proportion of traffic travels during the peak periods?
- what type of trips use the peak periods?
- is the peak period spreading or expected to spread in the future?
- what are the implications of peak spreading in travel forecasting and highway performance evaluation?
- how do all these issues shape transportation policy options and infrastructure investment policies?

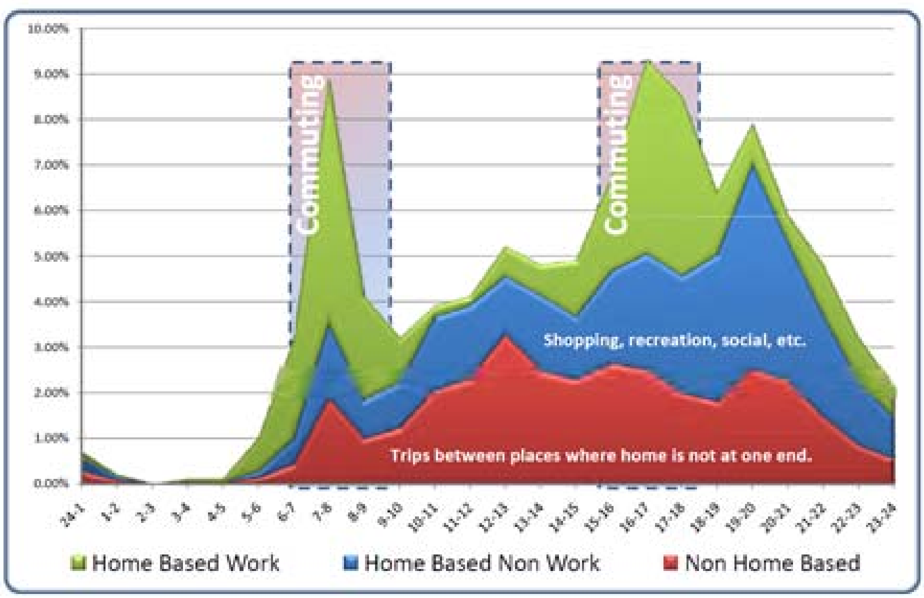

FIGURE 2.1 Hourly Traffic Distribution on a Typical Weekday

Allocation of resources to tackle congestion requires deep understanding of issues raised above, particularly the peak spreading phenomenon. Consistent with the objectives of this project, a detailed literature review was conducted to determine state-of-the-art and the state-of-practice in transportation planning to deal with peak-spreading characteristics based on 24-hour variation of traffic. The literature review focused on historical commuting trends in the United States, factors affecting peak spreading, data needs, and modeling of peak spreading. The following sections discuss in detail the findings of the literature review undertaking.

2.2. Commuting Trends in the United States

Although in the United States commutes make up less than 20 percent of all generated trips, they play a unique role within the mix of overall trips, as was seen in Figure 2.1, by determining peak travel demand across transportation systems. Transportation planners generally seek to understand and analyze commuting information to guide transportation improvement strategies, predict future travel demand, and evaluate how well the transportation system is performing in serving the traveling public.

The United States Census Bureau conducts annual statistical survey known as "American Community Survey (ACS)" which is aimed at giving communities the information they need to plan investments and services. The recently published 2009 American Community Survey revealed the following:

- Over three-quarters of the nation's workers drove alone to work,
- Workers took an average of 25.1 minutes to get to work, and
- Suburban workers drove alone at a rate of 81.5 percent, compared with 72.1 percent for workers living inside of a principal city.

The American Community Survey also asked respondents when they departed home to go to work. This information plays an integral role in the regional transportation planning process by contributing to an understanding of traffic flow patterns on the nation's roads and public transportation infrastructure. The results of the 2009 American Community Survey related to this question are displayed in Table 2.1.

TABLE 2.1 Time Leaving Home to Go to Work

Time Period	Total Workers	Percent Distribution
12:00 a.m. to 4:59 a.m.	5,209	3.8
5:00 a.m. to 5:29 a.m.	4,647	3.4
5:30 a.m. to 5:59 a.m.	6,420	4.6
6:00 a.m. to 6:29 a.m.	11,408	8.2
6:30 a.m. to 6:59 a.m.	13,620	9.8
7:00 a.m. to 7:29 a.m.	19,536	14.1
7:30 a.m. to 7:59 a.m.	17,686	12.8
8:00 a.m. to 8:29 a.m.	14,565	10.5
8:30 a.m. to 8:59 a.m.	7,425	5.4
9:00 a.m. to 9:59 a.m.	8,287	6.0
10:00 a.m. to 10:59 a.m.	3,705	2.7
11:00 a.m. to 11:59 a.m.	1,747	1.3
12:00 p.m. to 3:59 p.m.	9,270	6.7
4:00 p.m. to 11:59 p.m.	9,150	6.6

Table 2.1 shows that over half of the nation's workers left their homes for work between 6:00 a.m. and 8:59 a.m. The 30-minute period with the highest percentage of departures (14.1 percent) occurred between 7:00 a.m. and 7:29 a.m. Less than 25 percent of the nation's workers left for work between 9:00 a.m. and 11:59 p.m. The survey results in Table 2.1 mirrors the same temporal distribution on highways as was shown in Figure 2.1 in which the morning peak commuting time occurred between 7 a.m. and 9 a.m. The results in Table 2.1 cannot be translated into peak evening commuting time because workers were not asked when they leave their work places to go home.

2.3. Highway Performance Evaluation

Evaluation of performance of a transportation system, and indeed forecasting future travel conditions, requires using principles of demand and supply in which demand is represented by traffic volume, i.e., the number of persons desiring roadway services per unit of time while supply is represented by roadway capacity which is known to be influenced by a number of geometric, traffic, and control factors. Thus, transportation planners tend to quantify current and future demand and relate the demand to practical capacity in order to measure performance or predict future performance characteristics.

2.3.1 *Quantifying Demand*

Transportation demand refers to the amount and type of travel people would choose under specific conditions, taking into account factors such as the quality of transport options available and their prices. Understanding demand is important for highway performance evaluation, travel forecasting and analysis of alternative transportation improvement actions. A number of studies have indicated that there are many factors influence one's decision to make a trip, what mode to use, and which route to take. Changes to these factors, due to trends or by design, can affect travel activity and therefore costs and problems such as congestion, accidents and pollution emissions. Table 2.2 lists various factors that can affect travel demand.

TABLE 2.2 Factors influencing travel demand.

Demographics	Economics	Prices	Transport Options	Service Quality	Land Use
Number of people (residents, employees and visitors).	Number of jobs	Fuel prices and taxes	Walking	Relative speed and delay	Density
Incomes	Incomes	Vehicle taxes & fees	Cycling	Reliability	Mix
Age/lifecycle	Business activity	Road tolls	Public transit	Comfort	Walkability
Lifestyles	Freight transport	Parking fees	Ridesharing	Safety and security	Connectivity
Preferences	Tourist activity	Vehicle insurance	Automobile	Waiting conditions	Transit service proximity
		Public transport fares	Taxi services	Parking conditions	Roadway design
			Telework	User information	
			Delivery services	Social status	

2.3.2 *Capacity Determination*

The 2010 Highway Capacity Manual defines capacity as the maximum hourly flow rate at which vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions (Transportation Research Board, 2010). The manual makes additional important points related to this definition:

- The prevailing roadway, traffic, and control conditions should be reasonably uniform for any section of the facility analyzed.
- The capacity definition assumes good weather, good pavement conditions, and no incidents exist.
- Capacity normally refers to a point of uniform segment of a facility. The point or segment with the poorest operating conditions often determines the overall level of service of the facility.
- Capacity is defined on the basis of reasonable expectancy – that is, the rate of flow that can be repeated on facilities of relatively similar geometrics, traffic, and driver characteristics.

Transportation planners and engineers generally distinguish between base capacity and practical capacity. The base capacity represents the capacity of the facility, assuming that there are no heavy vehicles in the traffic stream and that all drivers are regular users of the segment. On uninterrupted flow facilities such as freeways, base capacity is related to the prevailing free flow speed. Table 2.3 shows base capacity values suggested by the Highway Capacity Manual for use in freeway analysis.

TABLE 2.3 Base Capacity for Freeway Segments

Free Flow Speed (mph)	Base Capacity (pc/hr/lane)
75	2,400
70	2,400
65	2,350
60	2,300
55	2,250

The base capacity values displayed in Table 2.3 are maximum flow rates that can be attained only under base conditions of represented by adequate lateral clearance, 12-foot lanes, level terrain. When these geometric characteristics are less than ideal, free flow speed is negatively affected resulting in decreased capacity. Researchers have long hypothesized (and field data has proved) that there is a decaying relationship between speed and traffic volume. Figure 2.2 shows a graph based on field data from a TTMS site on Interstate 95 in Pompano Beach, Florida. The site had three lanes in one direction with a speed limit of 65 MPH. The data were average hourly volumes and average hourly speeds collected for every hour of the day for a period beginning July 1, 2010 to June 30, 2011. It is clear that the observed maximum flow rate on Figure 2.2 will represent practical capacity. Although the volumes in Figure 2.2 have not been converted to equivalent passenger cars per hour per lane, the practical capacity will be lower than base capacities suggested in Table 2.3.

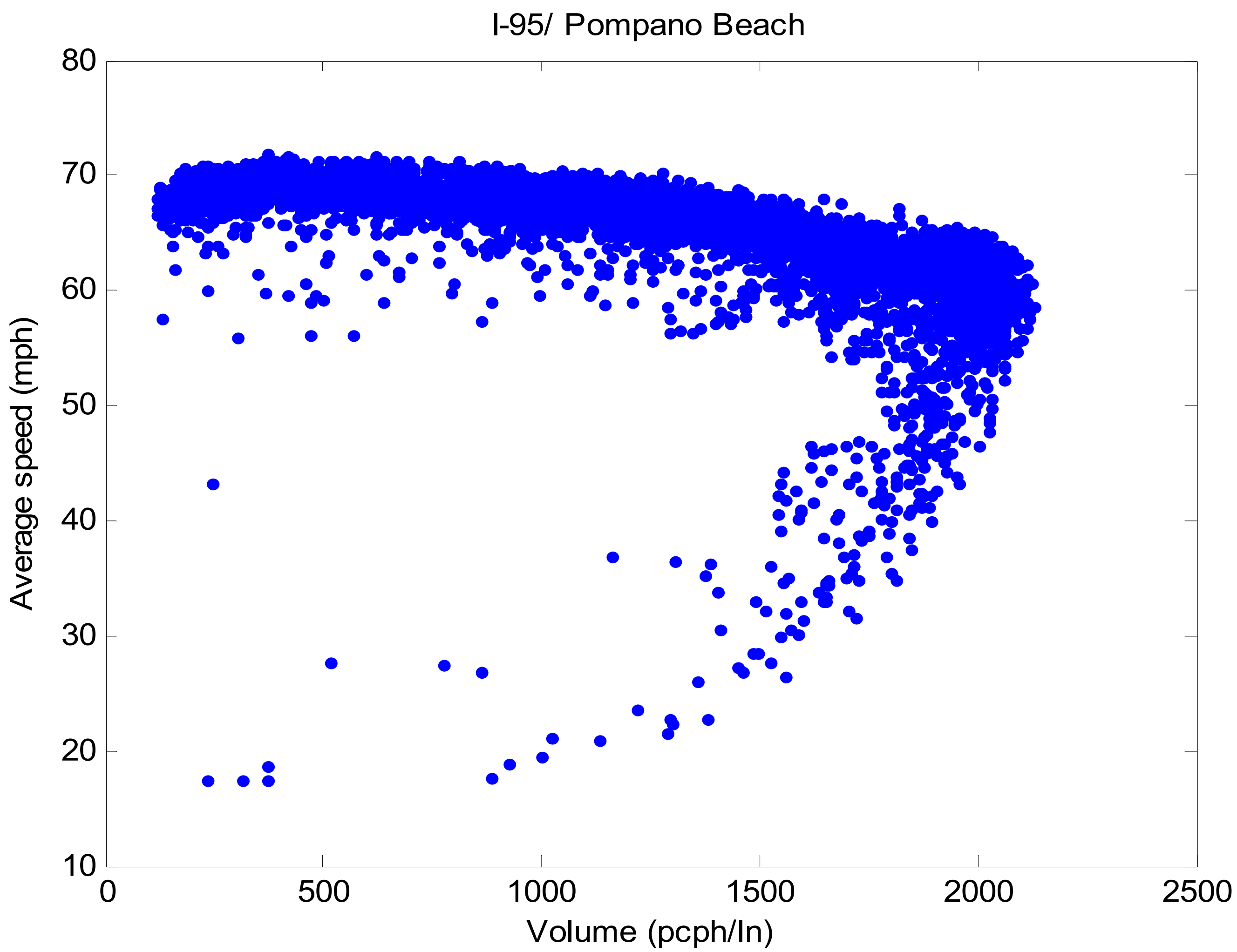

FIGURE 2.2 Variation of Volume with Speed at a TTMS Site

2.3.3 *Measures of Effectiveness*

Transportation professionals understand that traffic flow has temporal and spatial characteristics. Thus, measuring performance of a transportation system requires developing measures that account for the time aspect and geographic extent of congestion—which Lomax *et al.* (1997) defines as the travel time or delay in excess of that normally incurred under light or free flow travel conditions. Table 2.4 reproduced from Lomax *et al.* (1997) shows the dimensions that can be used to measure system's performance.

Lomax *et al.* provides the following definitions in relation to terms in shown in Table 2.4.

Travel rate = Travel time ÷ Segment length
Delay rate = Actual travel rate – Acceptable travel rate
Delay ratio = Delay rate ÷ Actual travel rate

TABLE 2.4 System performance dimensions

Dimension	System type		
	Single roadway	**Corridor**	**Areawide network**
Duration (e.g., amount of time system is congested)	Hours facility operates below acceptable speed	Hours facility operates below acceptable speed	Set of travel time contour maps; "bandwidth" maps showing amount of congested time for system sections
Extent (e.g., number of people affected or geographic distribution)	% or amount of congested VMT or PMT; % or lane-miles of congested road	% of VMT or PMT in congestion; % or miles of congested road	% of trips in congestion; person-miles of person-hours of congestion; % or lane-miles of congested road
Intensity (e.g. level or total amount of congestion)	Travel rate; delay rate; minute-miles; lane-mile hours	Average speed or travel rate; delay per PMT; delay ratio	Accessibility; total delay in person-hours; delay per person; delay per PMT
Reliability (e.g. variation in the amount of congestion)	Average travel rate or speed ± standard deviation; delay ± standard deviation	Average travel rate or speed ± standard deviation; delay ± standard deviation	Travel time contour maps with variation lines; average travel time ± standard deviation; delay ± standard deviation

Researchers have over the years forecasted travel time based on demand and supply principles. In other words, researchers have related deterioration of travel time as a function of volume-to-capacity ratio during a particular time frame or at a particular location. The most famous equation for this purpose was developed by the Bureau of Public Roads (BPR) and takes the form:

$$t = t_0\left[1 + \propto (v/c)^{\beta}\right] \qquad 2.1$$

where t_0 is the travel time in free flow conditions, c is the estimated link capacity, v is the prevailing volume on the link, and t is the predicted travel time based on the input values and calibrated parameters α and β.

2.4. Congestion and Peak Spreading Characteristics

With the passing of federal legislations such as Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Clean Air Act, more complex and accurate traffic operations and demand modeling approaches are needed in order to narrow the gap between state-of-practice and state-of-art transportation systems analyses. The extent to which the gap is narrowed depends on the availability of workforce, expertise, and financial capital – factors which have posed challenges among state agencies and metropolitan planning organizations (MPO). The need for understanding the occurrence of peak spreading cannot be overemphasized. Consider the following facts:

i. failure to capture peak spreading might lead to inaccurate prediction of traffic volumes, speeds, and other traffic metrics necessary for planning and operational studies,

ii. the shift from funding of new highway construction to upgrading, rehabilitating, and incremental improvements to the existing infrastructure requires more accurate modeling of the benefits that can be expected from these less substantial improvements, and
iii. increasing capacity may not alleviate the low speeds associated with congestion. The increased capacity can induce travelers who had previously waived their trips or started their trips earlier or later than desired to shift their travel back into the heart of the peak period, causing the peak hour volume to spike back up to congestion levels.

Changes in policies, growing congestion, and deficiency of land for right-of-way in urban areas dictate exploration of other options to improve transportation systems, different from expansion or new constructions. Transportation professionals are in search of more precise peak period and peak hour estimates, as these are periods when intolerable congestion and emissions are most prevalent. A conventional method used by MPOs and state agencies for predicting peak-hour link volumes and speeds has been to initially forecast link volumes on a daily basis and then apply a *K-factor* which converts daily volume to peak hour volume. Though this practice could provide representative average peak hour traffic volumes when applied on a network basis, the precision at link level has been extremely doubtful. This assertion is made by Loudon *et al*. (1988) who found out that peak-hour volume as a percentage of the daily volume was observed to vary widely throughout a network. This could be due to the likelihood that trips being made during the peak hour are characteristically distinct given all trips in the network. In other words, for all trips on the same link, characteristics of trips and the individuals making those trips have different attributes. In general, peak period models have been developed by creating peak period trip tables from the percentage of each trip type that falls within the peak period. However, Loudon *et al*. (1988) noted that a *K-factor* was still applied to the peak period to produce peak hour volume with no effort made to relate peaking characteristics to the anticipated level of congestion for the assignment of trips.

Understanding how travel behavior patterns in a congested transportation system change when capacity or congestion increases is vital when creating methods to produce better peak period and peak hour forecasts (Stopher, 1993). A common response of travelers to increasing congestion (particularly regular commuters) is to depart for work earlier or later than normally desired (with a similar response for the trip back home), to avoid peak congestion. This creates non-stationary traffic variability and peak-spreading. Bates *et al.* (1989) and Small *et al*. (1999) defined three distinct factors leading to traffic variability and peak-spreading. These factors include inter-day variability, inter-period variability, and inter-vehicle variability. Sources of such seasonal or day-to-day variation are regarded to be a result of demand fluctuations, traffic compositions, incidents, road construction, and weather conditions. There are also human factors that might cause traffic variability within a network. Such factors include personal driving preferences and responses to traffic control devices along a route, such as changeable message signs (CMS). From survey data, Abdel-Aty *et al*. (1995) found that traffic variability was the most important factor for route choice. Recognizing that changes in departure times are also a consequence of changes in congestion, Small *et al*. (1999) tried to fit an econometric model that treats scheduling considerations using preference survey data and calibrated the value of reliability in terms of reduction in travel time variation. Travelers' response to peak-hour congestion by changing their departure times, causes reduction in the proportion of peak hour to peak period volume, or a widening and flattening of the peak profile (i.e. peak spreading). Hounsell (1991) defined this form of peak spreading as active peak spreading, due to travelers retiming their journeys to avoid unacceptable levels of congestion during the peak. Hounsell also defined another form of peak spreading called "passive" peak spreading. This spreading can happen when increased congestion causes unserved trips in the most intense part of the peak period to shift into later time periods. Most research studies on peak spreading have not distinguished between active and passive peak spreading, but on capturing the overall effects of the combination.

2.5. Models and techniques used to describe peak-spreading

The literature search revealed a number of methodologies and mathematical techniques for analyzing temporal and spatial variation of traffic quantities used to assess highway performance. These methodologies range from simple mathematical models to advanced statistical pattern recognition techniques. The following sections explain in detail some of the methods and techniques used by researchers to study traffic variability and peak-spreading characteristics.

2.5.1 General mathematical models and trip-based methods

Allen (1991) presented a methodology for predicting imminent flattening or shifting of the peak hour on link-specific basis as congestion increases. The methodology employed a modified Poisson distribution (Equation 2.2) to describe the spread of four-hour volumes (6 a.m. to 10 a.m.) across each 15-minute period within the four hours.

$$f(x;\ \lambda,\theta) = P(X=x) = \begin{cases} (1+\theta\lambda)e^{-\lambda}, & for\ x=0 \\ (1+\theta\lambda)e^{-\lambda}, & for\ x=1 \\ \frac{\lambda^x e^{-\lambda}}{x!}, & for\ x=2,3,\dots,n \end{cases} \quad \text{......} 2.2$$

where, $\lambda = \mathrm{E}(X) = Var(X)$, is the mean 15-minute volume.

The volume data were collected from Interstate 80 in northern New Jersey and included four-hour volumes divided into 15-minute periods. A comprehensive ramp survey was undertaken to provide information about trip origin, destination, purpose, vehicle occupancy, and other roadways commuters used. The 15-minute traffic counts for each link in the corridor as a proportion of the total four-hour volume were tabulated and graphed. The modified Poisson curve was then hand-fitted to each of the graphs by adjusting the Poisson coefficients until the best fit was determined. These curves were then used as the observed data, to be fitted to one Poisson model for all links. A calibration file was built containing the Poisson coefficients and all available independent variables for each link. These variables were then used to estimate the Poisson coefficients using regression analysis. The independent variables used to estimate the Poisson coefficients included a speed difference variable equal to the free-flow minus congested speed, a delay variable, a dummy variable representing the link location, and a volume variable. Allen (1991) admitted that the research effort was a difficult attempt to quantify and forecast peaking and the results might have been unsuitable to generalize for use elsewhere. However, his technique was able to identify and use variables other than a single congestion measure. This was an important part of estimating a peak spreading model that is transferable to all links.

Post mode choice procedures in travel modeling have also been developed in an effort to study the peak-spreading phenomenon under congested conditions. For instance, Allen *et al*. (1996) conducted origin-destination (O-D) surveys on highway networks with peak and off-peak speeds. They used this information to predict the flattening of the AM peak hour as congestion and trip length increased. They estimated peak hour vehicle trips by first determining the proportion of the peak hour travel occurring in the three hour peak period and then applied this proportion to the estimated peak period trips. Data was collected for the calibration of the peak spreading model containing auto trips by purpose. Only those trips with valid production and attraction zones, valid start and end times, and were in progress between 6:30 and 9:30 AM, were kept. Network peak and off-peak travel times and distances were attached to each record. For each trip record, the vehicle hours of travel (VHT) spent between 6:30 and 9:30 a.m. and between 7:30 and 8:30 a.m. were calculated. The ratio of peak hour VHT to peak period VHT was used as the dependent variable in the estimation. The independent variables used in the model were the trip distance and a measure of congestion, which was quantified as the difference in minutes between the AM peak one-hour travel time and the off-peak travel time. No a priori assumptions were made about the model form, and initial data investigation found a great deal of scatter. The trip distance and congested time difference data were then grouped into ranges to accommodate the variation in data. The final model structure was a series of stratified curves.

The key outcomes from Allen *et al*. (1996) study were that trip purpose and trip distance, in addition to a congestion measure, were important variables for predicting the share of peak hour travel within a peak period. One of the successes about the technique used by Allen *et al*. (1996) was the incorporation of zone-to-zone congestion measure, as it enabled to determine if an individual would adjust his/her departure time in order to avoid unacceptable levels of congestion.

2.5.2 Data-driven methods and statistical pattern classification techniques

Other researchers who attempted to describe traffic variability and peak-spreading characteristics took advantage of huge amount of data available from public and private agencies. The available historical data enabled the development of more accurate models and applications of advanced statistical methods in explaining traffic patterns and peak-spreading characteristics. Nowadays, traffic management centers store and deal with an enormous and ever-increasing amount of traffic data (Alvarez *et al*., 2010) which, in their raw form, are overwhelming and meaningless from the macro point of view. Collection of data is only useful in the long term if the data are adequately processed and summarized. The traditional aggregated measures of traffic flow – i.e., annual average daily traffic (AADT), average daily vehicle hours of travel, average daily vehicle miles of travel – are not sufficient to characterize traffic behavior taking into account actual needs and data availability. In this situation, the ability of traffic managers to analyze and synthesize data takes on greater importance. As a result, researchers improvised systematic approaches to making more sense out of the vast amount of data through pattern recognition.

Patterns make it possible to summarize the recurrent characteristics contained in a huge amount of traffic data and are useful when it comes to synthesizing both the temporal and spatial variations of traffic variables. Pattern classification is suitable only when data are recurrent, in relation to some explanatory variable, contrary to completely random data. The underlying principle of pattern classification is based on Bayesian discriminant analysis as summarized by the equation below.

$$f(\boldsymbol{x};\boldsymbol{\theta}) = P(\boldsymbol{Group^i}|\boldsymbol{x},\boldsymbol{\theta}) = \frac{P(\boldsymbol{x}|\boldsymbol{Group^i})P(\boldsymbol{Group^i}|\boldsymbol{\theta})}{\sum_{G\epsilon all\ Groups} P(\boldsymbol{x}|\boldsymbol{G})P(\boldsymbol{G}|\boldsymbol{\theta})} \quad 2.3$$

where the feature vector input is $\boldsymbol{x}$, and the function f is typically parameterized by some parameters $\boldsymbol{\theta}$, and $\boldsymbol{Group^i}$ is a unique cluster $\boldsymbol{i}$**,** from feature input vector $\boldsymbol{x}$.

Although traffic is a microscopically random phenomenon, it is highly recurrent in macro dimension (Vanderbilt, 2008). Traffic demand is greatly correlated to human behavior. In this sense, and although individual travel decisions are difficult to forecast and sometimes not rational (Cherchi and Cirillo, 2010), from the macro point of view human communities follow strong recurrent activity patterns. For instance, it can be seen, day by day, how the traffic demand for a metropolitan freeway is almost the same for all similar days. The key issue is to know which days and durations should be considered similar in terms of traffic. It might not look like it, but this is a difficult task (FHWA, 2001).

Soriguera (2012) employed a cluster analysis technique to historical traffic data to systematically group similar days in terms of traffic demand. Although some traffic management agencies have systematic analysis tools (Danech-Pajouh, 2003), others still rely on subjective classifications. Subjective methods simply pre-establish a classification of dates and seasons based on the experience and knowledge of operators and disregarding the existence of special days, differences between locations or directions, or the possibility of newly emerging traffic patterns.

Scholars interest in traffic demand patterns emerged when the traditional approach to traffic demand forecasting based on pure time series models (Nicholson & Swann, 1974; Hogberg, 1976; Ahmed & Cook, 1979; Okutani & Stephanedes, 1984), proved to yield unsatisfactory results in comparison to heuristic methods based on pattern matching especially in recurrent conditions and medium to long-term horizons (Wild, 1997; Chrobok *et al*., 2004). Given this context, existing research has mainly focused on how to include traffic demand patterns in traffic flow forecasting methods in order to avoid the memoryless property in which the current traffic flow state entirely determines future states, with no considerations on past observations. Details to the alternative nonparametric methods can be found from studies by Davis & Nihan (1991), Smith & Demetsky (1997), and Clark (2003). In those studies only short term flow patterns were considered.

For weekly or monthly patterns, researchers have focused on long-term traffic demand patterns. Rakha & Van Aerde (1995) predefine demand patterns on a day-of-the-week basis (i.e., Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday) and analyzed the characteristics and statistical significance of the pattern differences using analysis of variance (ANOVA). They concluded that these groups of days represent different demand patterns, with higher recurrence on the weekdays. Weekends have a higher variability, and therefore demands are less predictable. Similarly, Chrobok *et al*. (2004) also constructed traffic demand patterns from a predefined classification of types of days, including the effects of holidays and days before holidays. The existence of seasonal demand variations was acknowledged. These research approaches were attempting to quantify the validity of subjective pattern classification.

In order to capture the intrinsic traffic trend, historical demand patterns should be systematically derived using pattern matching criteria instead of predefined day-of-the week classes. This would result in the possibility of obtaining site-specific adaptive sets of demand patterns. The Traffic Monitoring Guide (TMG) (FHWA, 2001) identifies this necessity. It also points out the cluster analysis technique as an appropriate tool. However, it does not advocate decisively for these methods, claiming that they do not allow for the creation of groups that are easier for agency staff to identify and explain to users. This conclusion follows from directly applying mathematical methods, with their quantitative benefits, but is very insensitive in terms of the human factor.

2.5.3 Volume-to-capacity ratio based methods

The literature search revealed that the v/c ratio on individual links is congestion measure that is frequently used parameter for capturing travel behavior of transportation network when users are faced with unacceptable levels of congestion. Various studies utilized this congestion measure in predicting the degree of peak spreading that occurred on a link.

Loudon *et al.* (1988) conducted a study for the Arizona Department of Transportation (ADOT) to investigate the characteristics of peak spreading on congested roadways. The study used data from 49 freeway and arterial corridors in Arizona, California, and Texas. The corridors were chosen due to the availability of historical hourly count data covering at least a five-year period. The data showed that the ratio of maximum one-hour volume counts to daily volume counts across the sites varied widely from the most often assumed value of 0.10, suggesting the need for more accurate modeling of peak hour volumes. The research report recommended changes to the Urban Transportation Planning System (UTPS)-based forecasting system used by the Maricopa Association of Governments (MAG) Transportation Planning Office, allowing future year forecasting to reflect the peak spreading phenomenon.

The initial steps towards producing peak hour trips were to divide total daily travel by trip purpose into three periods: 6-9 AM, 3-6 PM, and off-peak (the rest of the hours). The selection of these periods was based on the fact that there was some degree of stability within each period. The assumption was that travelers would not tend to shift out of these peak periods to avoid congestion. With no trips shifting out of these peak periods, the percentage of travel predicted for each peak period should remain constant with the level of congestion. This hypothesis was tested using least squares regression between the ratio of the three-hour peak period volume to twenty-four-hour volume (dependent variable) and the three-hour peak period v/c ratio (independent variable). The hypothesis would be rejected if the coefficient estimated for the independent variable was significant, indicating a relationship between the independent and dependent variables. Results from 36 regression equations showed some tendency for peak spreading to affect the three-hour peak period as 28 of the estimated coefficients had the correct sign (negative), but most were not significantly different from zero at the 95% confidence level.

Using the historical count data, a functional relationship was estimated between two quantities – the ratio of the peak hour volume to the peak period volume, and the overall v/c ratio during the peak period. Using ordinary least-squares regression, the parameter estimates were obtained. Analysis of the signs and significance of the coefficients on the v/c variable clearly demonstrated the presence of peak-spreading, as eighteen of the nineteen corridors in the analysis had a negative v/c coefficient (indicating a decrease in the proportion of the peak hour to peak period volume as the v/c increases), and more than half had slopes that were significantly different from zero with 95% confidence.

CHAPTER 3

ACQUISITION AND ANALYSIS OF TTMS DATA

3.1 Overview of TTMS Data

Traffic data from year 1996 to 2012 was supplied by the Transportation Statistics Office of the Florida Department of Transportation. This office is a central clearinghouse and the principal 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 collected by electronic equipment installed at these stations include individual vehicle records composed of the number of axles per vehicle, axle spacing, overall vehicle length, and operating speed. The individual vehicle records data are then used to derive a number of traffic variables including distribution of operating speeds, hourly volumes, the annual average daily traffic (AADT), and classification of vehicles using the FHWA's Scheme F. FDOT Statistics Office also operates other sites categorized as weigh-in-motion (WIM) sites that are set up to additionally collect individual axle weights and overall gross vehicle weight.

Various divisions of the Florida Department of Transportation classify roadways differently according to the management, inventory, and modelling needs of each division. For example, roadways have been classified in more than five area types and more than seven facility types for modeling purposes. The classification adopted for this research is the classification contained in the FDOT Quality and Level of Service Handbook which uses only four area types classification – that is, large urbanized, urbanized, urban and rural. This classification is based on population. According to the FDOT Quality and Level of Service Handbook, urbanized areas are defined by the FHWA approved boundary, which encompasses the entire Census Urbanized Area as well as a surrounding geographic area as agreed upon by FDOT, FHWA, and the Metropolitan Planning Organizations (MPOs). Figure 3.1 shows the classification of area types by the size of the population.

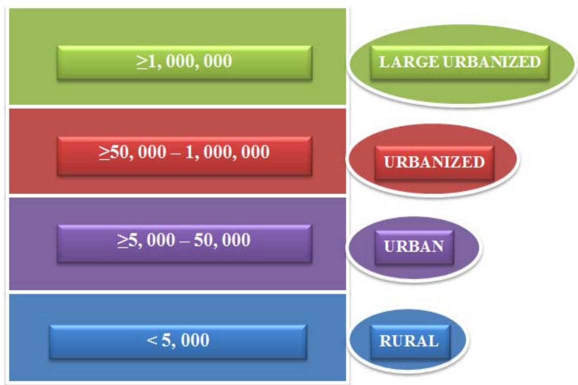

FIGURE 3.1 Analysis Area Types

The minimum population for an urbanized area is 50,000. Within the urbanized area type category, there are large urbanized areas which apply to the MPOs with over 1,000,000 populations. These areas include Ft. Lauderdale, Jacksonville, Miami, Orlando, St. Petersburg, Tampa, and West Palm Beach. Similarly, an urban area must have a population between 5,000 and 50,000 while areas with no or minimal population or development, or with less than 5,000 population are classified as rural areas. Figure 3.2 shows the location of traffic monitoring sites in the State of Florida as they existed in year 2012. The majority of these sites collected both speed and classification counts while a few sites collected speed only without classifying vehicles into the 15 categories of FHWA's Scheme F.

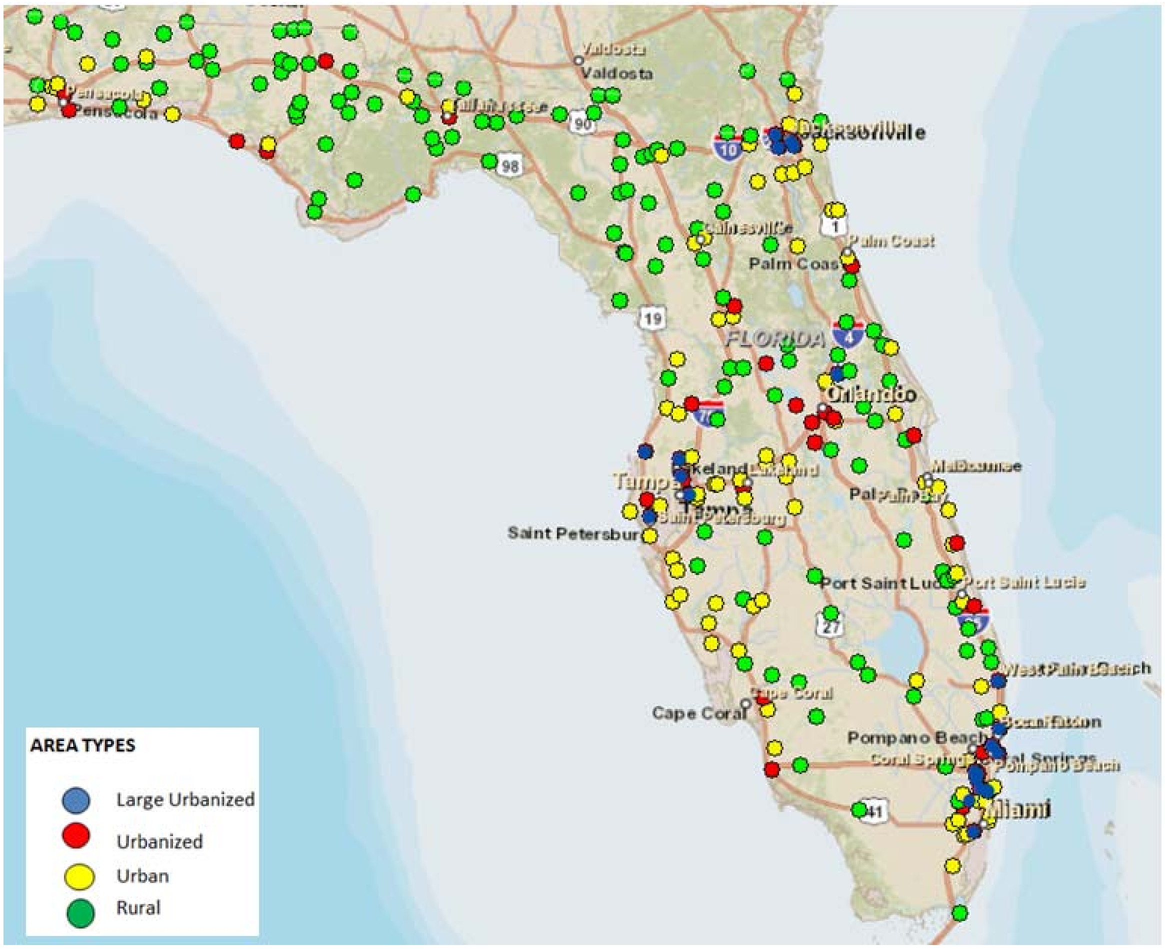

FIGURE 3.2 Geographical Distribution of Traffic Monitoring Sites

Table 3.1 shows the distribution of TTMS sites by area type and by facility type. Sites with HOV lanes are all located on freeways and are counted in the “Freeway & Expressway facility type” category. Closer examination of Table 3.1 reveals that the Florida Department of Transportation monitors high-class facility types comprising of freeways and arterials that are generally expected to have high traffic volumes. As indicated earlier, toll roads and highways with HOV lanes are also high-speed multilane facilities that are characterized by heavy traffic volumes. In addition, Table 3.1 shows that the majority of the monitoring sites are located outside urbanized areas. It is clear that the majority of centerline miles of highways are located in these areas and therefore logically it is expected that most monitoring sites will be located in urban and rural areas as well.

TABLE 3.1 Distribution of TTMS Sites by Area and Facility Type

Facility Type	Area Type				
	Large Urbanized	Urbanized	Urban	Rural	Total
Freeway & Expressway	8		23	22	53
Divided Arterials	10	17	43	33	103
Undivided Arterials	4	5	14	72	95
Collectors			4	8	12
One-Way Facilities					
Ramps					
Toll Roads	1	1	7	9	18
HOV Lanes	3		1		4
Total	26	23	92	144	285

3.2 File Format and Data Structure

The data were supplied by FDOT in two ways. All the data from 1996 to 2012 were supplied in hourly volume data files that were separate for each station and each date. In addition, for year 2012 the hourly speed data were supplied by lane in one yearly file. The one-year files were easy to work with but unfortunately, according to FDOT, that format was not available prior to 2011. The data structure of the hourly speed files is shown in Table 3.2.

TABLE 3.2 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
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

Description	Position	Start Column	End Column
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 travelling at or below 20 miles per hour (mph), one bin for vehicles travelling 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 3.2 shows the data structure of the file while Figure 3.2 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 3.3 Extract from Typical TTMS Hourly Speed Count Data File

3.3 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 2012 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 2012 holidays was obtained from the Florida Department of Management Services (DMS) website. These were added to a list containing each Day of Week for 2012 by date. Weekdays on which a holiday was observed were flagged as holidays. The 2012 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 dataset is associated with one of eight "Day of Week" types – namely, Monday; Tuesday; Wednesday; Thursday; Friday; Saturday; Sunday; and Holiday.

- *2012 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 dataset – 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.

Following data augmentation, cleaning and validation process, the following variables were of interest and thus retained for further analysis were County, Lane Number, Month, Day, Hour, Speed Bins (15 bins in 5-mph increments including < 20 mph and > 85 mph), Total Volume, Direction of Travel, TTMS Location, Functional Classification, AADT, K-Factor, Facility Type, Area Type, Posted Speed Limit, and Day of the Week.

3.4 Descriptive Statistical Analysis

In any scientific research, descriptive statistical analysis is conducted to determine patterns in the data and possibly identify outliers that might skew the results of an inferential statistical analysis. Descriptive statistical analysis generally involves calculating measures of the center (mean, median, and mode) and measures of dispersion (variance, percentiles, and coefficient of variation). While it is expected that traffic characteristics will vary by area type and facility type, it can also be hypothesized that the variation of traffic characteristics is also influenced by the speed limit. Generally, facilities designed with high geometric standards will have high posted speed limit while facilities designed for low speed, low traffic, will have low posted speed limit.

At this stage of the statistical analysis, descriptive statistics of hourly volumes and average hourly speeds were calculated. Since the raw data acquired from FDOT had speed bins aggregated on hourly basis, the first step towards generating the required statistical parameters was to determine the total hourly volume and average hourly speed. The hourly volumes were determined by summing up the individual volumes from each speed category as follows:

$$Hourly\ Volume = \sum_{b=1}^{b=15}(Count_{(b)}) \quad \text{.......... 3.1}$$

where b is the speed bin index (1 to 15) and $Count_b$ is the number of vehicles in speed bin "b". The average hourly speed was calculated as the harmonic mean of the speeds on hourly basis using the following formula:

$$Harmonic\ Mean\ Hourly\ Speed = \frac{\sum_{b=1}^{b=15}(Count_{(b)})}{\sum_{b=1}^{b=15}\left(\frac{Count_{(b)}}{Speed_{(b)}}\right)} \quad \text{.......... 3.2}$$

where $Speed_b$ is the mid-point of the speed range in bin "b" and other parameters are as were defined in Equation 1.

Table 3.1 displayed earlier showed that the area type with most permanent count sites was the Rural area type (which had 114 permanent count sites) followed by Urban area type (92 sites). The Urbanized area type had the least number of permanent count sites, i.e. 49 sites. The analysis was prioritized by sample size. Thus, the Rural area type which has the largest sample size is analyzed first.

3.4.1 Volume and Speed Analysis in the Rural Area Type

Descriptive statistics were summarized for volume and speed in Rural area type. Table 3.3 shows that volume analysis of roadway facilities located in rural areas. The results show that the highest recorded volume in rural area type was 1,651 vehicles per hour per lane which was observed on a freeway with speed limit of 70 MPH. For the interrupted flow facilities, the maximum observed volume was 1,446 recorded on divided arterials with speed limit of 55 MPH. The highest coefficient of variation (122.3%) of traffic flow is observed on divided arterials with speed limit of 60 MPH while the lowest traffic flow variation (54.7%) is on undivided arterials with 65 MPH speed limit. There were no data collected on HOV facilities and one-way facilities in rural areas.

TABLE 3.3 Volume Analysis in Rural Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	70 MPH	22	200,699	1,651	341	1	1,161	244.8	71.9%	0.546
Divided Arterials	30 MPH	1	6,057	1,077	406	19	976	271.1	66.7%	3.483
	35 MPH	3	11,407	964	315	2	853	248.1	78.8%	2.323
	45 MPH	3	36,236	870	150	2	522	127.9	85.0%	0.672
	55 MPH	10	81,504	1,446	169	2	1,100	195.1	115.7%	0.683
	60 MPH	3	18,120	1,005	230	5	599	167.2	72.7%	1.242
	65 MPH	13	130,520	774	149	2	469	113.1	75.8%	0.313

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99^{th} %tile	Std. Dev.	Coeff. of Variation	Std. Error
Undivided Arterials	45 MPH	5	21,790	759	156	1	620	131.5	84.5%	0.891
	55 MPH	46	294,120	1,155	98	1	567	113.7	116.2%	0.210
	60 MPH	20	174,545	993	87	1	528	106.6	122.3%	0.255
	65 MPH	1	11,904	329	93	6	188	51.0	54.7%	0.468
Collectors	35 MPH	1	11,916	250	61	1	168	47.4	78.0%	0.435
	45 MPH	1	11,856	861	255	4	605	172.3	67.6%	1.582
	55 MPH	5	40,825	244	38	1	103	26.4	70.0%	0.131
Toll Roads	65 MPH	2	11,916	250	61	1	168	47.4	78.0%	0.435
	70 MPH	7	11,856	861	255	4	605	172.3	67.6%	1.582

In order to capture the 24-hour peaking characteristics and variation of the volumes, the analysis was performed on hourly basis by speed limit and by facility type. Figure 3.4 and Figure 3.5 show the hourly volumes and coefficient of variation plotted on 24-hour basis for "undivided arterial" facility type. Plots for other facility types in rural areas are shown in Appendix A. Figure 3.4 reveals the traditional bi-modal peaking characteristics expected on roadway serving commuter traffic with the evening peak being higher than the morning peak. Regardless of the speed limit, the trend seems to be the same.

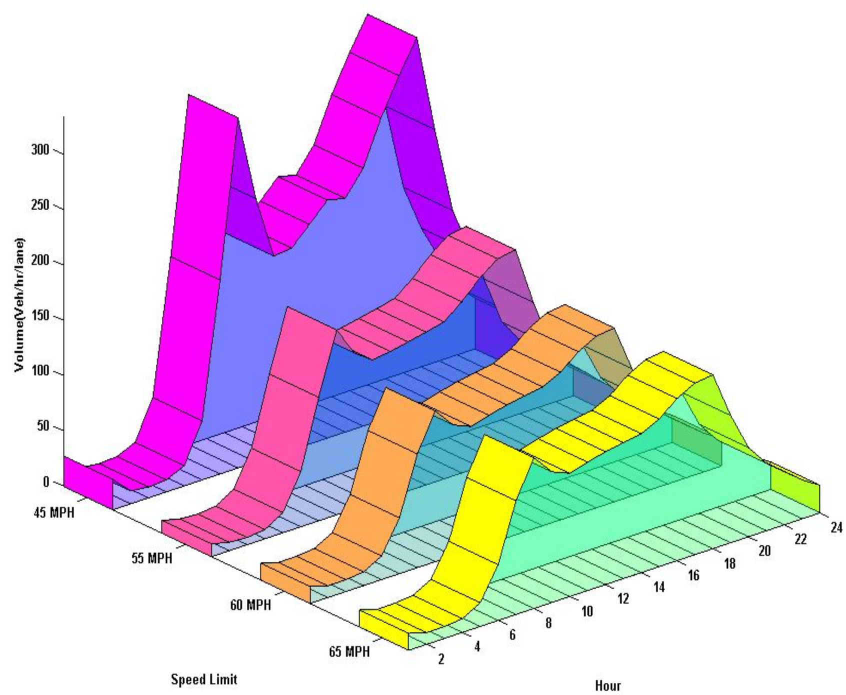

FIGURE 3.4 Hourly Volume Variation on Rural Undivided Arterials

The coefficient of variation was plotted on hourly basis as well as shown in Figure 3.5. The results in Figure 3.5 show that traffic flow is highly variable in early morning hours and late at night due to random flows. The trend seems to be similar regardless of the prevailing speed limit. The results further show that freeways with 65 MPH have lowest variations of volumes compared to other facilities.

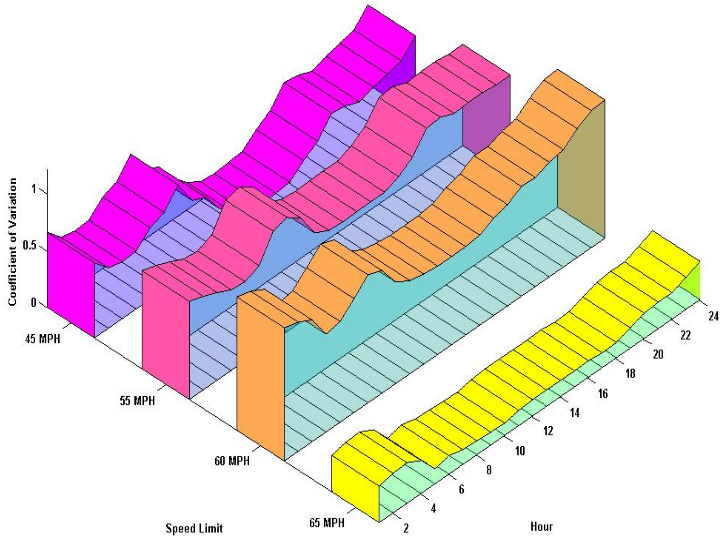

FIGURE 3.5 Coefficient of Variation on Rural Undivided Arterials

The analysis of hourly volumes was followed by the analysis of average hourly speeds. Figure 3.6 shows the plot of average speeds while Table 3.4 shows the descriptive statistics of the speeds. The results of distribution of average speeds showed that all facilities operate at fairly well.

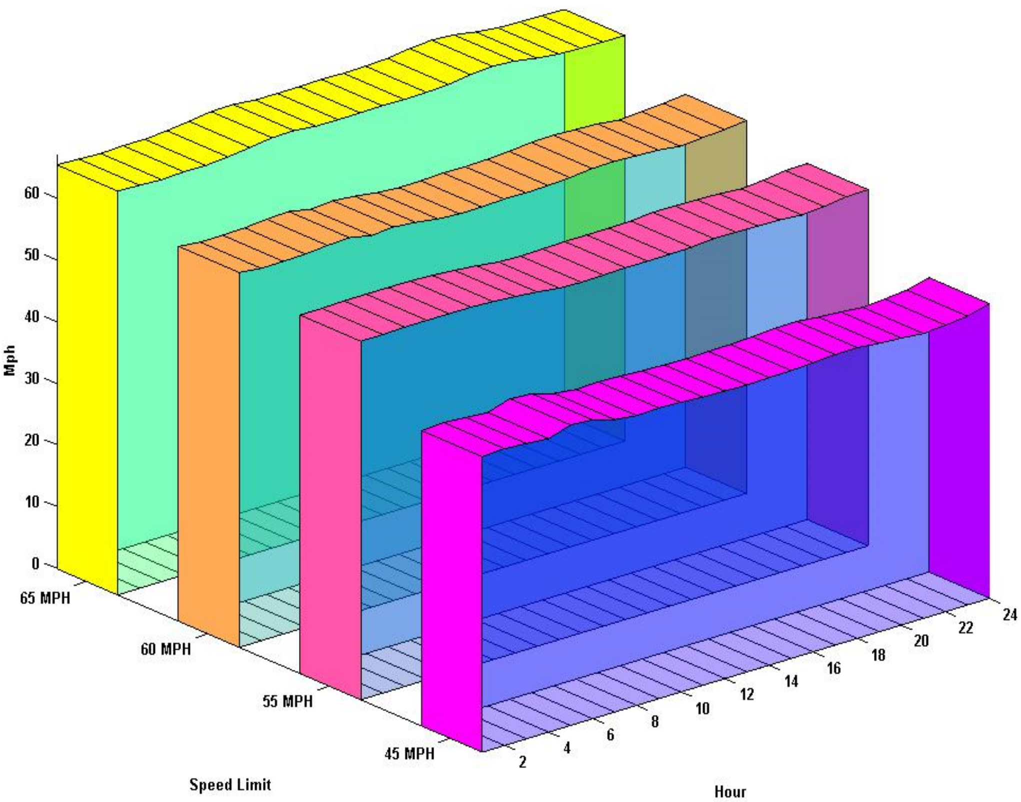

FIGURE 3.6. Hourly Average Speed by Time of Day and Speed Limit in Rural Area

The results in Table 3.4 show that the majority of the facility types have average speeds marginally above the speed limit. There were a few sites in which the average speeds were lower than the speed limit, but only by up to about 2 mph. The variation of speeds within the hour as indicated by the coefficient of variation shows that speeds were highly variable (16.9%) at sites located on divided arterials with speed limit posted at 35 MPH. In general, the majority of the sites had coefficient of variations of less than 10% indicating that driving speeds are fairly uniform within the hours.

The variation of the speeds was analyzed also using coefficient of variation statistic. Figure 3.7 shows the plot of coefficient of variation for rural undivided arterials. Figure 3.7 shows the expected trend of increasing average speed with increase in speed limit. Furthermore, it can be surmised that speeds are fairly stable in facilities with speed limit 55 MPH or higher and random in facilities with 45 MPH speed limit as shown in Figure 3.7. Regardless of speed limit, the higher coefficients of variation occur around and after the evening peak hours.

TABLE 3.4 Speed Analysis in Rural Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	70 MPH	22	200,699	83.5	71.1	17.61	75.7	2.9	4.0%	0.006
Divided Arterials	30 MPH	1	6,057	40.9	35.0	23.56	39.7	2.4	6.7%	0.030
	35 MPH	3	11,407	50.0	37.9	17.73	48.0	6.4	16.9%	0.060
	45 MPH	3	36,236	60.3	50.2	25.16	56.2	3.5	7.0%	0.018
	55 MPH	10	81,504	73.7	58.7	17.5	70.2	6.1	10.4%	0.021
	60 MPH	3	18,120	70.6	60.5	17.51	68.7	3.9	6.5%	0.029
	65 MPH	13	130,520	72.9	63.5	27.26	69.7	4.8	7.5%	0.013
Undivided Arterials	45 MPH	5	21,790	64.3	48.5	23.89	55.7	5.3	10.9%	0.036
	55 MPH	46	294,120	87.5	57.5	17.5	67.1	4.7	8.2%	0.009
	60 MPH	20	174,545	87.5	59.9	17.5	69.2	4.6	7.6%	0.011
	65 MPH	1	11,904	72.7	65.9	40.34	68.6	1.3	2.0%	0.012
Collectors	35 MPH	1	11,916	87.5	48.4	17.5	62.5	3.7	7.6%	0.034
	45 MPH	1	11,856	54.7	44.9	31.51	51.0	2.5	5.6%	0.023
	55 MPH	5	40,825	87.5	58.5	17.5	67.6	5.0	8.6%	0.025
Toll Roads	65 MPH	2	11,916	76.8	71.9	19.63	75.2	2.2	3.1%	0.019
	70 MPH	7	11,856	112.1	71.6	17.5	76.3	2.7	3.8%	0.010

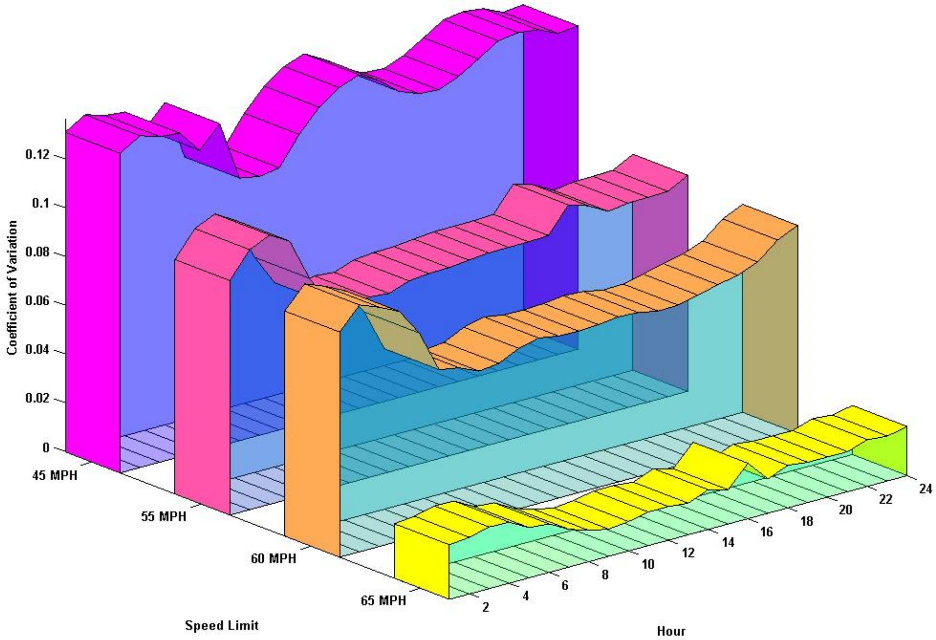

FIGURE 3.7 Coefficient of Variation of Average Speed

3.4.2 Volume and Speed Analysis in the Urban Area Type

Analysis procedure similar to the one used in analyzing volume and speed variation on rural roads was used for urban roads. Both graphical plots and tabular summaries were used in the analysis process. Figure 3.8 shows the plot of average hourly volume on urban divided arterials. Plot for other facility types in urban areas are shown in Appendix B. Figure 3.8 reveals the bi-modal peaking characteristics with the evening peak being higher than the morning peak. Table 3.5 shows descriptive statistics for urban facilities.

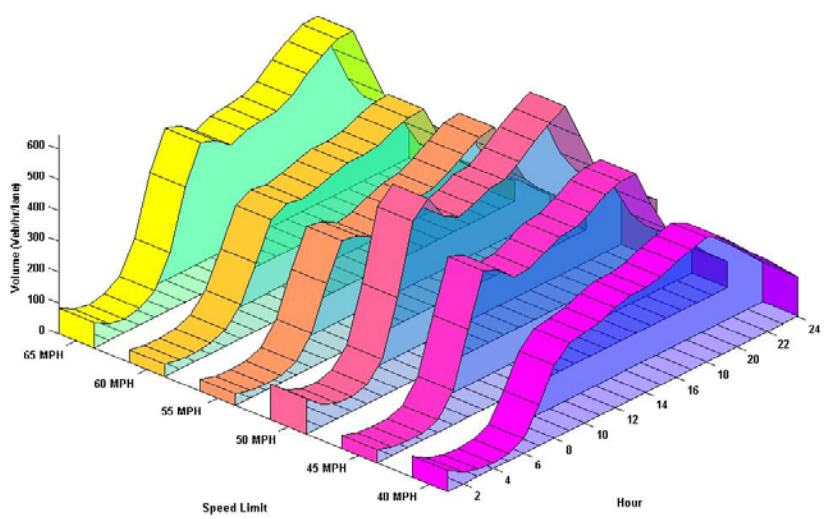

FIGURE 3.8 Hourly Volume by Speed Limit in Urban Divided Arterials

For the uninterrupted flow facilities located in urban areas, the results in Table 3.5 show that the highest recorded volume was 2,417 vehicles per hour per lane that occurred on freeway/expressway facilities with speed limit of 70 MPH. The maximum average hourly volume for the interrupted flow facilities was 2,625 vehicles per hour per lane recorded on divided arterial sites with 45 MPH posted speed limit. The 99th percentile analysis of the hourly volumes shows that only higher class facilities (freeways/expressways, toll roads and HOV lanes) have volume in which one percent of the hours in a year, traffic flow exceeds 1,300 vehicles per hour per lane. The analysis of variation shows that traffic flow on toll roads with 65 MPH speed limit was the most variable (93%) while traffic flow on divided arterials sites with 65 MPH speed limit was the least variable (59%).

TABLE 3.5 Volume Analysis in Urban Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	55 MPH	2	23,107	1,635	568	1	1,455	419	74%	2.76
	65 MPH	4	47,436	2,082	725	21	1,937	487	67%	2.24
	70 MPH	17	176,453	2,417	590	1	1,882	415	70%	0.99
Divided Arterials	40 MPH	3	14,743	560	230	3	485	145	63%	1.19
	45 MPH	22	185,136	2,625	282	2	819	227	80%	0.53
	50 MPH	5	48,086	1,225	356	2	1,084	287	81%	1.31
	55 MPH	10	88,376	1173	249	1	939	221	89%	0.74
	60 MPH	2	24,110	682	246	2	530	159	65%	1.03
	65 MPH	1	12,096	813	340	23	702	200	59%	1.82
Undivided Arterials	35 MPH	1	12,096	864	236	1	662	180	76%	1.64
	45 MPH	8	71,335	838	197	1	587	174	88%	0.65
	50 MPH	1	11,202	379	137	2	294	86	63%	0.82
	55 MPH	1	10,800	1253	151	2	387	109	72%	1.05
	60 MPH	3	24,114	425	123	1	300	80	65%	0.52
Collectors	45 MPH	4	24,133	820	289	6	705	189	66%	1.22
Toll Roads	55 MPH	1	5,568	1,745	559	29	1,358	362	65%	4.85
	65 MPH	4	40,556	1,768	403	1	1,530	373	93%	1.85
	70 MPH	2	21,178	1,572	488	16	1,392	330	68%	2.27
HOV Facilities	65 MPH	1	11,868	1,793	521	1	1,426	391	75%	3.58

Figure 3.9 shows the coefficient of variation of traffic flow in urban divided arterials. Summary of speed data collected on facilities located in urban areas is shown in Table 3.6. The analysis in Table 3.6 shows that the highest observed speed in interrupted flow facilities was 87.5 MPH that was recorded in undivided arterial highway with speed limit of 45 MPH. This is unexpectedly higher than normal speeds in interrupted flow facilities. For uninterrupted flow facilities, the maximum observed speed was 83.8 MPH occurring in HOV facility with speed limit of 65 MPH. The coefficient of variation analysis shows that, speed is highly variable on toll roads

with 70 MPH speed limit (12.25%), and least variable on divided arterials with 65 MPH speed limit (2.68%).

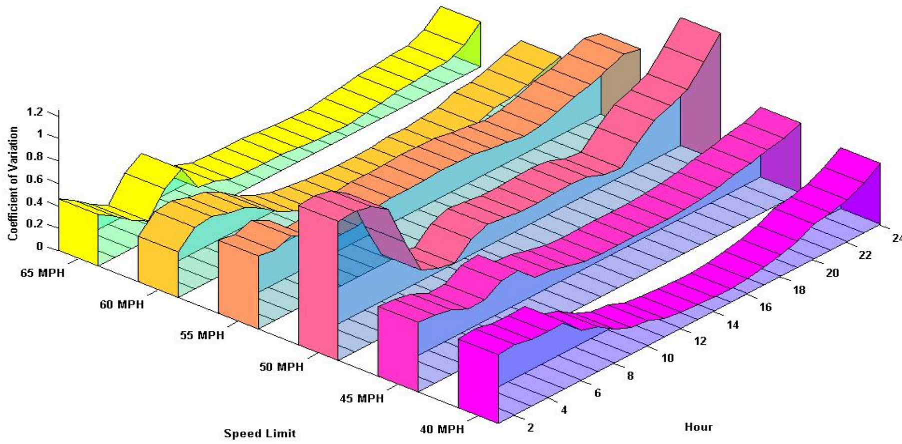

FIGURE 3.9 Coefficient of variation of hourly volume in urban divided arterials

TABLE 3.6 Speed Analysis in Urban Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	85th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	55 MPH	2	23,107	67.9	60.8	17.9	63.3	3.2	5.19%	0.02
	65 MPH	4	47,436	75.3	66.9	17.5	70.5	4.3	6.47%	0.02
	70 MPH	17	176,453	77.6	70.7	17.5	73.2	3.6	5.16%	0.01
Divided Arterials	40 MPH	3	14,743	42.3	35.7	22.9	37.2	2.0	5.56%	0.02
	45 MPH	22	185,136	60.2	45.8	17.5	50.0	4.6	9.96%	0.01
	50 MPH	5	48,086	59.6	51.9	17.5	55.1	4.4	8.56%	0.02
	55 MPH	10	88,376	66.0	53.8	18.2	58.0	4.0	7.35%	0.01
	60 MPH	2	24,110	67.6	61.8	17.5	64.0	2.0	3.19%	0.01
	65 MPH	1	12,096	60.6	56.3	27.3	57.6	1.5	2.68%	0.01
Undivided Arterials	35 MPH	1	12,096	62.5	39.3	18.2	40.8	1.7	4.32%	0.02
	45 MPH	8	71,335	87.5	49.4	24.9	54.7	4.4	8.82%	0.02
	50 MPH	1	11,202	63.5	53.6	30.9	55.5	2.0	3.82%	0.02
	55 MPH	1	10,800	74.8	63.0	18.5	65.3	2.8	4.43%	0.03
	60 MPH	3	24,114	77.5	56.8	25.0	59.2	2.8	4.89%	0.02
Collectors	45 MPH	4	24,133	58.1	47.6	30.5	52.2	4.1	8.55%	0.03
Toll Roads	55 MPH	1	5,568	59.0	55.8	17.6	57.3	1.9	3.42%	0.03
	65 MPH	4	40,556	79.3	68.3	19.6	71.5	3.5	5.08%	0.02
	70 MPH	2	21,178	78.1	70.2	17.6	75.3	8.6	12.25%	0.06
HOV Facilities	65 MPH	1	11,868	83.8	74.6	17.6	77.5	4.2	5.57%	0.04

3.4.3 Volume and Speed Analysis in the Urbanized Area Type

Table 3.7 shows the results of volume analysis on facilities located in areas categorized as urbanized. The results in Table 7 show that there is only one site in urbanized uninterrupted flow facilities which is located on toll road with speed limit of 60 MPH. This site experienced the maximum volume of 801 vehicles per hour per lane which was lower than the highest volume in interrupted flow facilities. The highest recorded volume for the interrupted flow facilities, the maximum average hourly volume was 1,484 vehicles per hour per lane which occurred on divided arterial sites with posted speed limit of 35 MPH. Another segments on interrupted flow facilities whose maximum volume exceeded 1, 000 vehicles per hour per lane were the divided arterials with speed limit of 45 MPH. There were no data collected on HOV facilities, freeways, collectors or one-way facilities in urbanized areas.

TABLE 3.7 Volume Analysis in Urbanized Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99^{th} %tile	Std. Dev.	Coeff. of Variation	Std. Error
Divided Arterials	35 MPH	6	36,940	1,484	282	2	936	225	80%	1.17
	40 MPH	2	11,852	635	223	6	553	164	73%	1.50
	45 MPH	7	72,430	1,464	336	4	961	249	74%	0.93
	55 MPH	2	11,808	741	196	3	447	141	72%	1.30
Undivided Arterials	30 MPH	1	11,952	347	105	1	251	86	81%	0.79
	35 MPH	2	11,999	738	242	1	622	181	75%	1.65
	45 MPH	2	11,774	654	203	2	535	150	74%	1.39
Toll Roads	60MPH	1	12,096	801	280	17	724	186	66%	1.69

Since average hourly volumes were computed on 24-hour basis, the results show that there are many hours on Florida urbanized area type highways that have very low traffic flow. In fact, in practically all locations, there were periods that traffic flow was zero (0). Analysis of the 99^{th} percentile of the hourly volumes shows that none of the segments recorded the volume in which one percent of the hours in a year, traffic flow reached 1,000 vehicles per hour per lane. Analysis of the coefficient of variation (i.e., the ratio of standard deviation to the mean) shows that traffic flow on undivided arterials with 30 MPH speed limit was the most variable (81%) followed by divided arterial segments with speed limit of 35 MPH (80%) while traffic flow on toll road site with 60 MPH speed limit was the least variable (66%). To further analyze and grasp the variation of volumes, the tabular results were plotted. Figure 3.10 shows the volume plot while Figure 3.11 shows the coefficient of variation plot. Plots for other sites are shown in Appendix C.

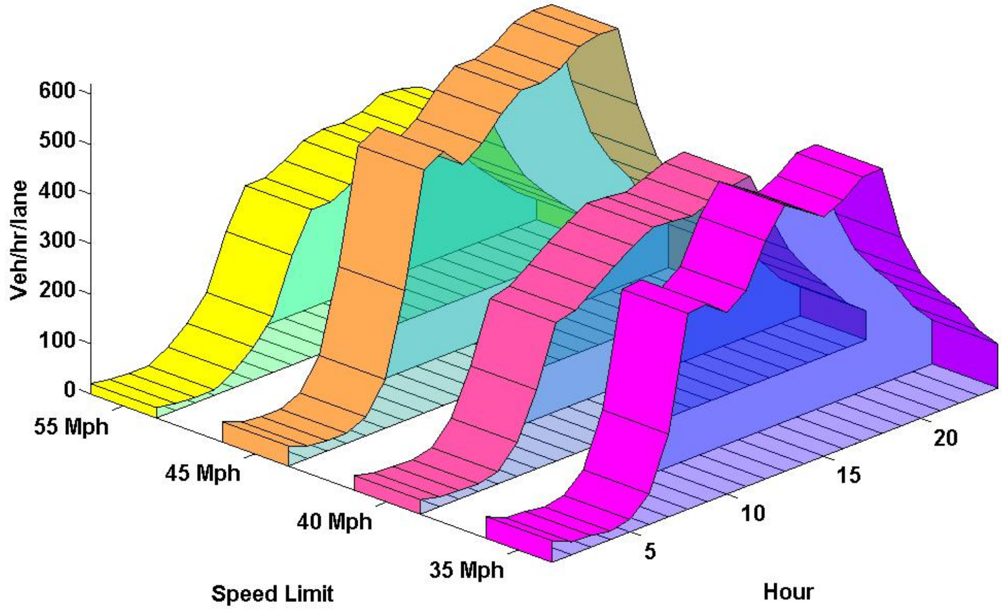

FIGURE 3.10 Hourly Volume by Speed Limit in Urbanized Divided Arterials

It can be deduced from Figure 3.10 that the morning peak period (around 7 a.m. to 9 a.m.) is fairly consistent for all speed limits. Additionally, urban divided arterials with 45 mph speed limit carry more traffic than other facilities. The coefficients of variation are higher during low traffic hours, early morning, and late night hours. These are characteristics of random flows. Analyses of day to day traffic show that both mid-day and afternoon peak periods for Thursdays and Fridays, prevail for more hours than other weekdays.

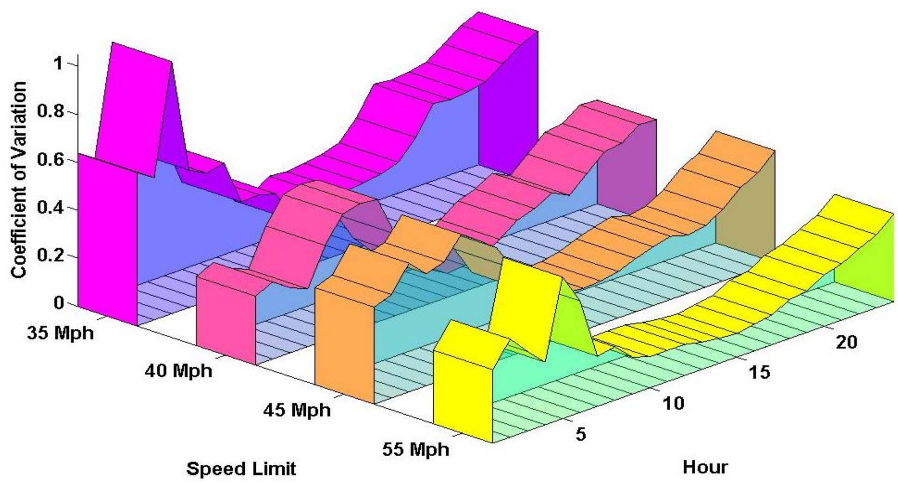

FIGURE 3.11 Coefficient of Variation of Hourly Volume by Speed Limit

Figure 3.11 shows the coefficient of variation plotted on hourly basis. The plots shows that regardless of the speed limit of the facility, traffic flow is highly variable in early morning hours and late at night. This result is to be expected as those are the periods of low volumes which create a random flow phenomenon resulting in high coefficient of variation.

Further analysis on daily and time of day basis show that there is a consistent increase in mid-day and afternoon peak traffic for Thursdays and Fridays as shown in Figure 3.12.

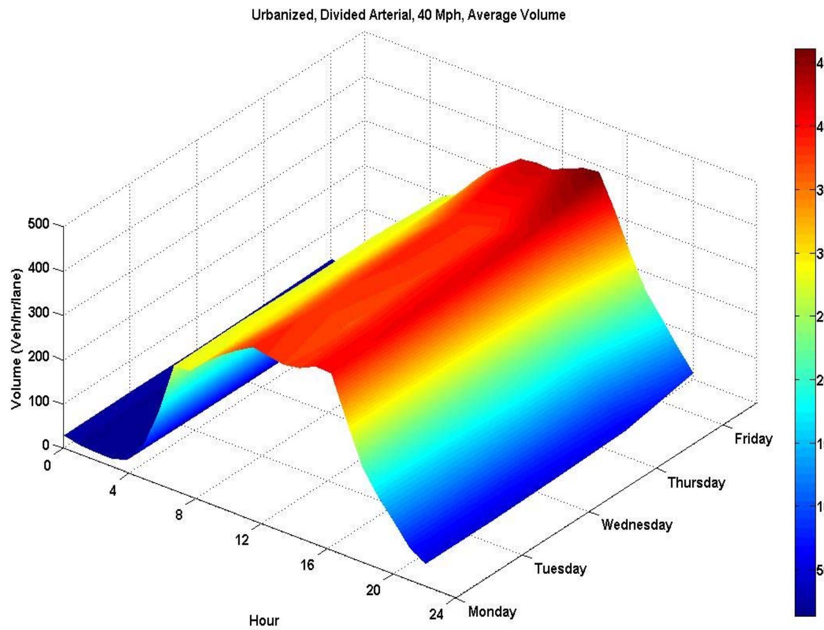

FIGURE 3.12 Hourly Volume by Week Day in Urbanized Divided Arterials

Speed summaries are shown in Table 3.8. The results in Table 3.8 show that the highest observed speed in interrupted flow facilities was 64.7 MPH that was recorded in divided arterial highway with speed limit of 45 MPH. For uninterrupted flow facilities, there is only one site located on urbanized toll road with posted speed limit of 60 MPH. The maximum speed for the toll road site was 69.7 MPH. The coefficient of variation analysis shows that, speed is highly variable on divided arterials with 35 MPH speed limit (15.41%), and least variable on toll roads with 60 MPH speed limit (2.03%).

TABLE 3.8 Speed Analysis in Urbanized Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	85th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Divided Arterials	35 MPH	6	36,940	51.1	38.6	18.2	46.8	5.9	15.41%	0.03
	40 MPH	2	11,852	45.5	38.1	27.6	40.4	2.1	5.49%	0.02
	45 MPH	7	72,430	64.7	46.2	17.6	53.7	6.1	13.21%	0.02
	55 MPH	2	11,808	59.2	54.1	45.4	55.4	1.3	2.33%	0.01
Undivided Arterials	30 MPH	1	11,952	46.6	33.3	26.0	34.7	1.5	4.47%	0.01
	35 MPH	2	11,999	47.5	31.2	19.8	34.2	3.2	10.17%	0.03
	45 MPH	2	11,774	47.1	40.5	28.4	41.7	1.2	3.04%	0.01
Toll Roads	60MPH	1	12,096	69.7	65.4	50.7	66.6	1.3	2.03%	0.01

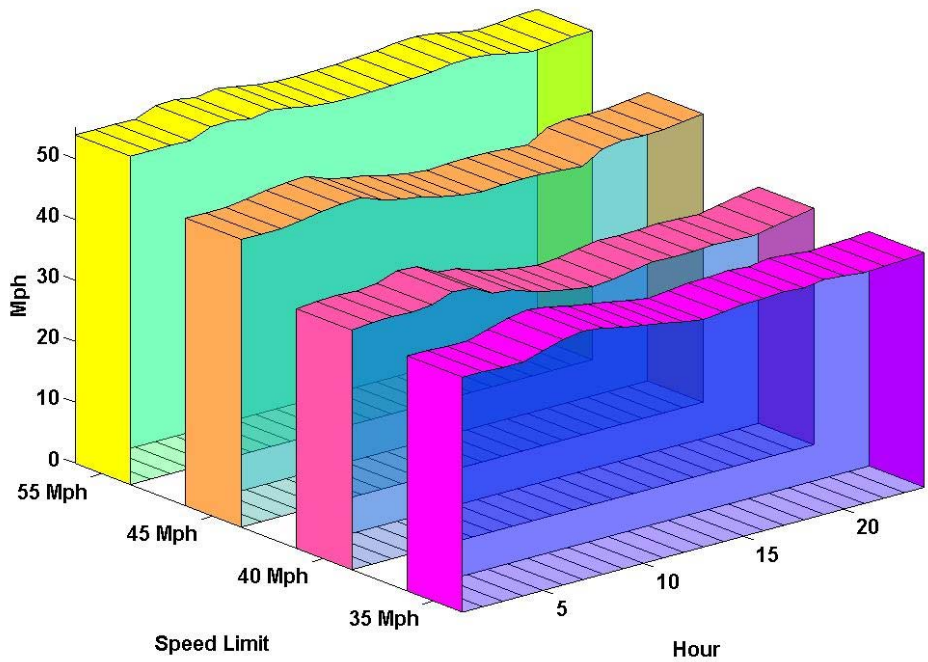

FIGURE 3.13 Hourly Average Speed by Time of Day and Speed Limit

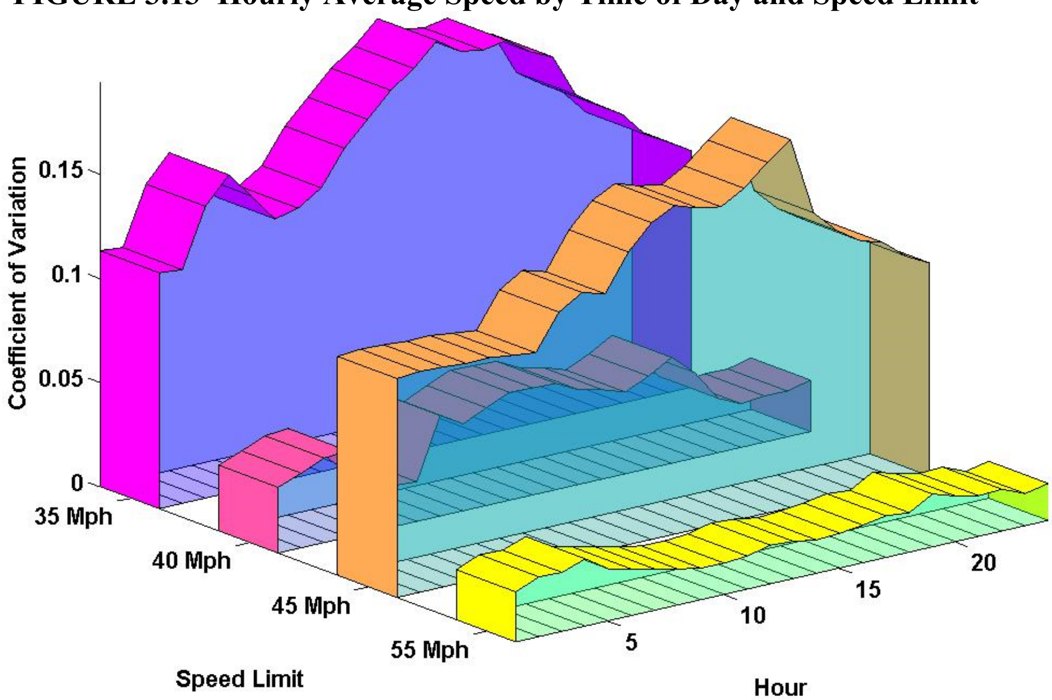

FIGURE 3.14 Coefficient of variation of average speed

3.4.4 Volume and Speed Analysis in Large Urbanized Area Type

Summary of volume analysis for facilities located in areas categorized as large urbanized are shown in Table 3.9. The analysis summary results in Table 3.9 show that, for the uninterrupted flow facilities located in large urbanized areas, the highest recorded volume was 2,354 vehicles per hour per lane that occurred on freeway/expressway facilities with speed limit of 65 MPH. The maximum average hourly volume for the interrupted flow facilities was 1,174 vehicles per hour per lane recorded on divided arterial sites with 45 MPH posted speed limit. The analysis of 99th percentile hourly volumes shows that only higher class facilities (freeways/expressways, toll roads and HOV lanes) have volume in which one percent of the hours in a year, traffic flow exceeds 1,500 vehicles per hour per lane. The analysis of variation shows that traffic flow on HOV lanes with 65 MPH speed limit was the most variable (88%) while traffic flow on freeways/expressways sites with 65 MPH speed limit was the least variable (60%).

TABLE 3.9 Volume Analysis in Large Urbanized Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	99th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	55 MPH	3	25,696	1,798	790	28	1,694	485	61%	3.03
	65 MPH	5	49,050	2,354	926	41	2,064	560	60%	2.53
Divided Arterials	40 MPH	1	1,536	736	269	14	608	168	63%	4.29
	45 MPH	8	72,062	1,174	440	1	967	286	65%	1.06
	50 MPH	1	11,822	987	401	28	890	250	62%	2.30
Undivided Arterials	35 MPH	1	3,216	267	114	2	235	75	65%	1.31
	45 MPH	2	17,760	864	218	3	711	169	77%	1.27
	50 MPH	1	11,448	771	269	10	680	187	70%	1.75
Toll Roads	65 MPH	1	4,728	1,858	839	45	1,743	514	61%	7.48
HOV Facilities	65 MPH	3	26,126	2,270	645	1	1,942	569	88%	3.52

Further analyses were performed through visualization as shown in the following figures. Figure 3.15 shows the volume plot while Figure 3.16 shows the coefficient of variation plot.

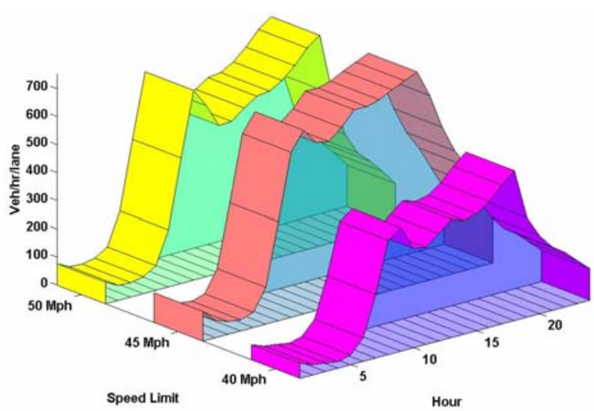

FIGURE 3.15 Hourly volume by speed limit in large urbanized divided arterials

It can be visualized from Figure 3.15 that the morning peak period is fairly consistent (around 7 a.m. to 9 a.m.) for all speed limits. As expected, Figure 3.16 shows that the coefficients of variation are higher during low traffic hours, early morning, and late night hours, characteristics of random flows.

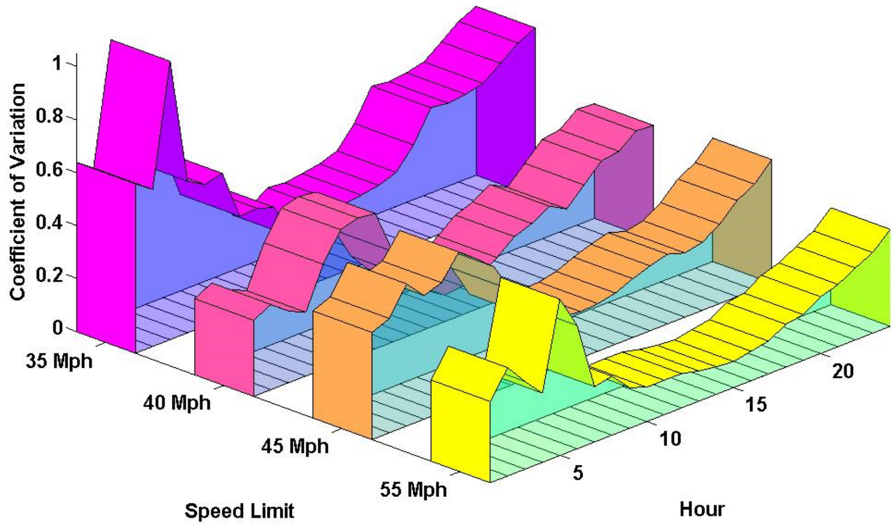

FIGURE 3.16 Coefficient of variation of hourly volume by speed limit

Speed analysis summaries are shown in Table 3.10. The results in Table 3.10 show that the highest observed speed in interrupted flow facilities was 58.9 MPH that was recorded in divided arterial highways with speed limit of 45 MPH. For uninterrupted flow facilities, the highest speed was 87.5 MPH recorded in HOV facilities with speed limit of 65 MPH. The coefficient of variation analysis shows that, speed is highly variable on divided arterials with 45 MPH speed limit (19.04%), and least variable on divided arterials with 50 MPH speed limit (3.74%).

TABLE 3.10 Speed Analysis in Large Urbanized Area Type

Facility Type	Speed Limit	No. of Sites	No. of Obs.	Max.	Avg.	Min.	85th %tile	Std. Dev.	Coeff. of Variation	Std. Error
Freeway & Expressway	55 MPH	3	25,696	71.6	61.5	17.5	66.0	6.3	10.27%	0.04
	65 MPH	5	49,050	73.3	64.9	17.5	68.0	5.3	8.24%	0.02
Divided Arterials	40 MPH	1	1,536	49.7	43.4	31.0	45.5	2.1	4.92%	0.05
	45 MPH	8	72,062	58.9	38.5	17.5	45.4	7.3	19.04%	0.03
	50 MPH	1	11,822	54.5	49.3	19.2	50.9	1.8	3.74%	0.02
Undivided Arterials	35 MPH	1	3,216	40.6	35.2	25.1	36.9	1.7		0.03
	45 MPH	2	17,760	54.2	46.3	21.9	48.4	2.4	5.10%	0.02
	50 MPH	1	11,448	50.1	43.1	19.3	46.9	5.2	12.17%	0.05
Toll Roads	65 MPH	1	4,728	72.6	67.4	19.4	69.8	4.0	5.87%	0.06
HOV Facilities	65 MPH	3	26,126	87.5	74.3	17.5	78.7	6.8	9.19%	0.04

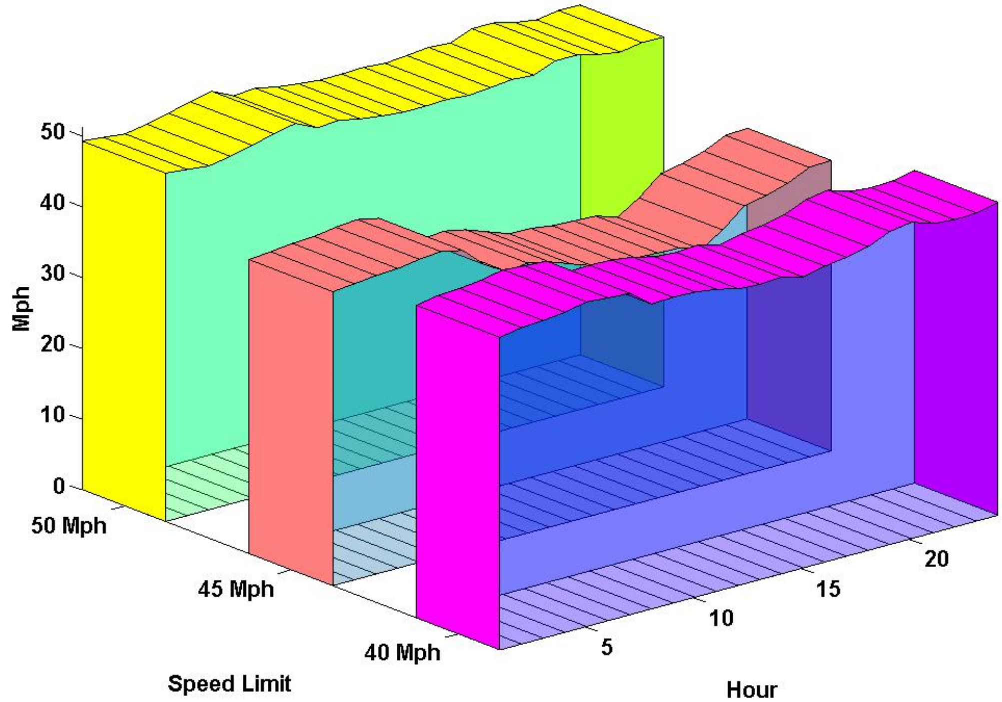

FIGURE 3.17 Hourly Average Speed by Time of Day and Speed Limit

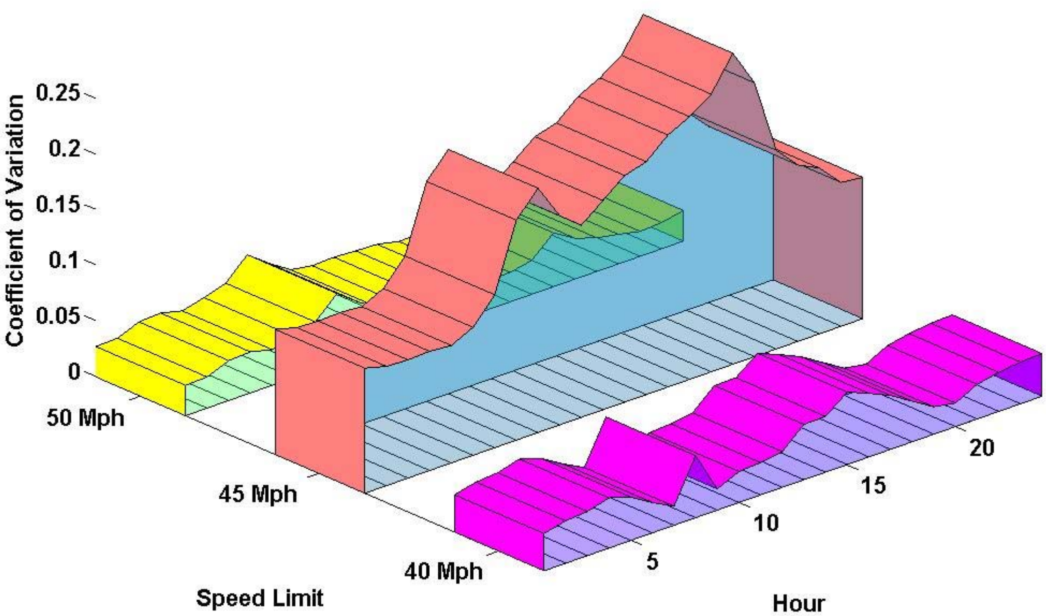

FIGURE 3.18 Coefficient of variation of average speed

3.4.5 Daily Variation Patterns

Traffic volumes and speeds conform to diurnal variation patterns resulting from trip purposes and the type of land use within which the facility is located. Figure 3.19 and Figure 3.20 reveals the diurnal variation of traffic flow in a typical urbanized divided arterial with a posted speed limit of 45 MPH.

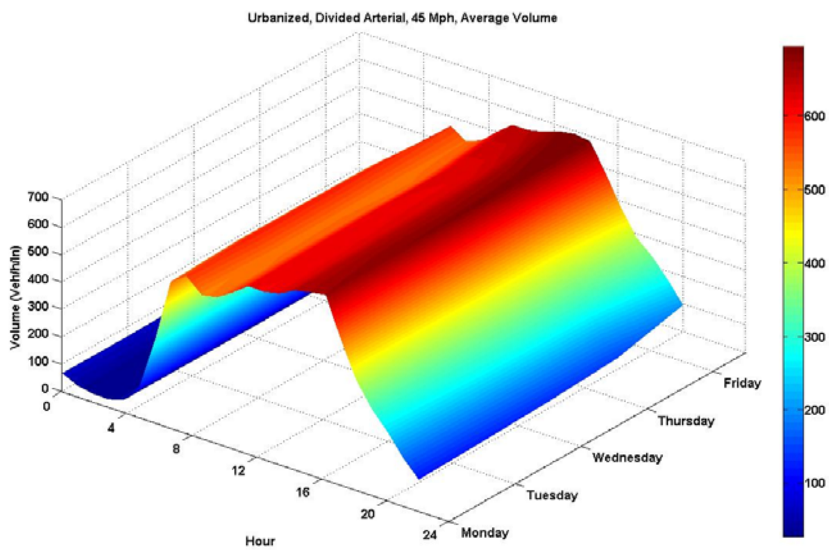

FIGURE 3.19 Hourly Volumes by Day of the Week in Urbanized Area Type

Figure 3.19 and Figure 3.20 display the recurrence of morning and evening peak hours. In terms of daily variation patterns, Thursday and Friday show wider and higher peaks compared to other weekdays. The pattern is somewhat similar in both Urbanized and Rural area types. The plots for other area types are shown in Appendix D.

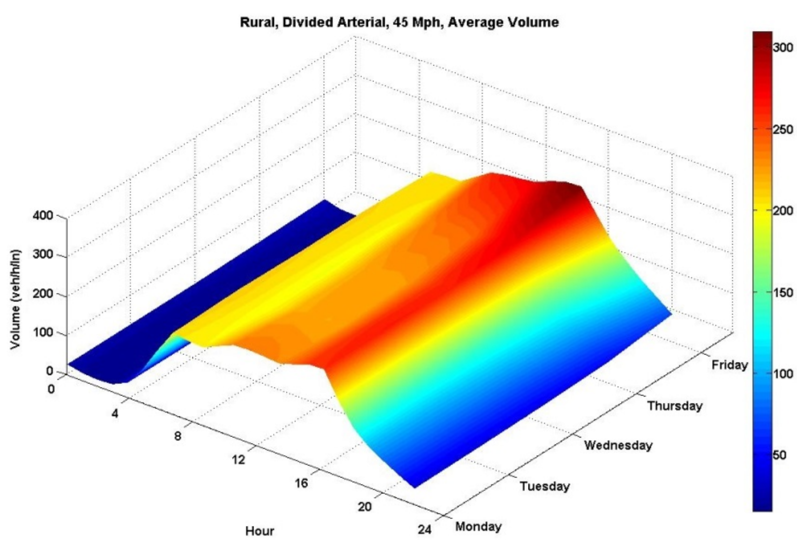

FIGURE 3.20 Hourly Volumes by Week Days in Rural Area Type

Although Figure 3.19 shows the typical bimodal peaking characteristics for all weekdays, traffic seems to be more intense in the afternoon peak on Thursdays and Fridays. Closer examination of Figure 3.19 indicates that there is peak spreading on those two days with deep red color (indicating intense traffic) spreading over many hours around the evening peak.

3.4.6 Combined Volume and Speed Analysis

Foregoing sections discussed volume and speed separately. To gain a better understanding of how hourly speed and hourly volumes are varying across different facility types, area types, and speed limit categories it is important we analyze all these variables in a combined fashion. Figure 3.21, Figure 3.22 and Figure 3.23 were produced in an attempt to capture speed and volume variation.

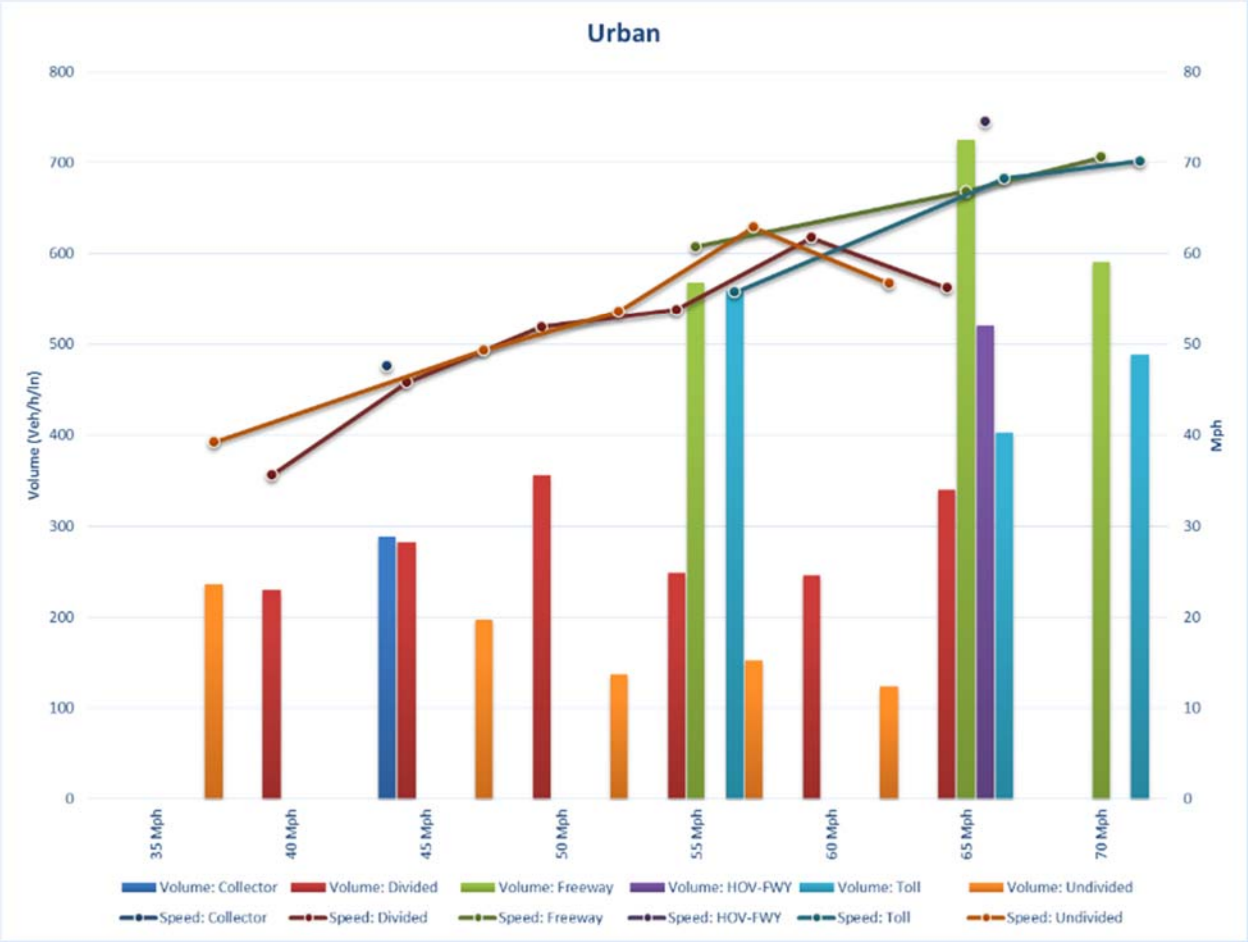

FIGURE 3.21 Combined Volume and Speed Analysis in Urban Area Type

The comparison of volumes between facility types show that in most cases, at the same speed limit, higher class facility types carry more volumes than lower classes. The relationship between volume and speed limit is not very distinct for all three area types; urbanized, urban and rural area types. As expected, there is a clear pattern which shows that the average speed increases consistently with increasing speed limit.

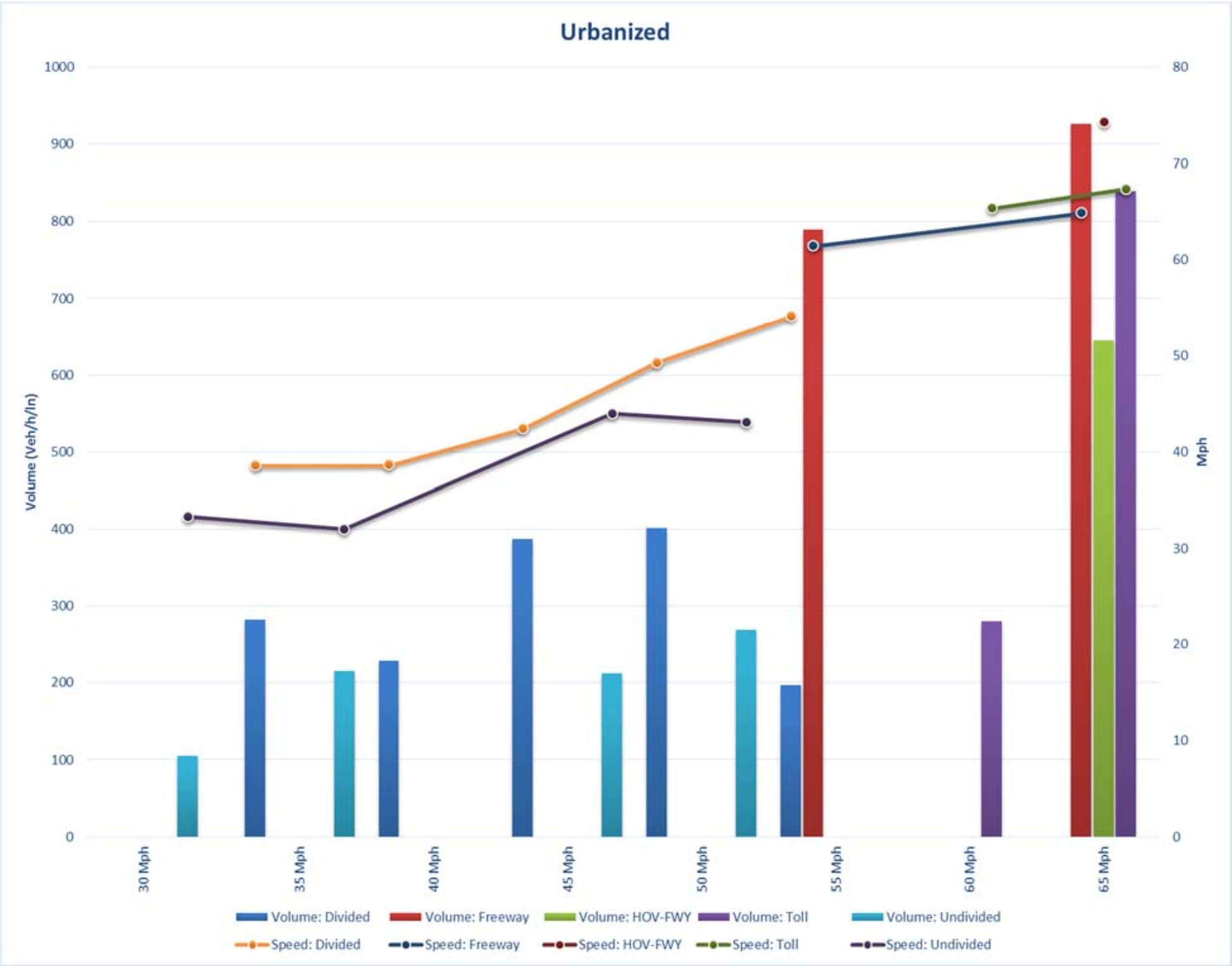

FIGURE 3.22 Combined Volume and Speed Analysis in Urbanized Area Type

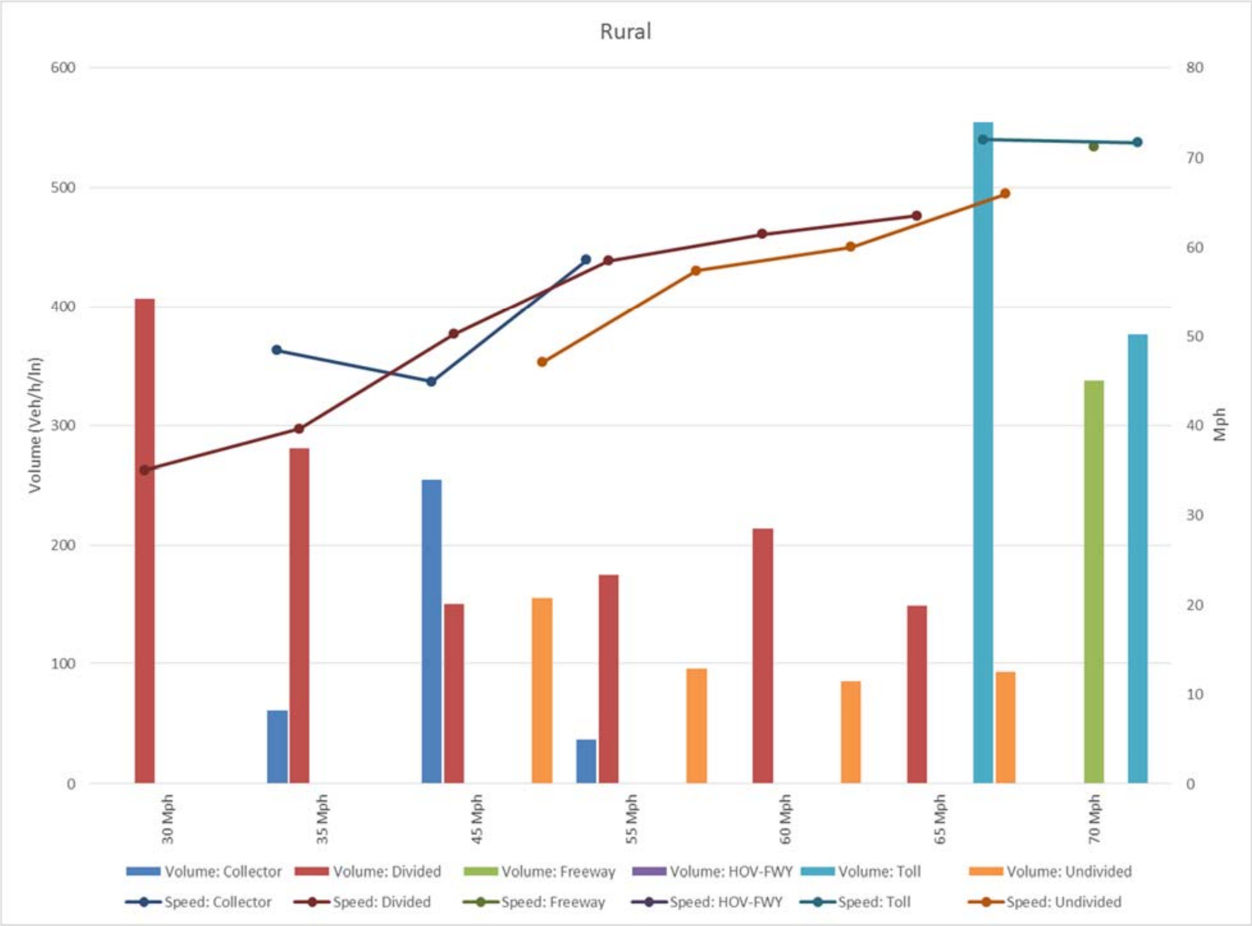

FIGURE 3.23 Combined Volume and Speed Analysis in Rural Area Type

3.5 Multi-year Analysis of Volumes and K-Factors

When hourly traffic patterns are anticipated, we have been accustomed to think of two peak hours of the day: morning and evening in which the morning peak is characterized by regular commuters going to work and the evening peak is characterized by these commuters returning home. These patterns tend to be repetitive and more predictable than other facets of traffic demand. This so called typical pattern holds only for weekday travel. Recent empirical observations suggest that this pattern is not as typical as we have been inclined to accept.

The hourly variation patterns for different years tend to shift for peak traffic as can be seen in Figure 3.24. In some cases the shift of traffic pattern tends to flatten in the AM and PM peaks leading to uniform traffic for a significant number of hours. The absence of clear AM and PM peaks is a spreading phenomenon. This phenomenon can be observed well with high temporal resolution data (15 minute interval data or lower). A tri-modal peak is consistently observed across multiple years studied and summarized in Figure 3.24. This is a typical volume profile for urban arterials that connect to the central business district. From Figure 3.24, it is difficult to clearly tell the differences in traffic patterns year by year. Additionally, data summarized in Figure 3.24 shows no clear evidence of peak spreading. The data used to produce Figure 3.24 was extracted from TTMS site located on Apalachee Parkway in the City of Tallahassee, Florida.

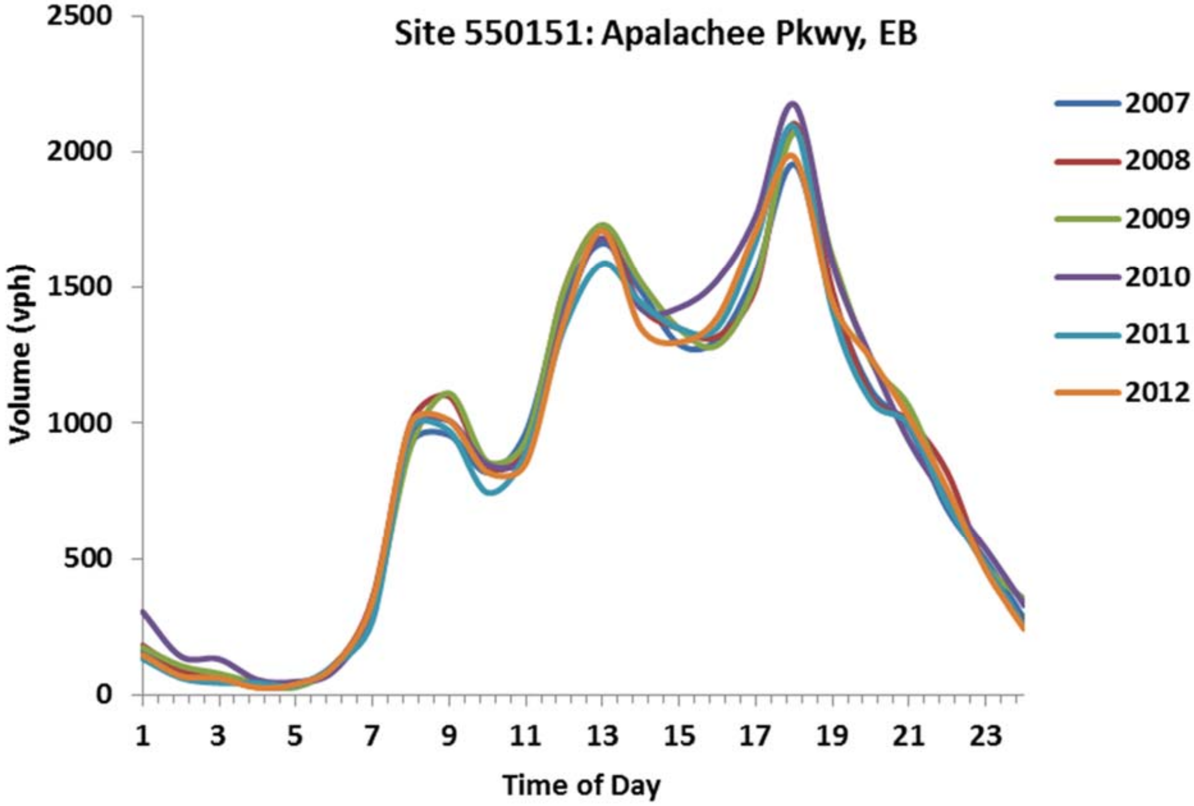

FIGURE 3.24 Change in Time of Day Volume Profiles on an Urban Arterial

To identify the shift or spread of peak traffic, K-factor is used. K-factor is the ratio of the traffic volume in the study hour to the annual average daily traffic (AADT). The K-factor generally decreases with spread out of traffic volumes over longer time periods. This characteristic is a direct result of system capacity constraints. Trips occurring during the normal peak hours cannot be accommodated if they exceed the practical capacity of the facility. Therefore, travelers begin to switch travel choices that allow them to travel during off-peak hours. The switching process continues until off-peak periods are nearly difficult to separate from peak periods. Since travelers are always switching their departure times in order to avoid the most congested hours, the yearly change in peak periods creates a non-stationary process as seen in Figure 3.25.

It can be deduced from Figure 3.25 that both K-30 and K-100 were higher in 1997 and there was a gradual decrease for the years 1998, 1999, and 2000 indicating that volumes were spread out over longer times during peak periods. In 2001, there were still longer peak periods compared to 1997, 1998 and 1999 but in comparison to 2000, the K-30 and K-100 are higher implying the shrinking of peak period. As stated before, the variations of K factors are not expected to be linear process since travelers are always switching between times of the day to undertake trips. Regardless of sinusoidal variations in K factors, there has been an indication that peak hour traffic has been growing in 2012 compared to 1997.

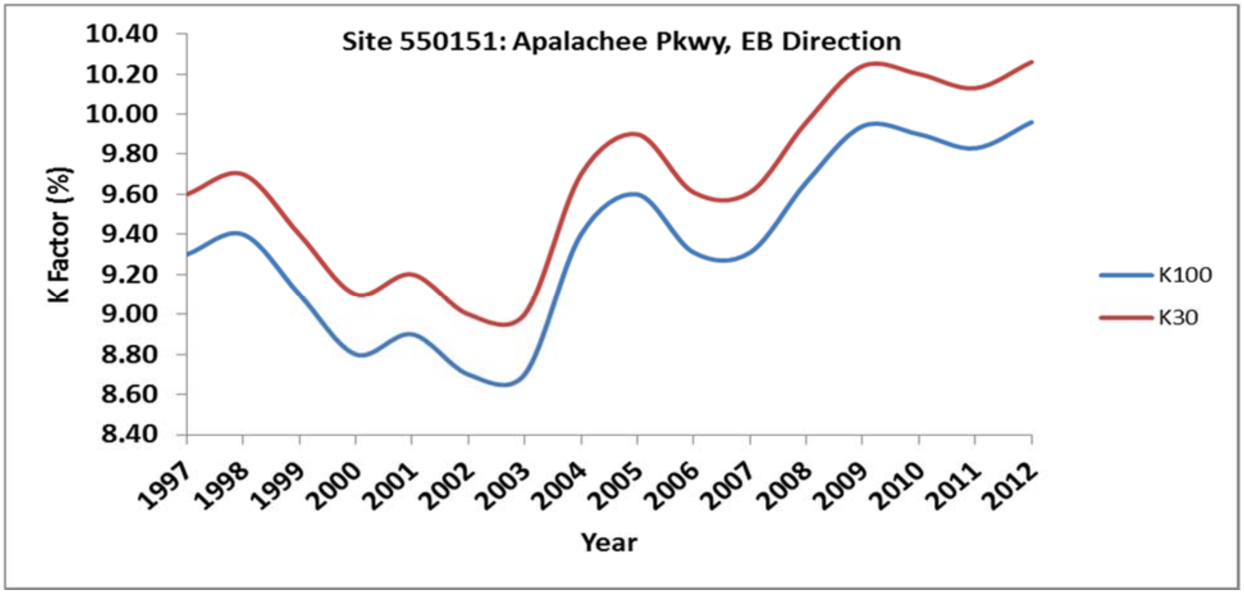

FIGURE 3.25 Yearly Change in K factors on Urban Arterial

Annual volume and K-factor variation of uninterrupted flow facilities were also examined. Figure 3.26 shows an example of an urbanized expressway. The site for the data used for Figure 3.26 is on Palmetto Expressway in Miami. Figure 3.26 shows that for uninterrupted flow facilities in urbanized area the change in K factors follow similar nonlinear properties but overall K-factors in 1996 were higher compared to 2012. Although the K-factor in 2012 is lower than the K-factor in 1996, there is no discernable trend that could lead to the conclusion that the overall trend in annual K-factor is downward.

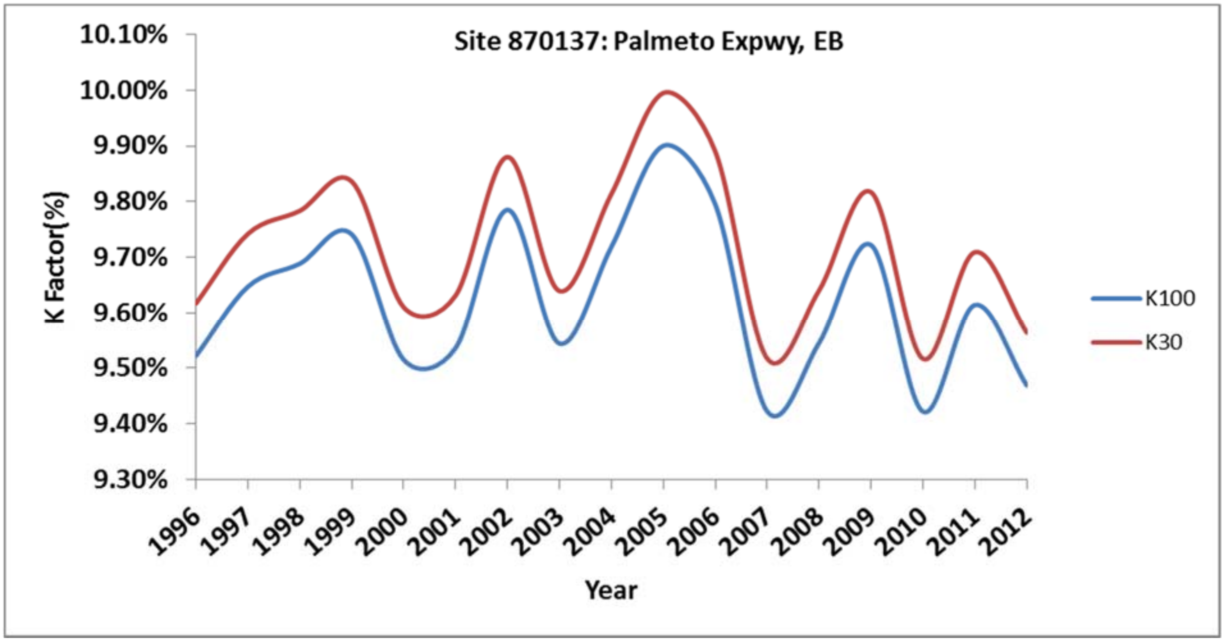

FIGURE 3.26 Yearly Change in K factors on Urbanized Expressway

3.6 Derivation of Measures of Effectiveness

Most urban transportation and traffic management agencies are developing programs to tackle increased congestion in urban areas. In addition to pursuing strategies to reduce the growth of congestion and provide mobility options, transportation agencies are also concerned with improving the reliability of the transportation system. To ensure that the analysis of system adequacy leads to a viable decision, there should be measures of both average conditions and indications of how often and how much the performance varies from the average. In the following subsections, congestion levels based on travel speed drop (as a percentage of the free-flow speed) and reliability measures are derived. In addition, the applicability and significance of these measures in system assessment is discussed. The derivation and analysis of these measures of are carried out in every hour of the day in order to capture the variations of traffic metrics within 24 hour period.

3.6.1 Analysis of Congestion Levels in 24-hour Period

Archived data can provide deep insight for the system managers, operators, analysts, and users of traffic operating characteristics. The archived data, which are relatively easy to access and process, can assist in the derivation of system performance measures which in turn can enable system managers to monitor congestion, program improvements, schedule maintenance, and provide a basis for investments prioritization and justification. In this section, we derive and analyze congestion characteristics. The congestion level is calculated based on the speed reduction factor (SRF) as defined in the 2012 Urban Mobility Report (Schrank *et al,* 2012), which calculates SRF by dividing the average combined peak period speed by the free-flow speed. The calculated SRF values were used to measure of congestion levels as follows:

1. For uninterrupted flow facilities (i.e., freeways):
   - SRF ranging from 90% to 100% (no to low congestion)
   - SRF ranging from 75% to 90% (moderate congestion), and
   - SRF less than 75% (severe congestion)
2. For interrupted flow facilities (i.e., non-freeways):
   - SRF ranging from 80% to 100% (no to low congestion)
   - SRF 65% to 80% (moderate congestion), and
   - SRF less than 65% (severe congestion)

The SRF cutoff points for the congestion levels in the interrupted flow facilities are relatively similar to those used in the 2010 Highway Capacity Manual (HCM 2010) urban arterials level of service (LOS) analysis (see Figure 3.27).

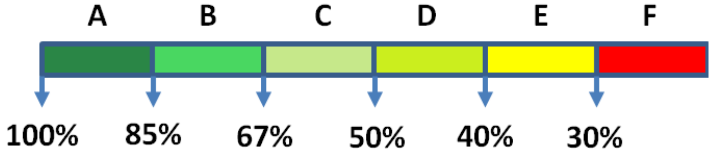

FIGURE 3.27 2010 HCM Automobile LOS Criteria

The free-flow speed assumption and the calculation used in the 2012 Urban Mobility Report were modified to fit the need of quantifying the measures of effectiveness for the 24-hour period. In the 2012 Urban Mobility Report the average combined peak period speed was used and the free-flow speed was assumed to be the speed observed between 10 p.m. to 5 a.m. In this study, the SRF is calculated for each hour within the 24-hour period. The free flow speed is determined according to the HCM 2010 definition of free-flow speed, which is the average running speed under very low volume conditions. In this study, a low volume condition was chosen to be less or equal to 200 vehicles per hour per lane representing an average headway of 18 seconds. After removing low-volume hours occurring at night, the hourly harmonic mean speeds (equivalent to space mean speeds) were again ranked in ascending order for only those hours that had volume less or equal to 200 vehicles per hour per lane. Subsequently, the time of day SRF was calculated as shown in the following equation:

$$SRF_t^i = \frac{S_t^i}{FFS^i} \quad \text{3. 3}$$

where SRF_t^i and S_t^i are the speed reduction factor and average travel speed for segment i at time t respectively and FFS^i is the free-flow speed for segment i. After calculating the time of day SRFs, the definitions of congestion levels described in the 2012 Urban Mobility Report are interpreted numerically in order to enable the representation of segment performance measures quantitatively. The interpretation is done by assigning numerical units to congestion levels (CONLEV_t^i) as follows:

1. For uninterrupted flow facilities (i.e., freeways):

$$\text{CONLEV}_t^i = \begin{cases} 1, & \text{if } 90\% < SRF_t^i \leq 100\% \\ 2, & \text{if } 75\% < SRF_t^i \leq 90\% \\ 3, & otherwise \end{cases} \quad \text{3.5}$$

2. For interrupted flow facilities (i.e., non-freeways):

$$\text{CONLEV}_t^i = \begin{cases} 1, & \text{if } 80\% < SRF_t^i \leq 100\% \\ 2, & \text{if } 65\% < SRF_t^i \leq 80\% \\ 3, & otherwise \end{cases} \quad \text{3. 6}$$

The process of defining congestion levels numerically was carried out for each of the 24-hour period for each facility type, area type, and speed limit combination. After defining the congestion levels numerically, several analyses were performed to identify system performance by using CONLEV_t^i values in combination with the hourly volume profiles. An example of the results from this process is shown in Figure 3.28. From Figure 3.28 it can be deduced that an urbanized undivided arterial segments with speed limit of 35 MPH would have expectation of Level 2 congestion (i.e., moderate congestion) from 1 a.m. to 6 a.m. The decrease in volume is consistent with the increase in speed from 1 a.m. up to 6 a.m. leading to change in congestion from Level 2 to Level 1 between 6 a.m. and 7 a.m. The steady increase in volume after 7 a.m. results in Level 2 congestion, which prevails from 7 a.m. to 11 a.m. From 11 a.m. up to 9 p.m. congestion jumps to Level 3. After 9 p.m. the decreasing volume reduces congestion to Level 2.

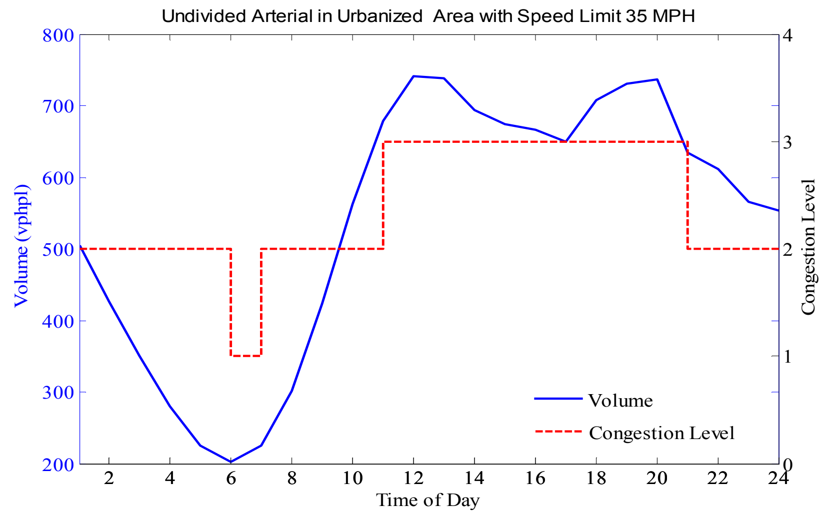

FIGURE 3.28 Hourly Volumes and Congestion Levels on Undivided Urban Arterials

Further analysis was carried out on uninterrupted flow facility type. Figure 3.29 shows that for freeways in urbanized areas with speed limit 55 MPH congestion is expected to be at Level 3 from 1 a.m. to 3 a.m. The volume decreases and travel speed increases leading to change in congestion to Level 1 between 3 a.m. and 5 a.m. The volume increases gradually which brings the congestion to Level 2 and stays at that level from 5 a.m. to 7 a.m. From 7 a.m. up to 11 a.m., the segments are experiencing morning peaks where the level of congestion jumps to Level 3 and after 11 a.m. the decrease in volume brings the congestion to Level 2 which prevails until 2 p.m. The afternoon peak spreads from 2 p.m. and 9 p.m. in which congestion climbs to Level 3 and after 9 p.m. it falls back to Level 2 for four hours until 12 a.m. The plots for segments from other facility types and area types are attached in Appendix E.

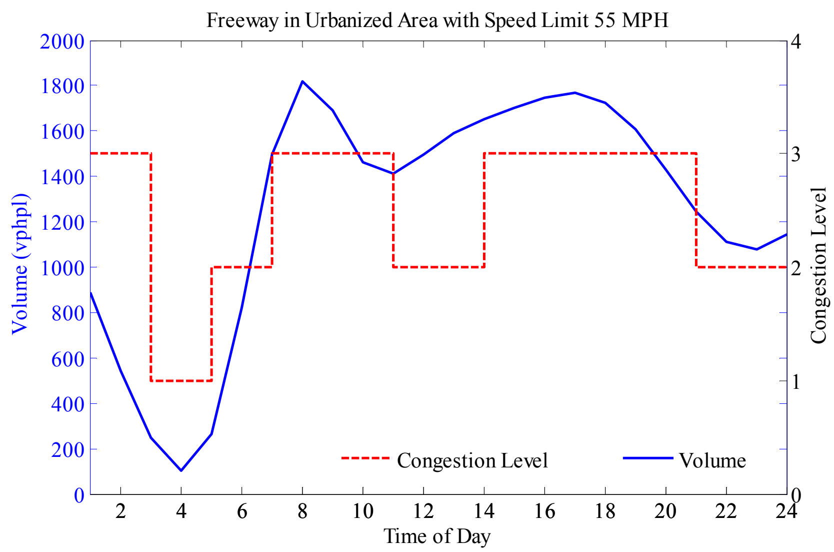

FIGURE 3.29 Hourly volumes and Congestion Levels on Urbanized Area Freeways

In addition to visual interpretations of congestion level calculated in this section, the segments were further analyzed to identify the proportion of hours within 24-hour period each congestion level prevails. Table 3.11 shows the prevalence of each congestion level for the facilities in urbanized area type. This kind of analysis is helpful in identifying failing segments in the network.

The results in Table 3.11 show that segmens experiencing congestion level 3 (severe congestion) for at least 50% of the time within 24 hour period are those in undivided arterials with speed limit of 35 MPH (58.3%), freeways with speed limit of 55 MPH (54.2%) and freeways with posted speed limit of 65 MPH (50.0%).

TABLE 3.11 Congestion Level Prevalence in Urbanized Facilities

Areal Type	Facility Type	SPEED LIMIT (MPH)	% (Average Number of Hours in a day)			Number of Vehicles (vpln)*		
			1	2	3	1	2	3
Urbanized	Undivided	30	16.7% (4)	45.8% (11)	37.5% (9)	40	1098	1393
Urbanized	Undivided	35	4.2% (1)	37.5% (9)	58.3% (14)	33	947	4171
Urbanized	Undivided	45	29.2% (7)	50.0% (12)	20.8% (5)	545	2830	1714
Urbanized	Undivided	50	16.7% (4)	54.2% (13)	29.2% (7)	175	3343	2936
Urbanized	Divided	35	16.7% (4)	41.7% (10)	41.7% (10)	109	1956	4699
Urbanized	Divided	40	33.3% (8)	37.5% (9)	29.2% (7)	420	2509	2555
Urbanized	Divided	45	16.7% (4)	50.0% (12)	33.3% (8)	512	3925	4861
Urbanized	Divided	50	29.2% (7)	41.7% (10)	29.2% (7)	846	4295	4485
Urbanized	Divided	55	29.2% (7)	37.5% (9)	33.3% (8)	279	1974	2458
Urbanized	Freeway	55	8.3% (2)	37.5% (9)	54.2% (13)	195	5771	12977
Urbanized	Freeway	65	12.5% (3)	37.5% (9)	50.0% (12)	523	8507	13188
Urbanized	HOV/HOT	65	25.0% (6)	41.7% (10))	33.3% (8)	676	6860	7933
Urbanized	Toll	60	29.2% (7)	50.0% (12)	20.8% (5)	1073	3245	2404
Urbanized	Toll	65	0.0% (0)	50.0% (12)	50.0% (12)	0	7863	12280

*These are the total number of vehicles that were caught in the corresponding congestion level.

CHAPTER 4

PREDICTION OF HOURLY VOLUME VARIATION

4.1 Overview

This chapter analyzes and models link-based hourly volume variation in urbanized areas using data extracted from telemetered traffic monitoring sites (TTMS). The TTMS data only gives the vehicular flow parameters (i.e., volume, speed, etc.) but do not give information about the composition of trips within a particular hour – i.e., whether the trip is home-based or non-home based and other subcategories thereof. Understanding trip making characteristics and modeling traffic demand profiles and peaking characteristics would require collection of origin-destination information as well as survey data of commuters' travel behavioral characteristics. Acquisition of such information was cost-prohibitive and beyond the scope of this research study.

The morning and evening peak periods typically occur in the urban transportation networks when travel demand is high. In large urbanized areas, morning peak traffic is characteristically lower than the evening peak traffic. The evening peak traffic extends over longer time period due to the influence of various kinds of trips which take place in the evening. During the evening peak, there are wider shoulder hours which occur immediately before and after the peak hour(s) where travel demands build and diminish, respectively.

Development of models to characterize 24-hour volume variation is important for planners because of insufficient resources to collect data on all possible combinations of facility types, area types, and speed limits. Thus, the use of models would enable analysts to analyze existing patterns on similar facilities that do not have traffic monitoring stations. The models can also be used to reconstruct and validate or reconstruct characteristics where there is data gap due to malfunctioning of the detectors. Additionally, the analyst can predict future traffic patterns utilizing models that were created by existing data. Such model may answer transportation policy questions such as how will the shape of the traffic demand profile look like in the future. The prediction models can also be used to test sensitivity of the traffic volume variation to changes in geometric, traffic and demographic factors.

The traffic models developed in this study have some limitations. First, these models do not represent actual travel demand to use the facility during peak periods because they are based on traffic counts. Experience shows that when demand to use transportation facility exceeds the capacity of the facility, some trips may divert to other routes, modes or destinations. TTMS data do not incorporate such trip diversions. Second, due to the limitation of the data, the models developed were not calibrated and validated with independent data set. Users should at least attempt to validate the amplitude, centroid, width and number of peak periods of the hourly volume models before using these models.

4.2 Peak Volume Models

Variables used for model development were taken from TTMS data collected in year 2012. This was the latest complete data available from FDOT at the time of the analysis. Change in traffic and peak characteristics were performed using year 1996 to year 2012 data. Two types of models were fitted to predict a.m. and p.m. peak volumes and hourly volume variations. These models are link based as the data used to develop the models do not capture detailed information about the trips. Therefore, only variables that could be associated to count stations were used to develop the models. Independent variables used in peak modeling were area type, facility type, speed limit and ADT/lane. Independent variable used for hourly volume modeling were area type, facility type, speed limit and time of day. Variables such as population, employment, or regional median household income were not associated with the TTMS data because they are indirectly captured by the area type classification. These variables were considered later in developing area-wide models based on trip purposes.

Peak volume models were specified in terms of area type (AT), facility type (FT), speed limit (SPL) and average daily traffic per lane (ADT) using the following linear regression equation:

$$V_{peak} = \beta_0 + \beta_1 AT + \beta_2 FT + \beta_3 SPL + \beta_4 ADT \quad \text{.......} \quad 4.1$$

where β_o, β_1, β_2, β_3, and β_4 are model coefficients. Speed limit and ADT/lane were assumed to be continuous. Area type and facility type (FT) were coded as multilevel categorical variables. Area type had three categories – large urbanized, urbanized and urban. Facility type had six categories – freeway, HOV, tollway, divided arterial, undivided arterial, and collector).

The results of AM and PM peak period modeling are shown in Table 4.1. The results of the AM and PM peak prediction show that Facility type, ADT/lane and speed limit are the significant variables when determining the factors influencing peak volumes. This could be due to differences in peaking characteristics among different facility types with different speed limits and ADT/lane in urban, urbanized and large urbanized areas in Florida. The area type was not a significant variable, possibly because of similarity of peaking characteristics in urban, urbanized and large urbanized areas. Overall, the model R-squared was reasonably high (85%) to indicate a reasonably degree of fit and can help planners to predict peak volumes under similar conditions.

TABLE 4.1 Peak Volume Model

Variable	**Coefficient (*p-value*)**	
	Morning Peak	**Afternoon Peak**
Intercept	393.4322 (*0.5192*)	484.5424 (*0.4103*)
AT	-72.5576 (*0.3223*)	-51.3441 (*0.2323*)
FT	-13.4792 (*0.021*)	-12.4792 (*0.0220*)
SPL	2.1602 (*0.0425*)	2.1810 (*0.0413*)
ADT	0.0431 (*0.0022*)	0.0522 (*0.0024*)
R-Square	0.8551	0.8662
Adj R-Sq	0.7745	0.8256

4.3 Typical Weekday Hourly Volume Models

The function for time of day volume for an average typical weekday was fitted to the raw data. Values of the function parameters were tweaked to ensure that the function matched the raw data as well as possible. The best values of the coefficients are the ones that minimize the value of Chi-square which given by:

$$\chi = \sum_{i=1}^{n} \left(\frac{f(x_i|\theta) - y_i}{\sigma_i} \right)^2 \quad \text{...} 4.2$$

where $f(x_i|\theta)$ is a fitted value for a given point x_i given function parameter θ, y_i is the measured data value for the point x_i and σ_i is an estimate of the standard deviation for y_i. For parameter estimation, Levenberg-Marquardt algorithm was used to solve the following optimization formulation:

$$\min_{\theta} \sum_{i=1}^{n} \left(\frac{f(x_i|\theta) - y_i}{\sigma_i} \right)^2 \quad \text{...} 4.3$$

The Levenberg-Marquardt algorithm searches for the minimum value of Chi-square in a multidimensional error space. The search process involves starting with an initial guess at the coefficient value and then moves downhill from the starting point on the Chi-square surface.

In this research, the function for time of day volume $V(h|\theta)$ for an average typical weekday was fitted using Gaussian function. The aim was to capture multiple peaks that are experienced during the day because time series plots of hourly volumes consist of multiple amplitudes. Gaussian model are preferred when the observed data have multiple peaks. Gaussian peaks are encountered in many areas of science and engineering. The strength of the Gaussian peaks models is that, it fits the data in piece-wise fashion for every region of data with similar trend. The mathematical form of Gaussian model is given as follows:

$$V(h|\theta) = \sum_{i=1}^{n} \alpha_i e^{\left[-\left(\frac{h-\mu_i}{\sigma_i} \right)^2 \right]} \text{...} 4.4$$

where α_i is the amplitude for the peak hour i, μ_i is the centroid of the peak period, σ_i is related to the peak width, n is the number of peaks to fit, and h is the centered hour of day according to $h = \frac{(H-12.5)}{7.071}$, H being the actual hour of day. The results for the fitted model are given in Table 4.2.

The measures of statistical fit that were selected in analyzing the predictive power of the fitted model were the coefficient of determination (R^2) and the root mean square error (RMSE).

Based on R^2 and RMSE values, the results in Table 4.2 show that, the fitted model is suitable for prediction of hourly volumes for an average typical weekday. The results displayed in tabular and graphical form show that, the fitted models trace the field data well, across the whole range of the analysis period hours showing *R*-squared values higher than 0.95 for all facility types. This is confirmed further by the visual observation of the model hourly volume and field observed volume plots. Figure 4.1, Figure 4.2, and Figure 4.3 represent fitted models and field data for divided arterials with speed limit of 50 MPH, freeways with speed limit of 55 MPH, and freeways with 65 MPH in large urbanized areas, respectively.

TABLE 4.2 Large Urbanized Area Model Results and Fit Statistics

FT	SPL	n	i	α_i	μ_i	σ_i	RMSE	R^2	Adj. R^2
Div	40	5	1	157	0.7379	0.1087	15.35	0.9967	0.9917
			2	-32300	-0.346	0.2893			
			3	32510	-0.3472	0.2912			
			4	720.4	16.6	10.18			
			5	378	0.511	0.7372			
	45	7	1	0	0.7104	0.006656	29.32	0.9983	0.9872
			2	969.3	-0.1438	1.329			
			3	975.5	-0.3871	1.136			
			4	426.4	-0.5913	0.2705			
			5	-43.82	-0.1275	0.2652			
			6	-240.6	0.3348	0.3212			
			7	-1606	-0.6046	0.9315			
	50	7	1	1006	0.0595	0.6531	16.6	0.9994	0.9953
			2	395.7	-0.6397	0.2134			
			3	265.3	0.982	0.8681			
			4	286.5	0.7516	0.1858			
			5	101.3	0.4373	0.07511			
			6	-517.2	0.07955	0.5326			
			7	3.71E+16	-82.57	13.87			
Undiv	35	7	1	-41.05	0.4805	0.2005	9.801	0.9977	0.9825
			2	1.91E+09	-24.79	6.398			
			3	163.3	0.5831	0.6199			
			4	-8.06E+04	-6.504	2.744			
			5	143.3	-0.5137	0.2343			
			6	-456.2	-1.277	1.576			
			7	73.83	-0.1005	0.2394			
	45	7	1	-369.7	0.3665	0.2639	14.11	0.9988	0.9911
			2	-145	0.584	0.1109			
			3	-890.5	-0.6872	0.5098			
			4	86.87	1.404	0.3409			
			5	3655	-0.1188	0.7213			
			6	194.4	-0.5973	0.1575			
			7	-3131	-0.08028	0.5456			
	50	7	1	0	-3.015	0.08939	32.44	0.995	0.9615
			2	91.57	1.496	2.709			
			3	202.3	-0.7652	0.1583			
			4	112.6	0.1528	0.2355			
			5	414	0.7051	0.4821			
			6	243.2	-0.1898	0.321			
			7	286.2	-0.5529	0.1973			

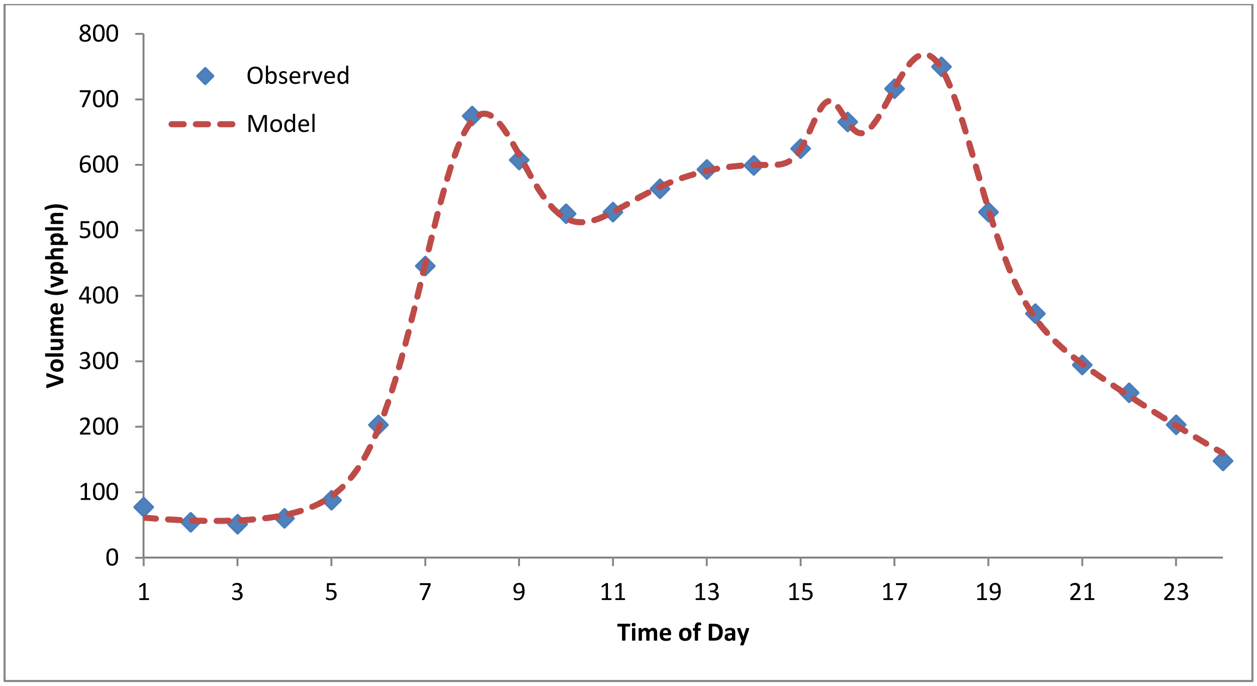

FIGURE 4.1 Modeling on 50 MPH Divided Arterials in Large Urbanized Areas

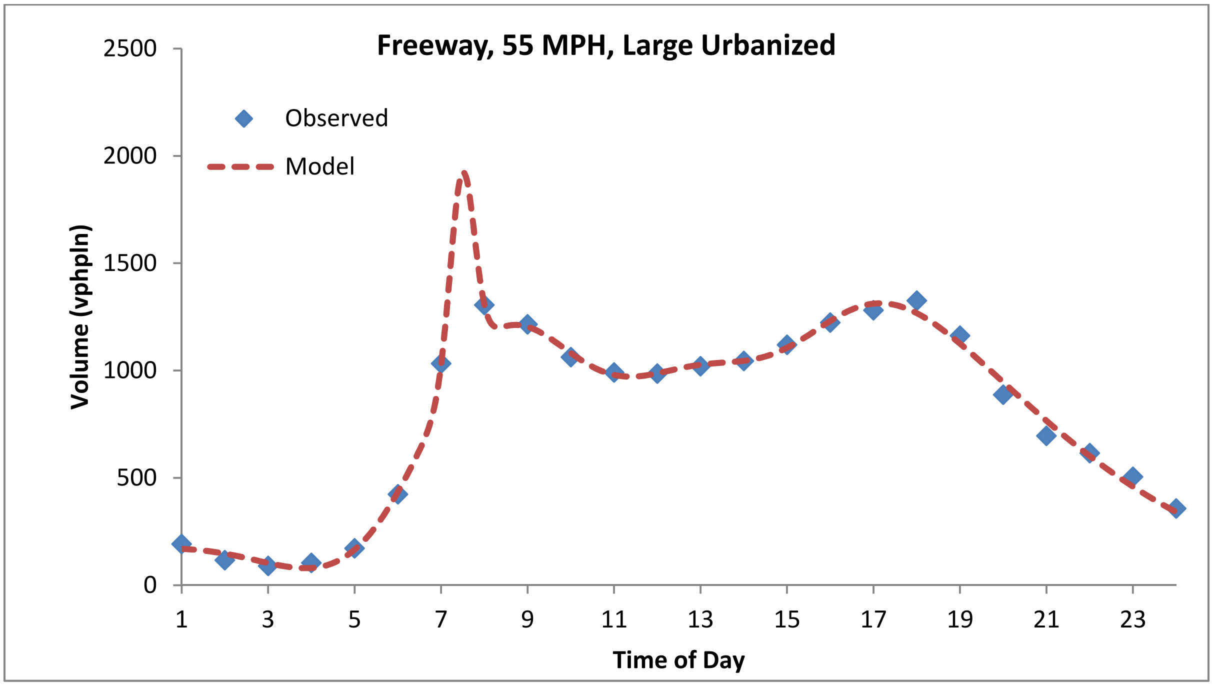

FIGURE 4.2 Modeling on 55 MPH Freeways in Large Urbanized Areas

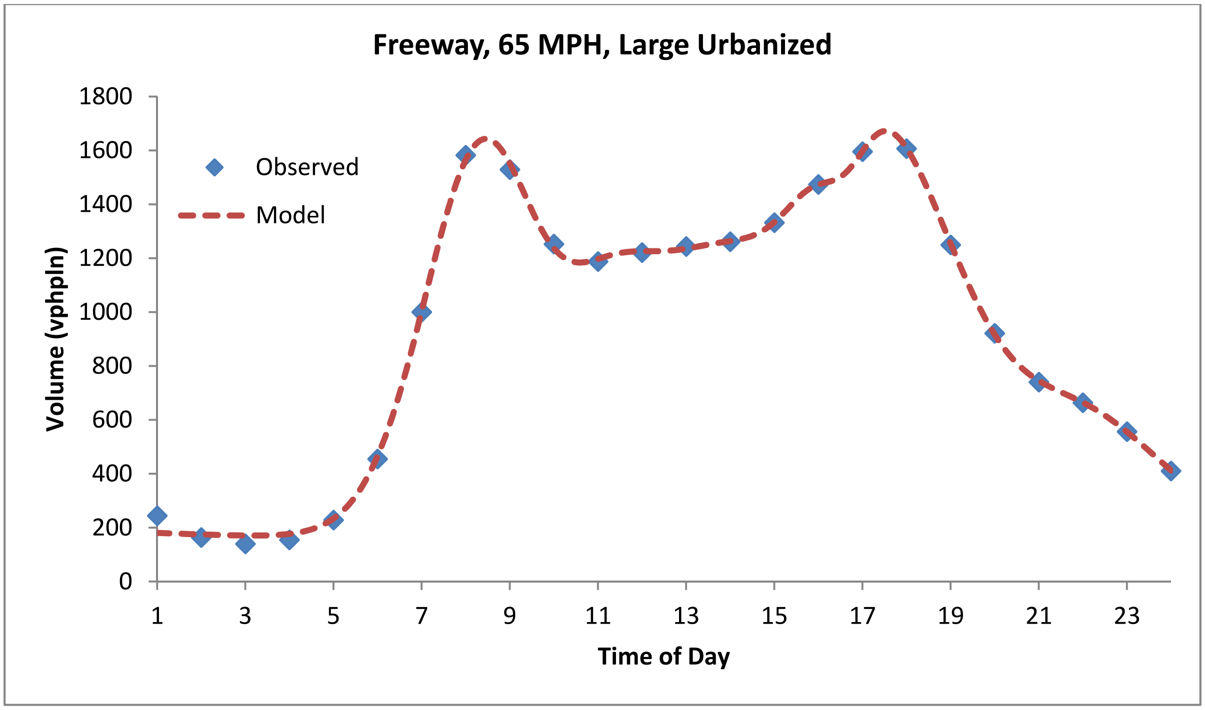

FIGURE 4.3 Modeling on 65 MPH Freeways in Large Urbanized Areas

4.4 Adjusted Daily Hourly Volume Models

The function $V(h|\theta)$, predicts the hourly volumes for an average typical weekday. However, sometimes in transportation systems analysis, there are needs to estimate hourly volumes, for a particular weekday. Since different weekdays have different traffic patterns, it is important to modify the fitted models, $V(h|\theta)$ to capture the effects of varying traffic patterns. The modification is done by incorporating the modification factors $\emptyset(h|Day\ j)$ in order to convert the function $V(h|\theta)$ to $V(h|Day\ j)$. The daily correction factors $\emptyset(h|Day\ j)$ are calculated as:

$$\emptyset(h|Day\ j) = \frac{V(h)^{Day\ j}}{V(h)^{Typical}} \qquad 4.5$$

where $\theta(h|Day\ j)$ is the correction factor for volume on hour h given day J, $V(h)^{Day\ j}$ is the volume on hour h for day j and $V(h)^{Typical}$, is the average typical day volume on hour, h. The results of the calculated daily correction factors for divided arterials with speed limit of 45 MPH in large urbanized areas are shown in Figure 4.4.

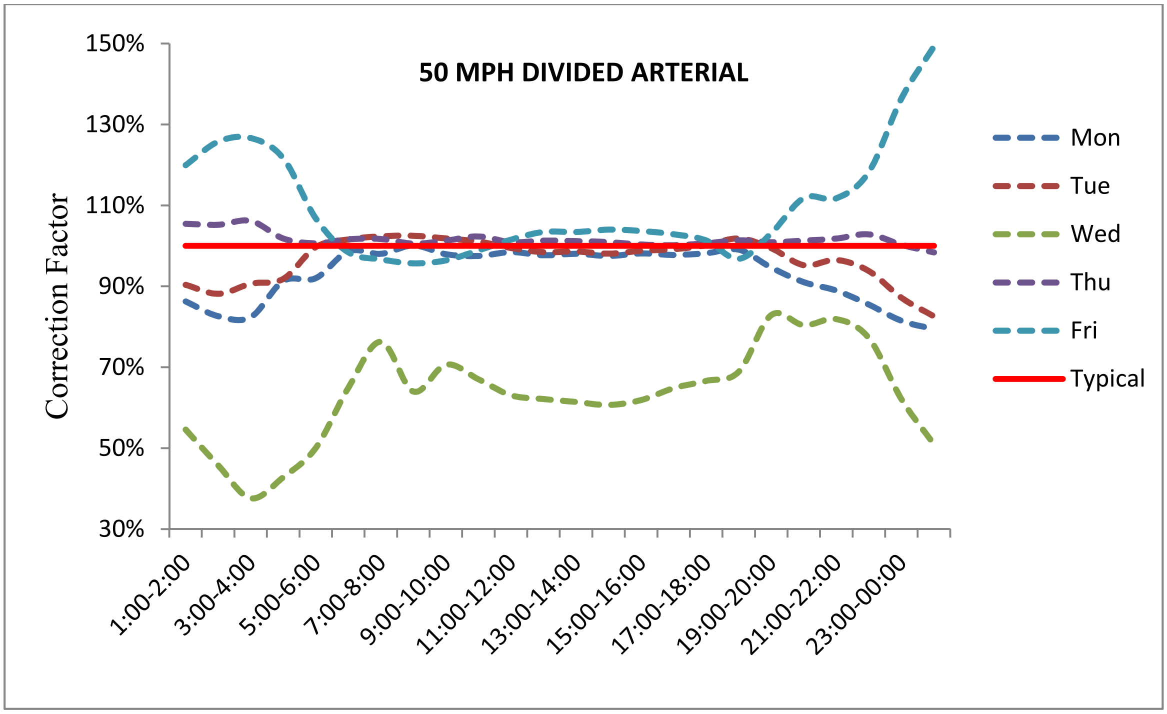

FIGURE 4.4 Correction Factors for 50 MPH Divided Arterial

Figure 4.4 shows that, there are significant deviations of daily traffic volumes from the average typical weekday volumes especially early in the morning and evening hours. In terms of daily variation patterns, Thursday and Friday show higher deviations from typical day compared to other weekdays.

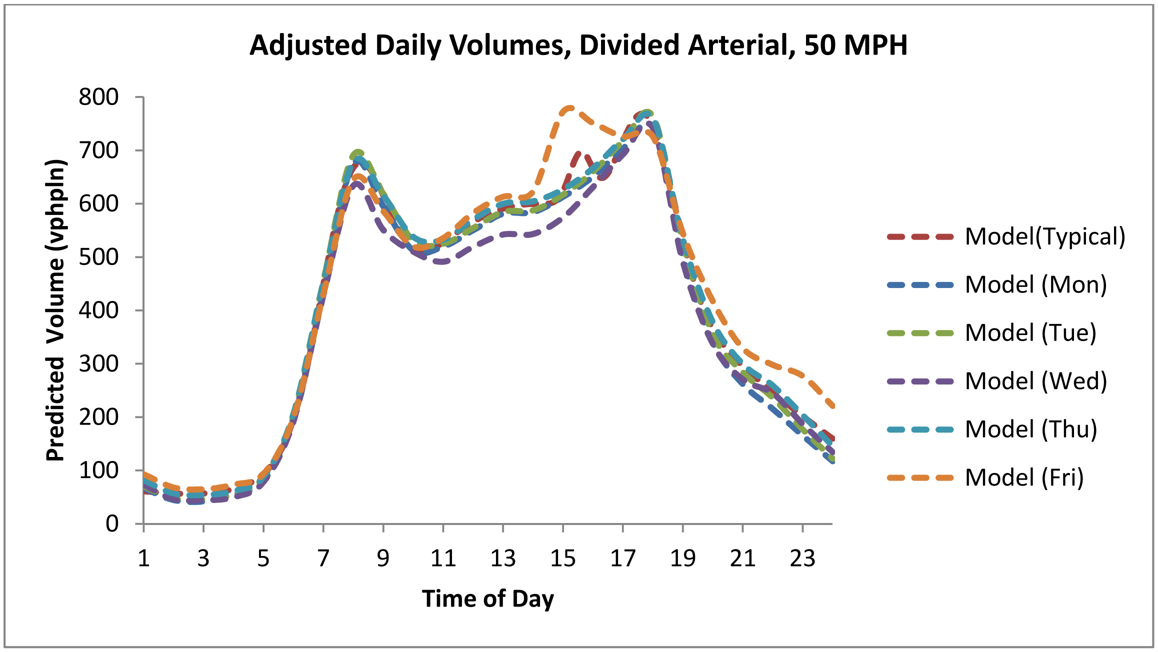

FIGURE 4.5 Modeling on 50 MPH Divided Arterial in Large Urbanized Areas

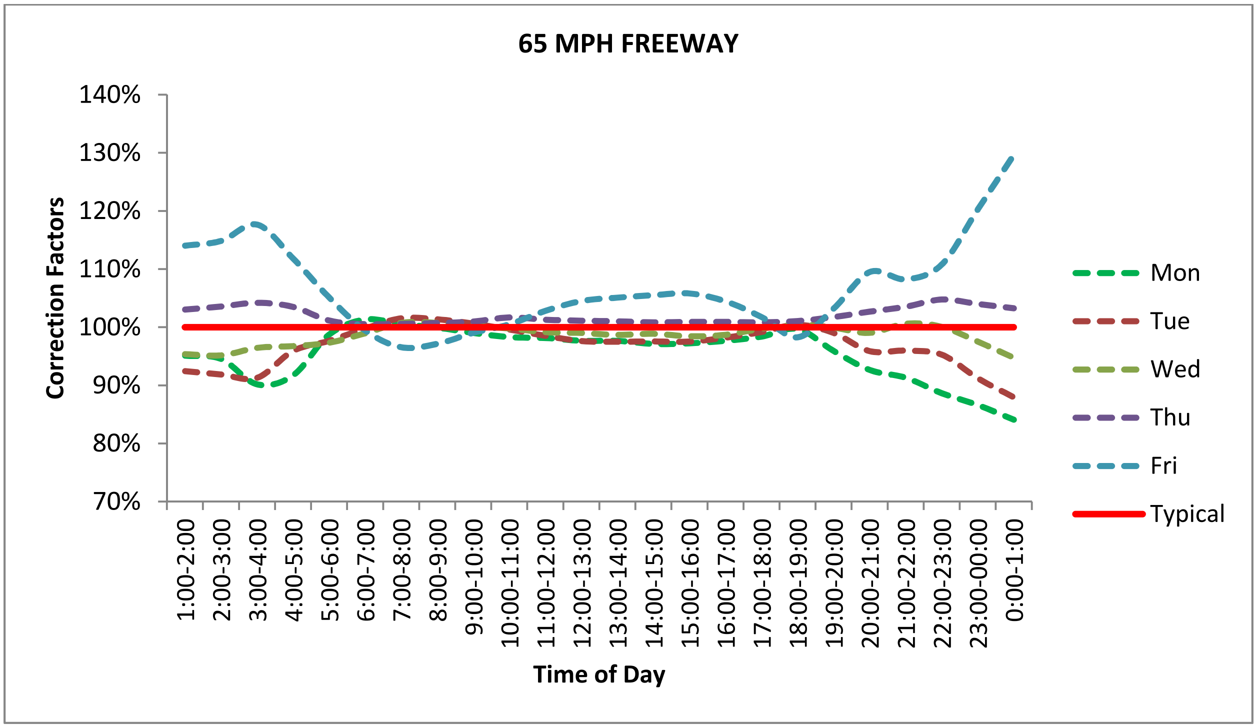

FIGURE 4.6 Correction Factors for 65 MPH Freeway in Large Urbanized Areas

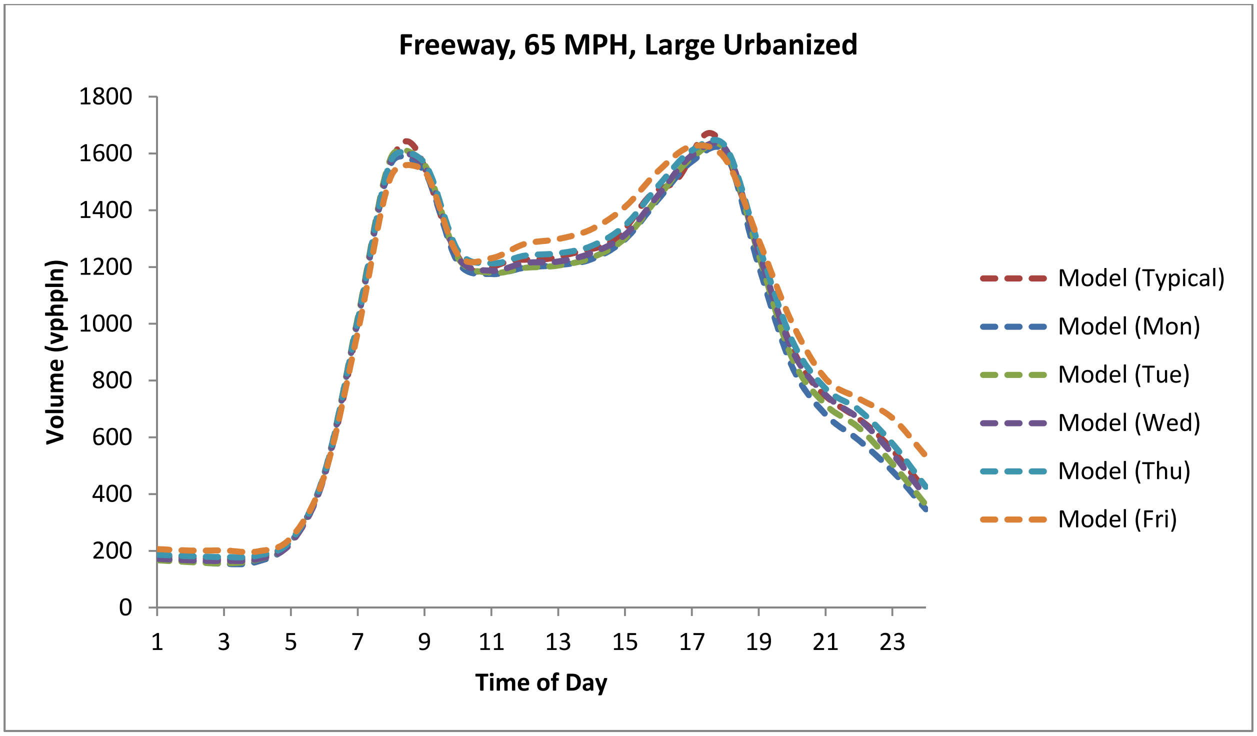

FIGURE 4.7 Adjusted Daily Volume for 65 MPH Freeway in Large Urbanized Areas

4.5 Trip timing and travel behavior

To determine the time at which commuters travel and other associated characteristics, the National Household Travel Survey (NHTS) data were reviewed. NHTS is the only national source of travel data that connects the characteristics of the trip (e.g., mode used, trip purpose, trip length) with the characteristics of the household. It is a vast database of information on the respondents' personal, household and trip making characteristics. However, NHTS data has under-coverage limitation because they do not represent all samples households and all people within the sampled households.

The analysis of the NHTS database provided information on the most recent travel patterns and trip-making behavior for residents in Florida's large urbanized metropolitan areas which are Jacksonville, Miami-Fort Lauderdale-Pompano Beach, Orlando-Kissimmee and Tampa-St. Petersburg-Clearwater. The NHTS database categorizes trips resulting from surveys as follows:

- *Home- based Work (HBW)* – Home is one end of the trip and work to be the other.
- *Home-Based School (HBS)* – Home is one end of the trip and school is the other.
- *Home-Based Shop (HBSH)* – Home is one end of the trip and shop is the other.
- *Home-Based Social Recreation (HBSocRec)* – Home is one end of the trip and social recreation is the other.
- *Home-Based Other (HBO)* – Home is one end of the trip and the other end is not work, school, shop or social recreation.
- *Non-Home-Based Work (NHBW)* – one end of the trip is not home and the other end is work
- *Non-Home Based Other (NHBO)* – one end of the trip is not home and the other end is not work, school, shop or social recreation.

Using the NHTS data, peak period travel movements as well as factors and trip types contributing to the peak period traffic congestion were determined. For instance, Figure 4.8 shows peaking characteristics for work related trips. The highest morning peak which accounts for 14% of all work related trips, occurs around 7:00 a.m. while the pre-peak and post-peak shoulders occur between 6:00 a.m. and 7:00 a.m. and between 7:00 a.m. and 8:00 a.m., respectively. The highest evening peak which accounts for about 10% of all work related trips occurs around 5:30 p.m. with pre-peak and post-peak shoulders occurring between 4:30 p.m. and 5:30 p.m. and between 5:30 p.m. to 6:30 p.m.

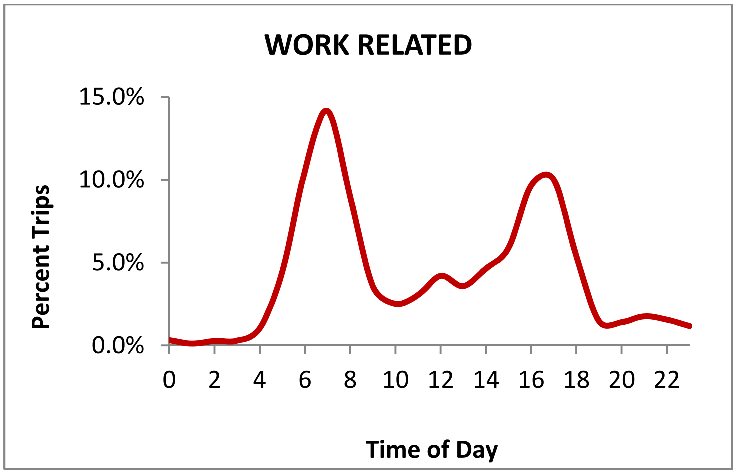

FIGURE 4.8 Peaking Characteristics of Work Related Trips

Figure 4.8 showed only work related trips but when all trips are considered and plotted together as shown in Figure 4.9, there are a few revelations. Figure 4.9 shows that, when all trips are considered, there seems to be multiple peaks occurring throughout the day with earliest peak occurring at 7:00 a.m. Other peaks occur at 10:00 a.m, 12:00 p.m, 2:00 p.m and the latest and the highest peak occurs at 4:00 p.m. More time of day peaking characteristics analysis by trip purpose are shown in Appendix F. These trips have trip length distribution as shown in Figure 4.3 and they experience an average trip length of 23 minutes.

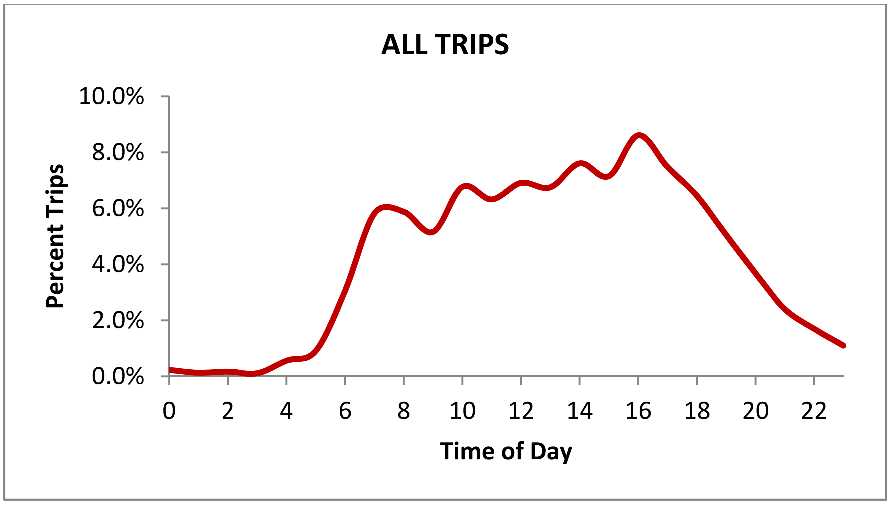

FIGURE 4.9 Peaking Characteristics of All Trips

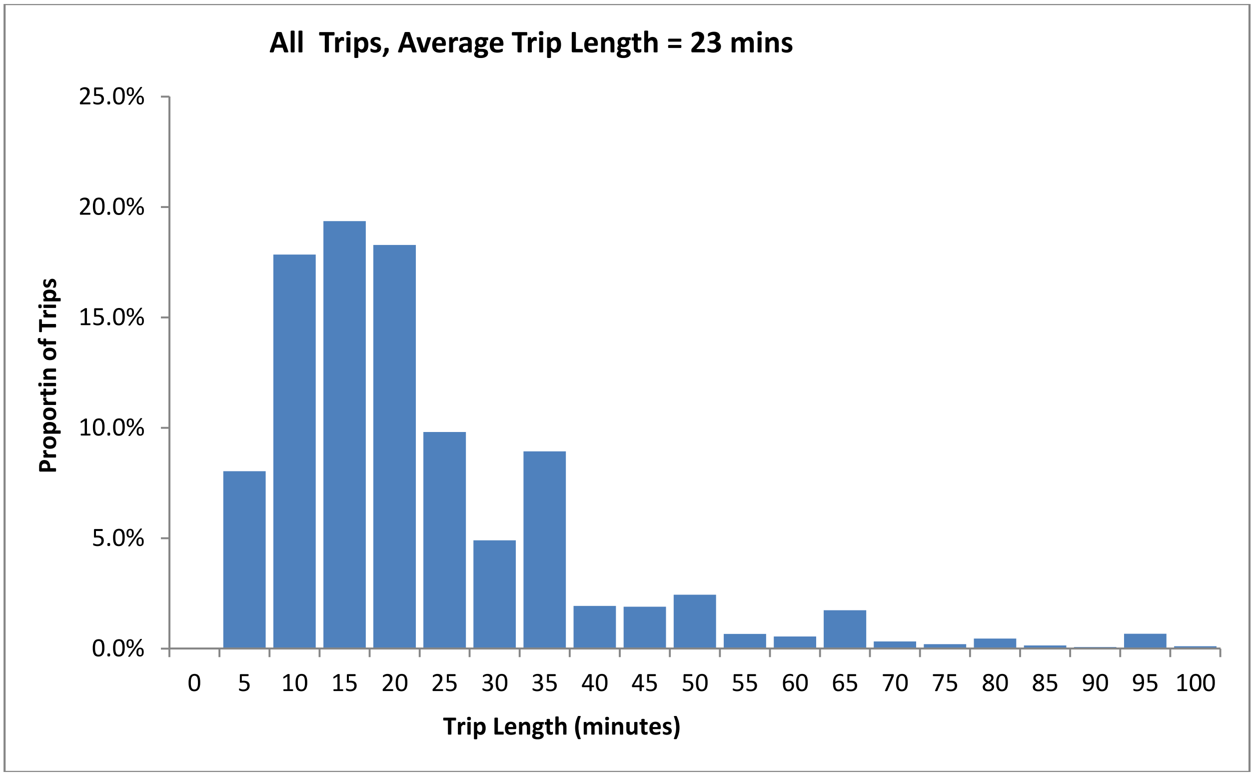

FIGURE 4.10 Trip Length Distribution for All Trips

Figure 4.10 shows that the distribution graph of trip lengths is skewed to the left suggesting that the majority of trips have shorter trip lengths. In fact, the figure shows that the majority of trips experience trip lengths between 10 and 20 minutes. There is a small proportion of trips experiencing trip lengths of more than 35 minutes. This phenomenon suggests that the majority of the trips in these large urbanized areas are made by regular commuters who on the average live approximately 25 minutes from their workplaces. Other plots for trip length distribution by trip purposes are included in Appendix G.

4.6 Proportion of trip purpose by time of day

Identification of the proportion of each type of the trip within each hour of the day required plotting one graph which has all trip categories that were defined earlier. Figure 4.11 shows the proportions for trip departures as they occur throughout the day. The categorization of trip purpose was clustered into home-based (HB) and non-home based (NHB) trip types as was defined earlier.

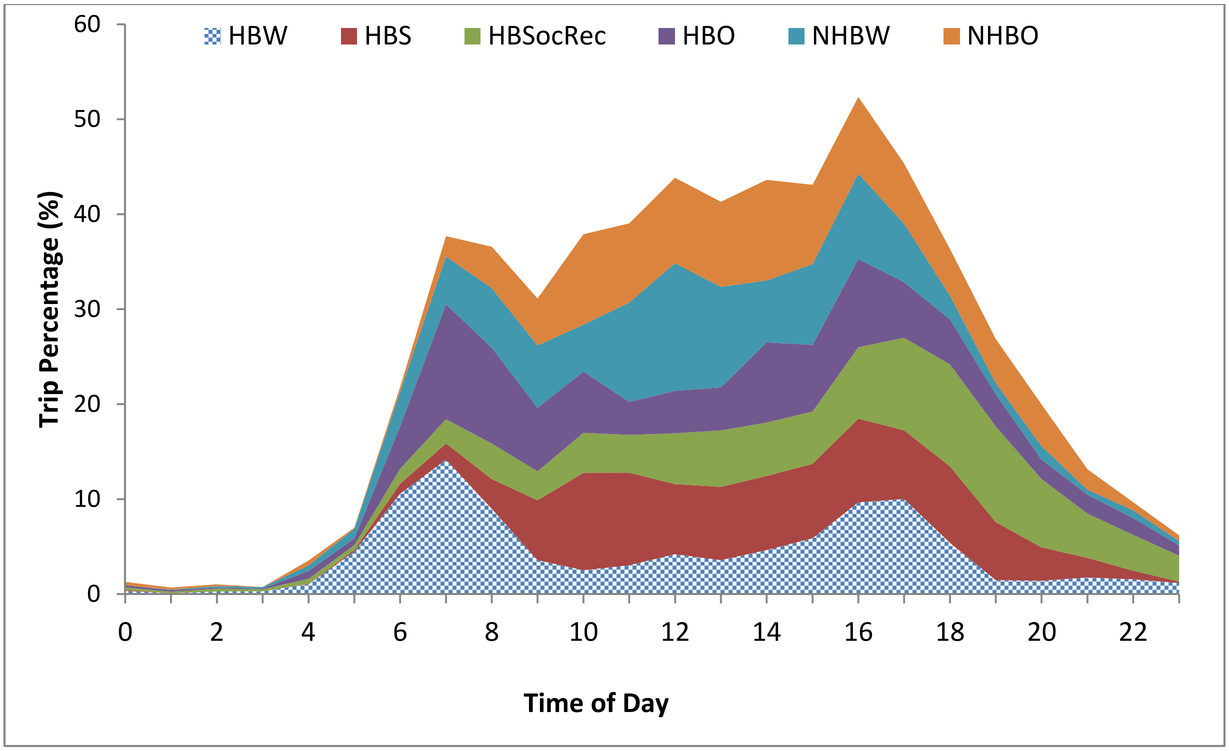

FIGURE 4.11 Departure Time Profile by Trip Purpose

Closer examination of Figure 4.11 shows that NHB work trip category is the most prevalent throughout the day judging by proportion of trips in each hour. The NHB trips were plotted as the summation of Non-Home-Based Work (NHBW) and Non-Home Based Other (NHBO). The second most frequent trip type is the Home-Based Work (HBW) category which, according to Figure 4.11, has significant influence to the peak period departures with more than 25% of trip departures occurring between 4.00 a.m. and 9.00 a.m. are generated by travelers going to and from work. Home-Based School (HBS) trips contribute significantly to the A.M. peak during the 7.00 a.m. to 9.00 a.m. timeframe and again in the P.M peak during the 3.00 p.m to 5.00 p.m timeframe. Home-Based Social Recreation (HBSocRec) trip departures generate most trips extending from 4.00 p.m. throughout the evening.

The AM peak departure period which includes its shoulders is captured within the 6.00 a.m. to 9.00 a.m. time period whereas the PM peak departure period seems to be longer in duration extending from 2.00 p.m. to 6.00 p.m. It should also be noted that the HBW critical peak occurs earlier within the AM peak period when compared to the PM peak. This phenomenon, combined with the longer duration of the HBW PM peak, suggests a more flexible departure times in the evening leading to the extended PM peak period. Table 4.3 shows the peaking characteristics for aggregated work related and all trips in Florida large urbanized areas.

TABLE 4.3 Peak and Peak-Shoulders Analysis

Time Period	Peak Position	Duration	All Trips	Work Trips
AM	Pre-peak Shoulder	6:00-7:00	5%	9%
	Critical Peak	**7:00-9:00**	**13%**	**32%**

Time Period	Peak Position	Duration	All Trips	Work Trips
	Post-peak Shoulder	9:00-10:00	6%	4%
Mid-Day	Inter Peak	10:00-14:00	25%	8%
PM	Pre-peak Shoulder	14:00-15:00	8%	4%
	Critical Peak	**15:00-18:00**	**24%**	**20%**
	Post-peak Shoulder	18:00-19:00	8%	8%
Night	Off Peak	19:00-6:00	11%	15%

The data in Table 4.3 reveal that the highest proportion of work trips occur during the critical morning peak. The evening critical peak has lower proportion of work related trips compared to morning peak but the post peak shoulder is broader than the morning post peak shoulder. This is an indication of a more extended peak period during the evening compared to morning peak period. Shoulder peak times are included in this analysis due to their importance in the quantification of the peak spreading phenomenon.

4.7 Mode choice by trip purpose

The analysis of mode share by trip purpose was conducted for the purpose of estimating the number and categories of users served by the transportation system. Figure 4.12 shows the method that was devised and used to classify the mode used by each trip purpose.

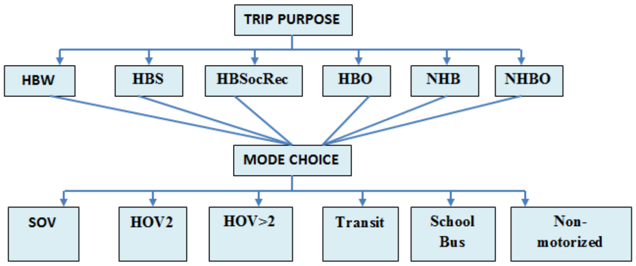

FIGURE 4.12 Analysis of Mode Choice by Trip Purpose

The results of the mode choice by trip purpose are shown in Figure 4.13. The results show that the single occupant vehicles (SOVs) are the most preferred modes of travel followed by high occupant vehicles with two occupants (HOV2). High occupant vehicles with more than two occupants (HOV>2) are more significant in HBO and NHBO trips compared to the remainder of the trip categories. Transit and school buses are the least used modes of travel while non-motorized modes are most preferred in HB social recreation trips. The HB work trips made by SOVs contribute more than 80% to total trips while NHB work trips made by SOVs account for more than 70% of total trips. The average occupancies for each trip category by time of day are shown in Figure 4.14.

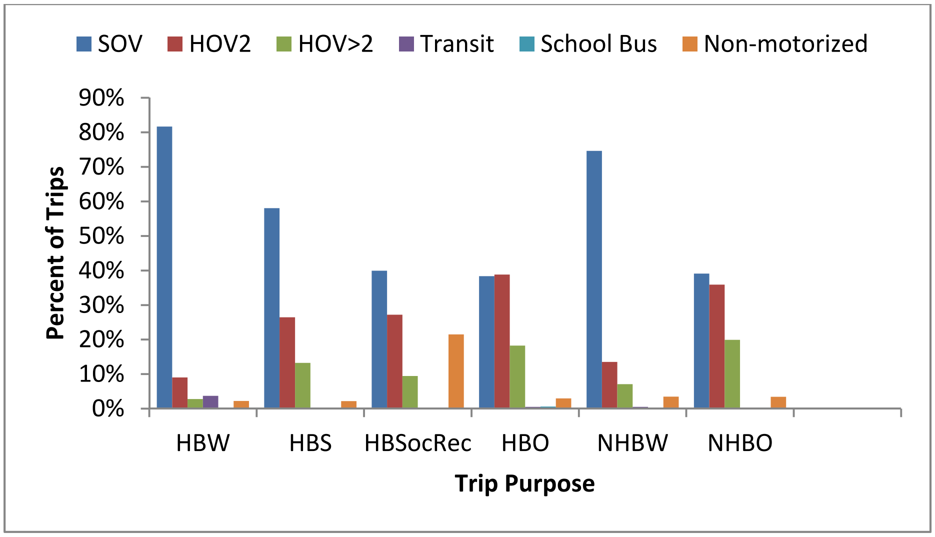

FIGURE 4.13 Mode Choice by Trip Purpose

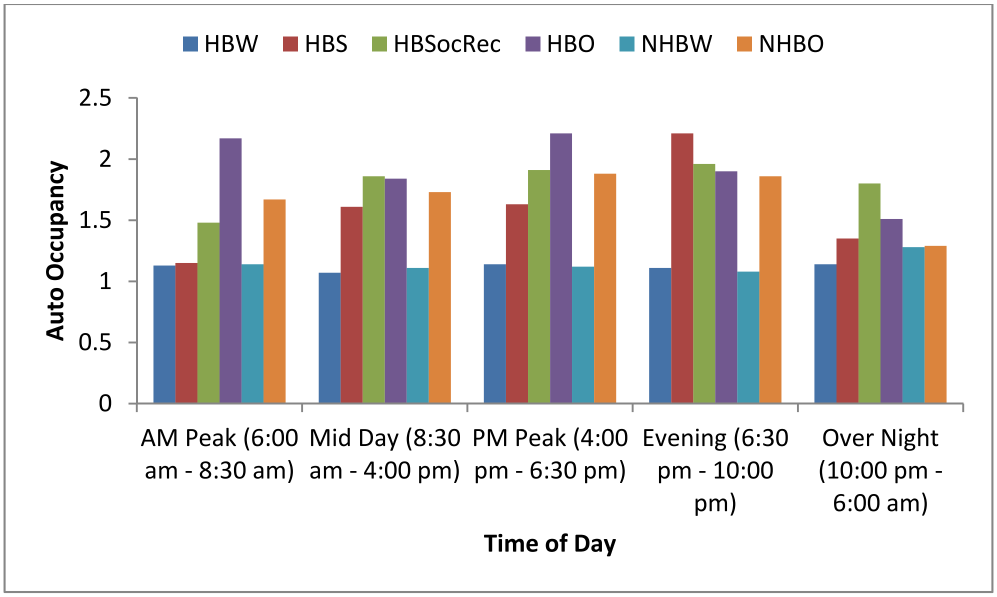

FIGURE 4.14 Mode Choice by Trip Purpose

4.8 HERS Model and Induced Demand

This section discusses the concept and the application of induced demand in predicting traffic variation. The term induced demand is used to describe the relationship between highway capacity expansion and increasing traffic. The expansion of capacity and induced demand has a cause-and-effect relationship. When the alternatives include the possibility of not making any improvement and the improvements being considered affect the quality of service, then the volume and the type of traffic are likely to be affected by the presence or absence of the improvement. However, these effects are beyond changes in demand that occur due to demographic and economic factors that may cause an increase or decrease of demand regardless of the facility characteristics. HERS which stands for Highway Economics Requirement System is a tool for analyzing improvement costs versus system performance. Through this tool modeling of future traffic flow based on induced demand can be investigated.

4.5.1 The Concept of Elasticity

Elasticity is a term used in economics to define the degree of responsiveness of the amount of a good that is purchased to the price of the good. Mathematically, this is the slope of the demand curve at any given point. By quantifying travel time, vehicle operating costs, crash risk and out of pocket travel charges as being components of price, elasticity can be used to estimate the change in traffic volume resulting from an improvement. It is worth noting the assumptions made when using elasticity to estimate the change in traffic volume resulting from capacity expansion or any improvement made to a highway section. It is assumed that demand is a combination of exogenous and endogenous factors. This means that, demand is determined by economic and demographic factors external to the highway system and factors characteristic to the highway itself (e.g., speed, travel time, reliability, crash risks, etc.).

The elasticity used in the HERS model forces traffic volumes to respond to changes in demand factors characteristic to the highway (endogenous factors), such as pavement quality. The mechanism for the response is the generalized price of travel (largely travel time) and an elasticity that relates price to volume. Travel demand forecasting (TDF) model is used to capture the response of traffic volume to factors external to the highway system (exogenous factors), such as economic growth, population growth, land use patterns, available transportation alternatives, and other factors. The relationship and the application of both TDF model and HERS are summarized in Figure 4.15. An analyst must provide the standard value of demand elasticity accepted by the agency for analysis segment in HERS. In Figure 4.15, it can be observed that the HERS methods can be integrated in the TDF model for comprehensive estimation of future demand due to endogenous and exogenous factors. The analyst can choose to use each model independently if demand due to specific factors need to be estimated.

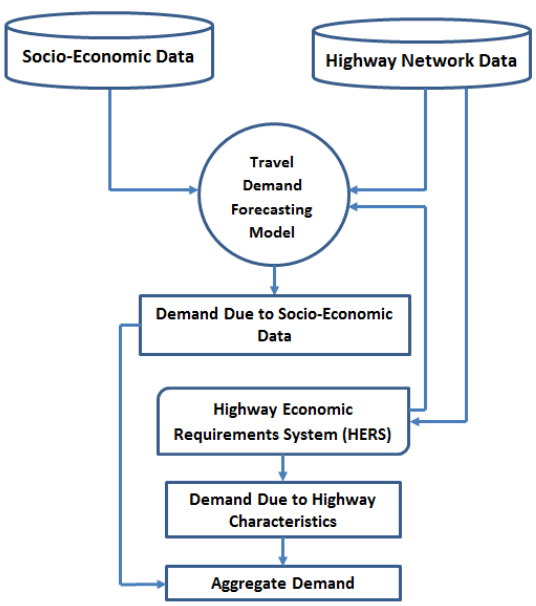

FIGURE 4.15 Relationship and Application of TDF and HERS

4.5.2 Mathematical Definition of Elasticity

Elasticity is the change in demand as a result of change in cost or price. Price is the generalized cost for travel purposes including travel time, operating costs, and crashes, as well as user charges. The factors included in the generalized travel cost are endogenous with respect to induced traffic. Since the relationship between demand and generalized cost are not linear, arc elasticity is used rather than linear elasticity. If the initial travel demand and the corresponding cost are V_0 and C_0 respectively, and the future change in traffic volumes and costs are ΔV and ΔC, respectively then the elasticity from this initial point is defined as:

$$e = \frac{\Delta V / V_0}{\Delta C / C_0} \qquad 4.6$$

In HERS model, a typical application is to start from a given cost-volume point, estimate the change in the cost to the user that will result from an improvement, and use an estimated elasticity to calculate the change in volume.

4.5.3 Default Values of Short-Run and Long-Run Elasticities

In order to use the HERS, the analyst is required to know the default elasticities accepted by the agency. In HERS, the short-run elasticities fall in a -0.5 to -1.0 range and long-run elasticies from -1.0 to -2.0. However, if information on trip length is available, the diversion of trips due to changes made to the facility can be quantified. Table 4.2 shows the acceptable diversion elasticities in HERS.

TABLE 4.4 Diversion Elasticity by Area Type and Facility Type

Area Type	Facility Type	Average Trip Length (mins)	Diversion Elasticity
Rural	Interstate	15.0	-0.1
Rural	Principal Arterial	12.0	-0.2
Rural	Minor Arterial	10.0	-0.4
Rural	Collector	8.0	-0.4
Urban	Interstate	12.0	-0.4
Urban	Other Freeway and Expressway	10.0	-0.4
Urban	Principal Arterial	8.0	-0.6
Urban	Minor Arterial	6.0	-0.6
Urban	Collector	4.0	-0.6

4.5.4 Possible Applications of Elasticity with Hourly Volumes Models

The models fitted using Gaussian peaks function, can be used to estimate the base volume, V_0, and apply Equation 4.2 to estimate changes in future traffic volumes, ΔV, due to improvements made to a roadway segment. From Equation 4.2, the change in volume can be estimated as:

$$\Delta V = e \times (\frac{\Delta C}{C_0}) \times V(h|\theta) \qquad 4.7$$

In order to apply this model, the analyst should know the base cost of travel C_0, the future change in cost of travel ΔC, and the elasticity, e, for the analysis period. The value of C_0, and ΔC will depend on how many factors are included in the estimation of the generalized travel cost. The generalized cost for travel purposes may include travel time, operating costs, and crashes, as well as user charges.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This sections discusses several observations and findings from this research. The section closes by summarizing peaking characteristics models that were developed by using statistics and probability information from 24-hour volume data collected from permanent count stations.

The review of the literature revealed that about 75% of the nation's workers drive alone to work and an average commuting time to work is 25 minutes. The 2009 American Community Survey sought to understand traffic flow patterns on the nation's roads showed that over 50% of the workers left their home for work between 6:00 a.m. and 8:59 a.m., with a 30-minutes departure occurring between 7:00 a.m. and 7:30 a.m. The survey results confirms that the morning traffic peak volume is dominated by home based work (HBW) trips. The American Community Survey did not characterize the trips associated with evening commuting periods.

In order to understand traffic peaking characteristics on Florida State Highway Systems (SHS) traffic data from year 1996 to 2012 were obtained from the FDOT Transportation Statistics Office. The research team reclassified the data into four geographic area types – rural, urban, urbanized, and large urbanized – according to the FDOT Quality and Level of Service Handbook guidelines. The data were also categorized by facility type, namely freeways, divided arterials, undivided arterials, collectors, and toll roads. Upon evaluating the data, it was found that only data from 2012 were coded by lane in one year file. Data from the rest years were coded by direction, hence were deemed not useful to meet the objectives of this research. 2012 data were further reduced to eliminate bad counts data, holidays and special events.

Descriptive statistics such as minimum hourly flow, maximum hourly flow, coefficient of variation, standard deviation, and 99th percentile were computed to capture the 24-hour volume peaking characteristics by speed limit and facility type. The results indicated that divided arterials with 55 MPH speed limit and undivided arterials with 55 MPH and 60 MPH speed limits had the largest variations of traffic hourly volumes. Facilities that experienced lower hourly volume variations were divided arterials with 30 MPH speed limit, undivided arterials with 65 MPH speed limit, collectors with 45 MPH and toll roads with 70 MPH speed limit. Most of these roads were operating below their capacities.

Analysis of 24-hourly volumes by speed limit and facility type revealed the traditional bi-modal peaking distribution on roadway serving commuter traffic with the evening peak being higher than the morning peak. Weekly variation of traffic showed that peak hour volumes were higher on arterials located in urbanized areas on Friday evening. The results of the 24-hour average hourly volumes also showed that there are many hours on urbanized area highways that are operating with low traffic flows. In all locations that were studied, there were hourly periods with no flows (zero vehicles in an hour). Analysis of the 99th percentile of the hourly volumes shows that none of the segments recorded the volume in which one percent of the hours in a year, traffic flow reached 1,000 vehicles per hour per lane. The hourly distribution plots for coefficients of variation of the hourly flows showed that regardless of the prevailing speed, the traffic flows were highly variable in early morning hours and later at night. The variation can be explained by random flows that occur during periods of low traffic demand and operations.

Traffic volume analysis on freeways/expressways located in large urbanized areas showed that the maximum hourly volume recorded was 2,354 vehicles per hour per lane. The maximum average hourly volume for arterials located in large urbanized areas was 1,174 vehicles per hour per lane. This occurred on arterials with 45 MPH posted speed limit. The results of volume analysis further indicated that only higher class facilities (freeways/expressways, toll roads and HOV lanes) have volumes in which one percent of the hours in a year, traffic flow exceeds 1,500 vehicles per hour per lane. The analysis of variation of traffic volume within 24 hour period showed that traffic on HOV lanes had high variability compared to freeways/expressways general use lanes.

Analysis of 24-hour distribution of vehicle speeds showed that the majority of the facility types have average speeds marginally above the speed limit, mainly because these facilities are operating acceptably below the capacity. According to the traffic flow theory, operating speeds start to drop when the volumes are approaching the capacity of the facility. The majority of the sites evaluated had coefficient of variations of less than 10% confirming that driving speeds are fairly uniform within the day. Further evaluation of the coefficients of variation indicated that speeds are fairly stable in facilities with speed limit 55 MPH or higher and random in facilities with 45 MPH speed limit. Additionally, the analysis showed that regardless of speed limit, the higher coefficients of variation occur around and after the evening peak hours.

To explore the effect of both speed and volume on the peaking characteristics, a combined analysis of these variables was performed across area types, facility types and speed limits. The results of this analysis confirmed that in most cases higher facility classes carry more volumes than lower classes. It should be noted that higher facility classes have higher posted speed limits. However, the results of the analysis did not discern a distinct relationship between volumes and speed limits in all four area types—large urbanized, urbanized, urban, and rural.

Traffic data from the permanent count stations were analyzed to identify the proportion of hours within 24-hour period each congestion level prevails. Congestion levels in a 24-hour period were analyzed using methodology contained in the 2012 Urban Mobility Report by Texas A&M Transportation Institute in which speed reduction factor (SRF) is calculated dividing the average combined peak period speed by the free-flow speed. The table below shows that segments experiencing congestion level 3 (severe congestion) for at least 50% of the time within 24 hour period are those in undivided arterials with speed limit of 35 MPH (58.3%), freeways with speed limit of 55 MPH (54.2%) and freeways with posted speed limit of 65 MPH (50.0%). These results can be used to inform practitioners and road users about trip reliabilities made on similar facilities in urban areas.

Areal Type	Facility Type	SPEED LIMIT (MPH)	% (Average Number of Hours in a day)			Number of Vehicles (vpln)*		
			1	2	3	1	2	3
Urbanized	Undivided	30	16.7% (4)	45.8% (11)	37.5% (9)	40	1098	1393
Urbanized	Undivided	35	4.2% (1)	37.5% (9)	58.3% (14)	33	947	4171
Urbanized	Undivided	45	29.2% (7)	50.0% (12)	20.8% (5)	545	2830	1714
Urbanized	Undivided	50	16.7% (4)	54.2% (13)	29.2% (7)	175	3343	2936
Urbanized	Divided	35	16.7% (4)	41.7% (10)	41.7% (10)	109	1956	4699
Urbanized	Divided	40	33.3% (8)	37.5% (9)	29.2% (7)	420	2509	2555
Urbanized	Divided	45	16.7% (4)	50.0% (12)	33.3% (8)	512	3925	4861
Urbanized	Divided	50	29.2% (7)	41.7% (10)	29.2% (7)	846	4295	4485
Urbanized	Divided	55	29.2% (7)	37.5% (9)	33.3% (8)	279	1974	2458
Urbanized	Freeway	55	8.3% (2)	37.5% (9)	54.2% (13)	195	5771	12977
Urbanized	Freeway	65	12.5% (3)	37.5% (9)	50.0% (12)	523	8507	13188
Urbanized	HOV/HOT	65	25.0% (6)	41.7% (10))	33.3% (8)	676	6860	7933
Urbanized	Toll	60	29.2% (7)	50.0% (12)	20.8% (5)	1073	3245	2404
Urbanized	Toll	65	0.0% (0)	50.0% (12)	55.0% (12)	0	7863	12280

*These are the total number of vehicles that were caught in the corresponding congestion level.

Analysis of the 2010 National Household Travel Survey (NHTS) database provided information on the most recent travel patterns and trip-making behavior for residents in Florida's large urbanized metropolitan areas which are Jacksonville, Miami-Fort Lauderdale-Pompano Beach, Orlando-Kissimmee and Tampa-St. Petersburg-Clearwater. The table below shows the peaking characteristics for aggregated work related and all trips in Florida large urbanized areas.

Time Period	Peak Position	Duration	All Trips	Work Trips
AM	Pre-peak Shoulder	6:00-7:00	5%	9%
	Critical Peak	**7:00-9:00**	**13%**	**32%**
	Post-peak Shoulder	9:00-10:00	6%	4%
Mid-Day	Inter Peak	10:00-14:00	25%	8%
PM	Pre-peak Shoulder	14:00-15:00	8%	4%
	Critical Peak	**15:00-18:00**	**24%**	**20%**
	Post-peak Shoulder	18:00-19:00	8%	8%
Night	Off Peak	19:00-6:00	11%	15%

The data in the table above reveal that the highest proportion of work trips occur during the critical morning peak. The evening critical peak has lower proportion of work related trips compared to morning peak but the post peak shoulder is broader than the morning post peak shoulder. This is an indication of a more extended peak period during the evening compared to morning peak period. Shoulder peak times are included in this analysis due to their importance in the quantification of the peak spreading phenomenon.

Knowledge of the variations of traffic trips before and after the peak hour can help to determine the length of analysis periods on urban roads. The shoulder hour volumes has a tremendous effect on the peak operations of the facilities as they occur on the congestion build up and dissipation periods. The congested build up period is the period where the roadway may operate at near capacity or bottleneck may be activated. Inclusion of the shoulder hours in the analysis periods would help the transportation practitioners to realistically plan for operational improvements strategies.

The results of the linear models for the peak volumes developed from the hourly data collected by lane showed that area type was not a significant predicting variable. Similarity between 24-hour peaking profiles in urban, urbanized and large urbanized areas might explain the cause of statistical insignificance.

The observed 24-hour peaking profiles were modeled using probabilistic (Gaussian) functions. Gaussian models were found to model the weekday hourly volumes by reasonably replicating the peaking profiles with R-squared values higher than 0.95 for all facility types. These models do not represent actual travel demand to use the facility during peak periods because they are based on field traffic counts. Experience shows that when demand to use transportation facility exceeds the capacity of the facility, some trips may divert to other routes, modes or destinations. TTMS data do not incorporate such trip diversions.

The Gaussian hourly volume models can be used to predict future traffic volumes if the characteristics of future trip making are known. Such characteristics may be used to modify or calibrate the amplitude, centroid, width and number of peak periods.

The Gaussian models were also related to the demand elasticity to determine future traffic. Estimates of future change in traffic volumes can be obtained by multiplying the average function of the hourly volume by elasticity parameter and the fraction of the change in cost of travel. Estimation of future change in traffic volume can be used by transportation planners to determine if the peak period is expecting to spread in the future.

5.2 Recommendations

It should be noted that this study focused primarily on analyzing existing data that were obtained from telemetered traffic monitoring sites (TTMS). While data from 1996 to 2012 were collected, only data from 2012 were most useful to this study as it included vehicle data by lane. Although the 2012 traffic by lane data was used, the level of detail of the data was not sufficient to understand the behavior of travelers during peak periods. For instance, data from TTMS did not have any detail about trip making characteristics of the commuters. Additionally, the volume profiles analyzed from the TTMS data could not represent actual travel demand to use the facilities during peak periods. When peak spreading occur, there could be travelers who shift to other modes or discontinue to make the trip—effects of these travelers cannot be captured by TTMS data. Supplemental data from the National Household Travel Survey (NHTS) only provided a high-level and generalized information of trip-making behavior and travel patterns in large urbanized areas. The analysis of these data were able to provide some answers about the duration of the peak periods and typical type of trips that are made during peak periods. However, the NHTS data could not be directly linked with the TTMS data or facility types.

Therefore, there is a need to expand the research of peaking characteristics to incorporate the variables that affect the traveler's decision to make trips during congested conditions. Such research could incorporate consideration of probability distributions to describe the implication of peak spreading in travel demand forecasting and highway performance evaluation. The research could also utilize data from traffic management centers which can enable studying volume profiles at a microscopic level where driver behavior can be understood. The results for such research expansion could help transportation practitioners in making decisions regarding transportation policies and investment options.

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APPENDIX A – PLOTS OF RURAL SPEEDS AND VOLUMES

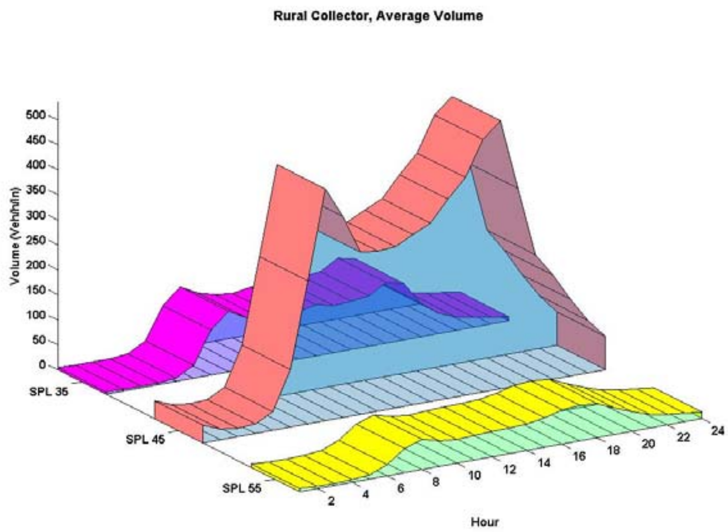

Figure A.1. Hourly Volume Variation on Rural Collectors

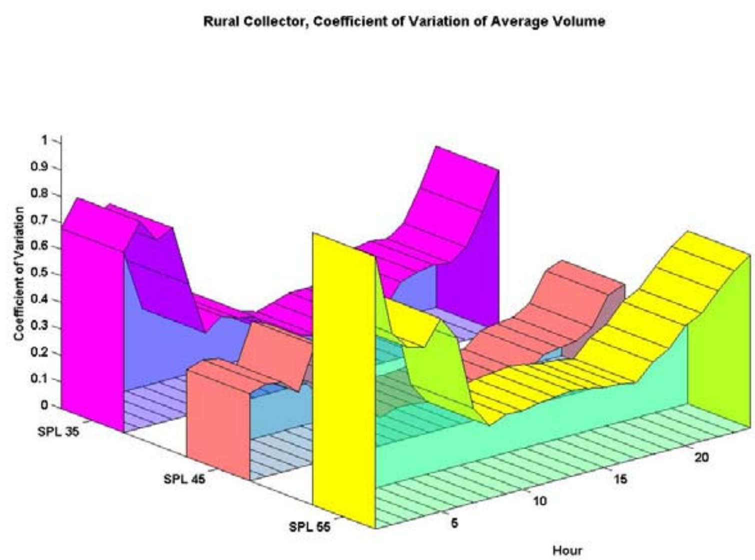

Figure A.2. Coefficient of Variation of Hourly Volume on Rural Collectors

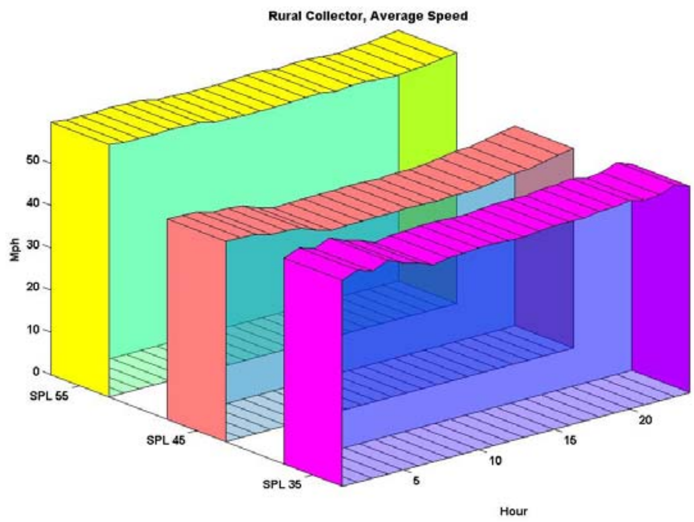

Figure A.3. Hourly Average Speed by Time of Day and Speed Limit in Rural Collectors

Figure A.4. Coefficient of Variation of Average Speed in Rural Collectors

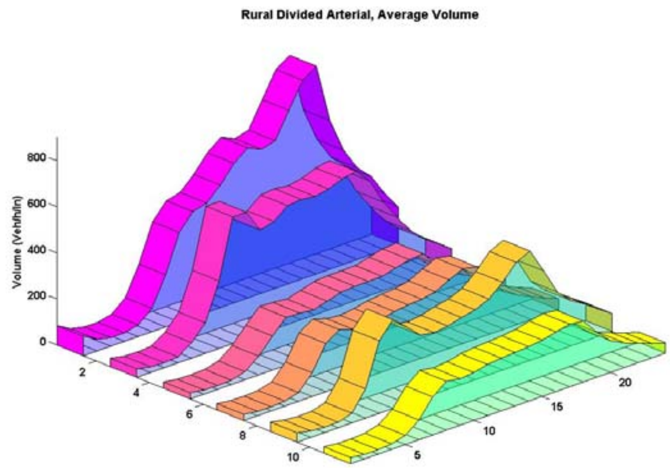

Figure A.5. Hourly Volume Variation on Rural Divided Arterials

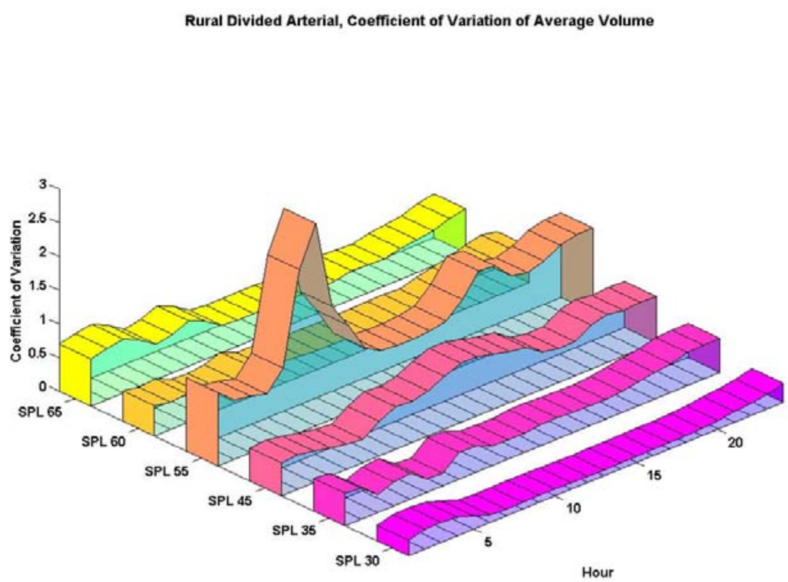

Figure A.6. Coefficient of Variation of Hourly Volume on Rural Divided Arterials

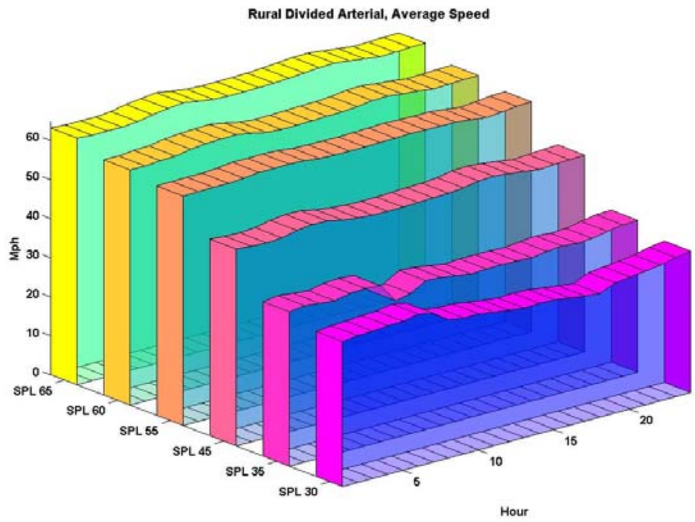

Figure A.7. Hourly Average Speed by Time of Day and Speed Limit in Rural Divided Arterials

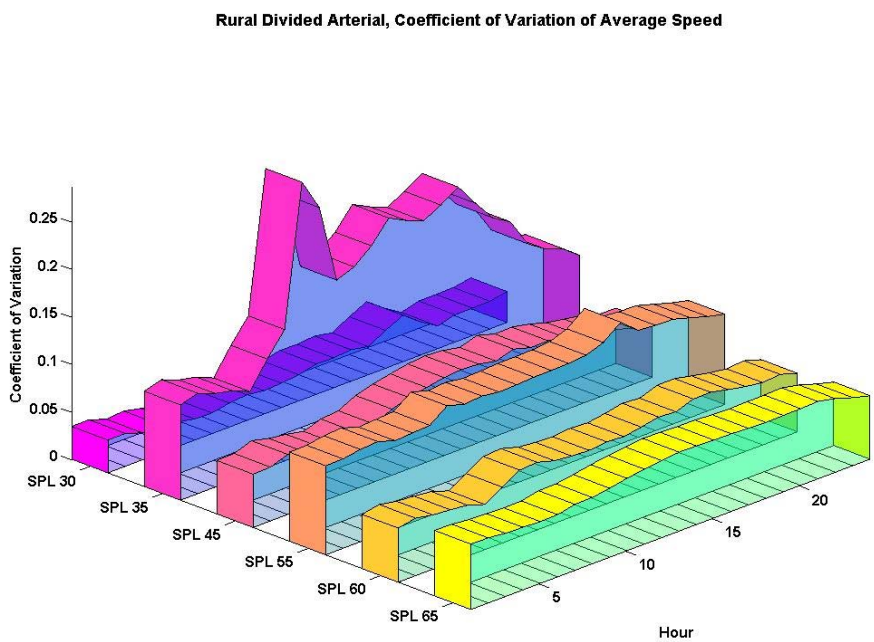

Figure A.8. Coefficient of Variation of Average Speed in Rural Divided Arterials

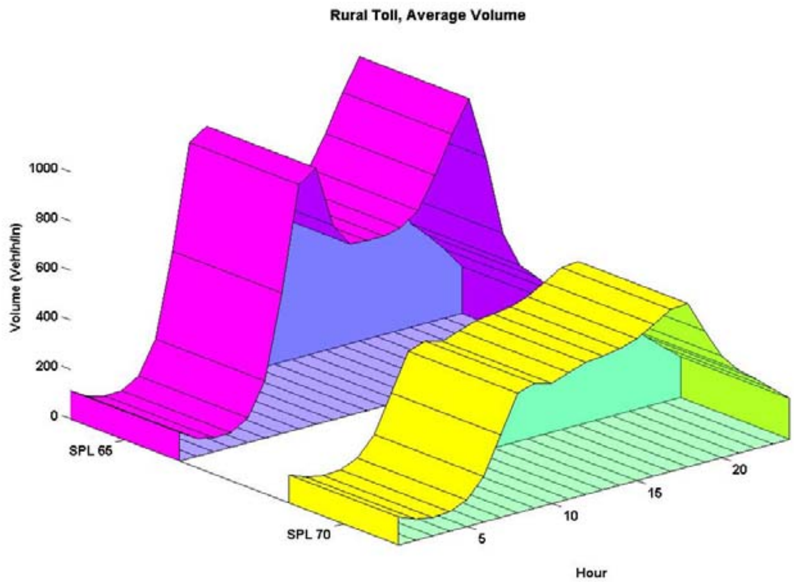

Figure A.9. Hourly Volume Variation on Rural Toll Roads

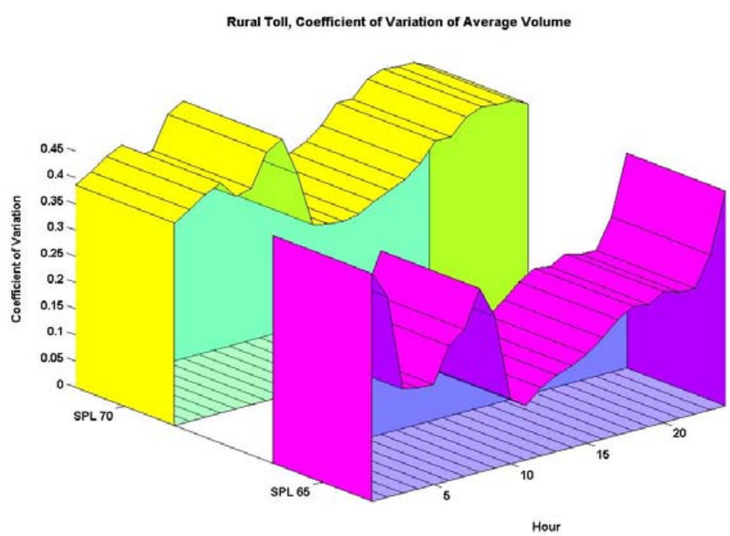

Figure A.10. Coefficient of Variation of Hourly Volume on Rural Toll Roads

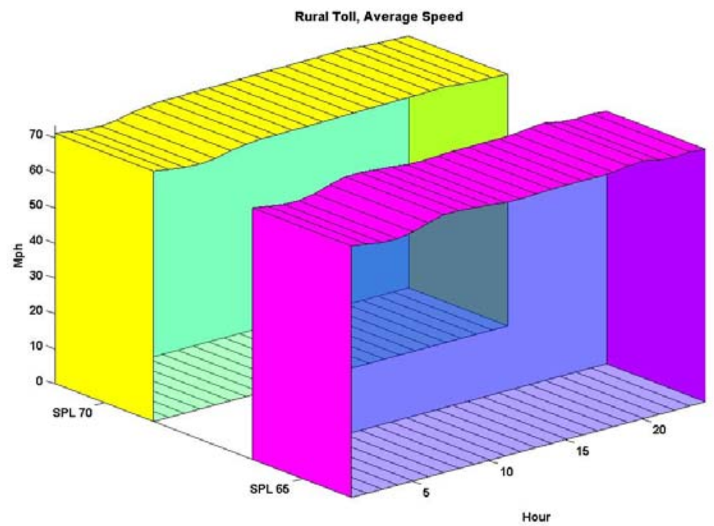

Figure A.11. Hourly Average Speed by Time of Day and Speed Limit in Rural Toll Roads

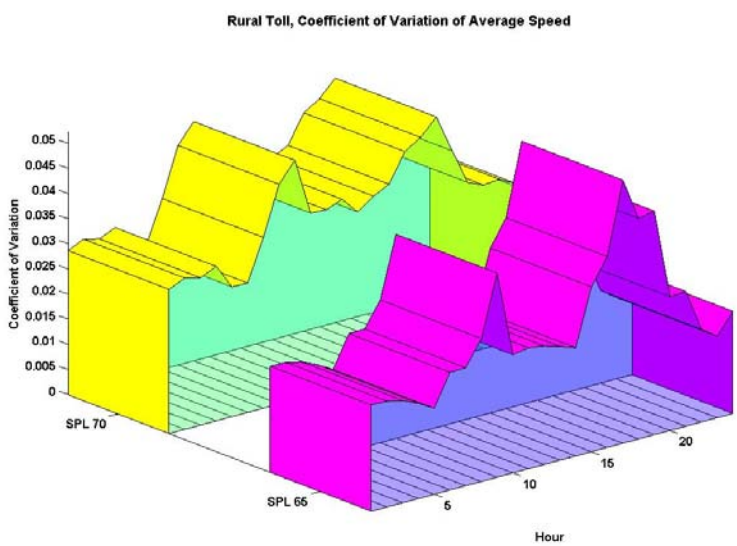

Figure A.12. Coefficient of Variation of Average Speed in Rural Toll Roads

APPENDIX B – PLOTS OF URBAN SPEEDS AND VOLUMES

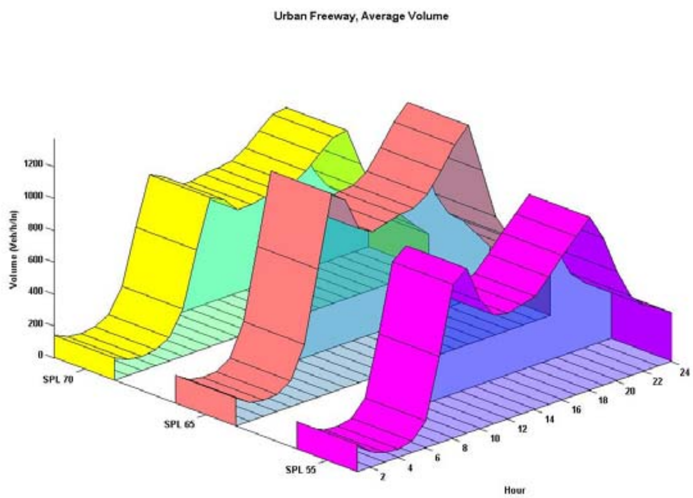

Figure B.1. Hourly volume by speed limit in urban freeways

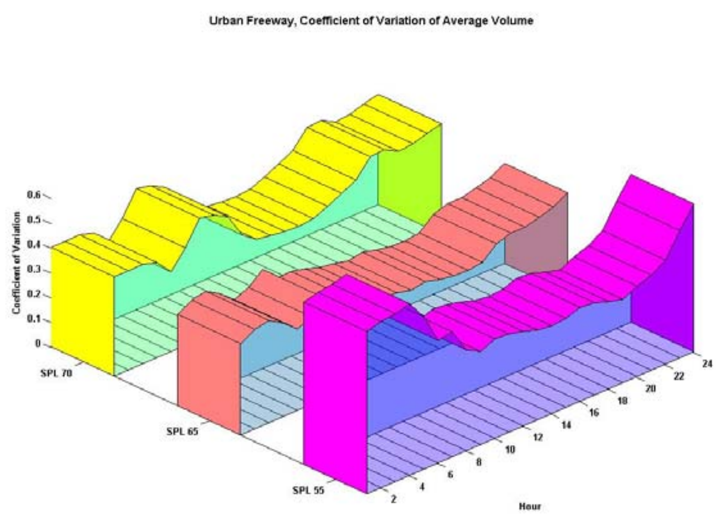

Figure B.2. Coefficient of variation of hourly volume in urban freeways

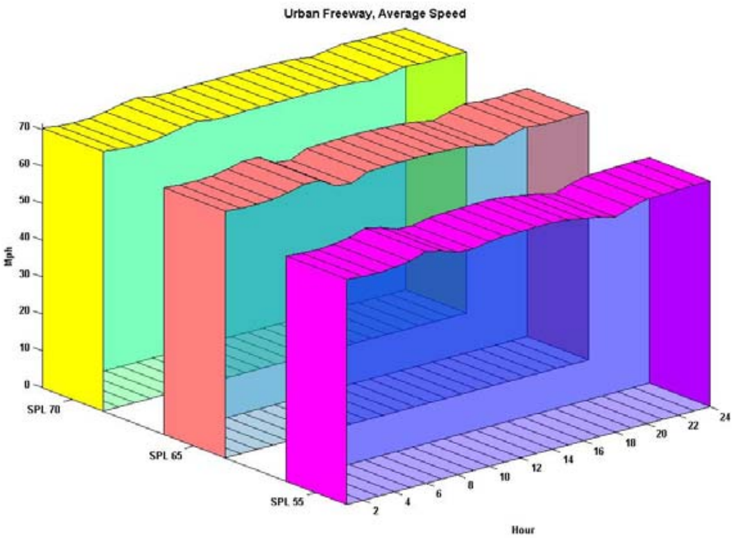

Figure B.3. Hourly Average Speed by Time of Day and Speed Limit in Urban Freeways

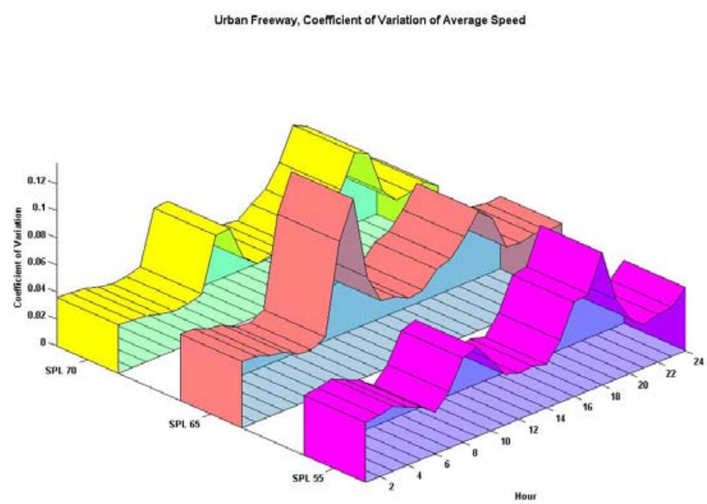

Figure B.4. Coefficient of Variation of Average Speed in Urban Freeways

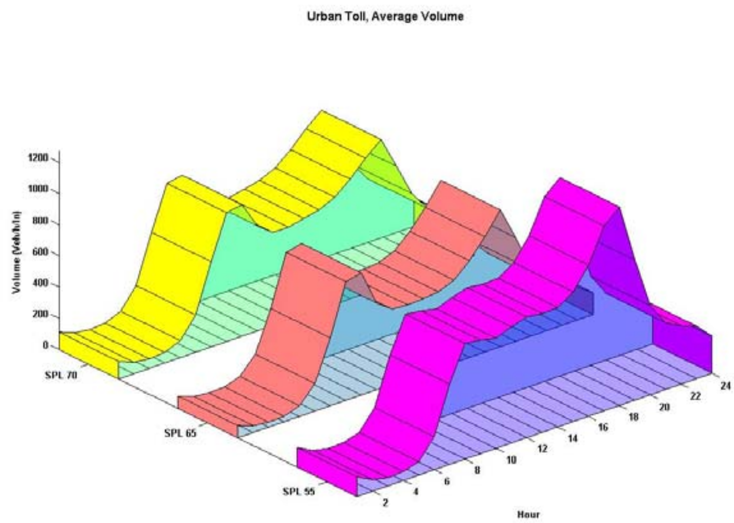

Figure B.5. Hourly Volume by Speed Limit in Urban Toll Roads

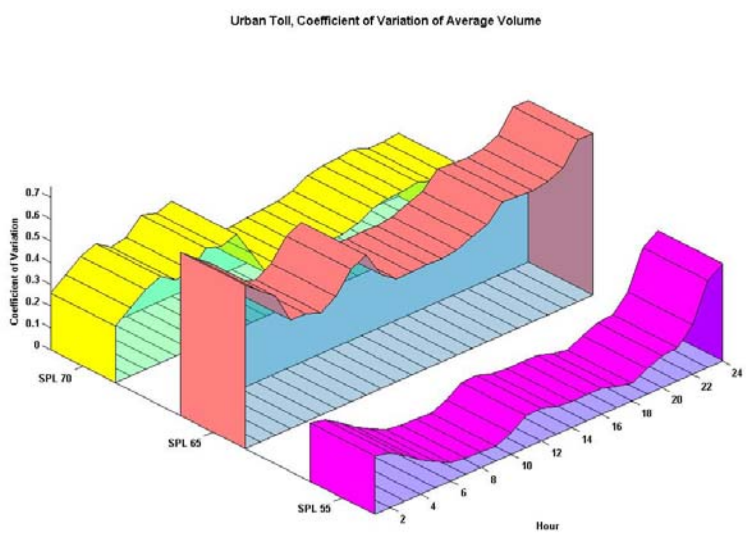

Figure B.6. Coefficient of Variation of Hourly Volume in Urban Toll Roads

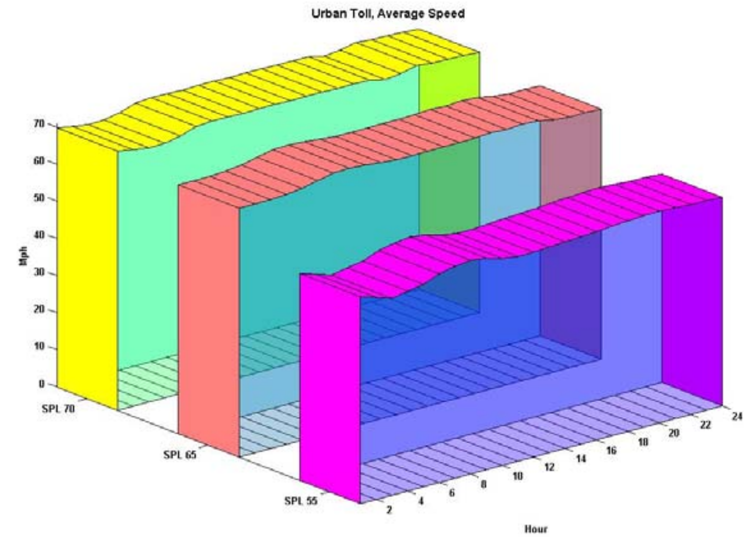

Figure B.7. Hourly Average Speed by Time of Day and Speed Limit in Urban Toll Roads

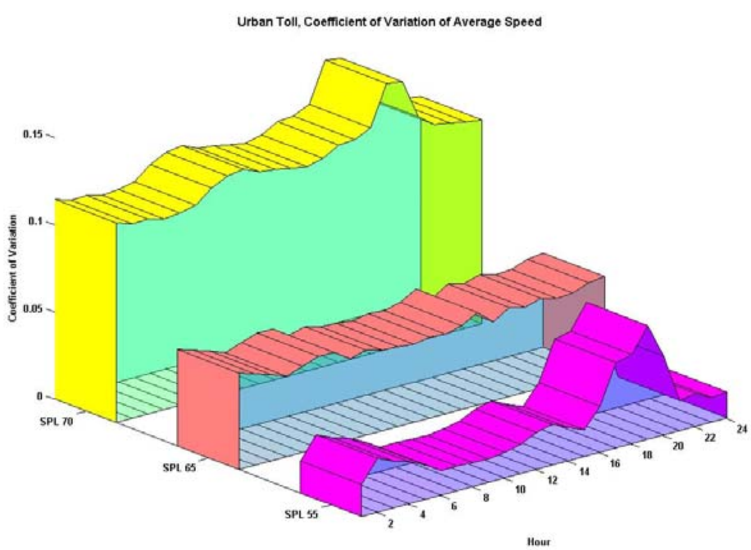

Figure B.8. Coefficient of Variation of Average Speed in Urban Toll Roads

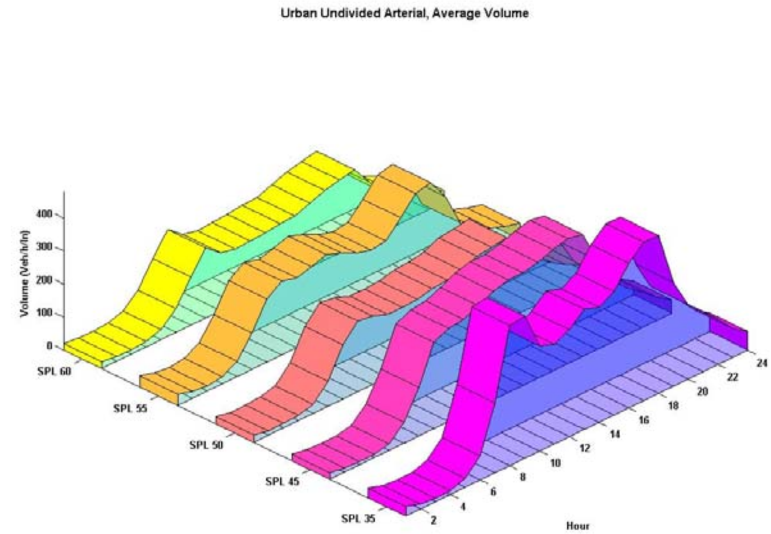

Figure B.9. Hourly Volume by Speed Limit in Urban Undivided Arterials

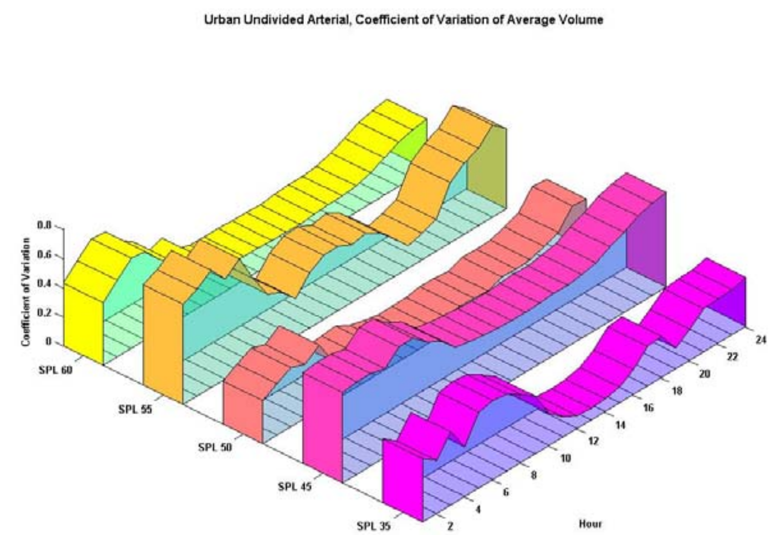

Figure B.10. Coefficient of Variation of Hourly Volume in Urban Undivided Arterials

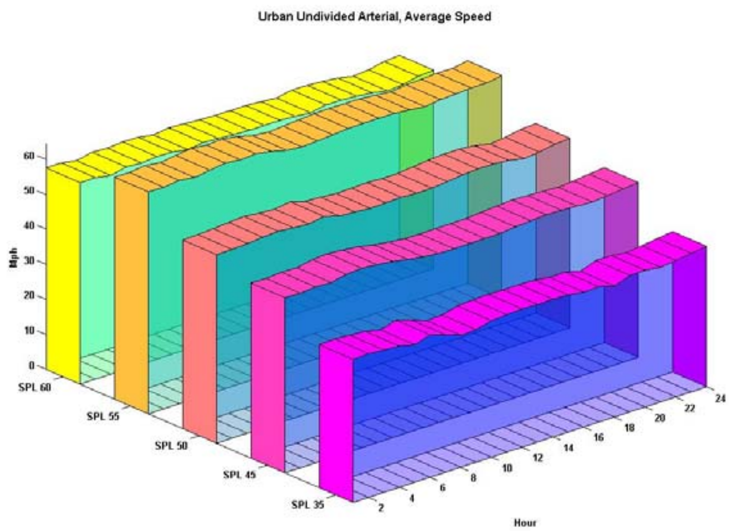

Figure B.11. Hourly Average Speed by Time of Day and Speed Limit in Urban Undivided Arterials

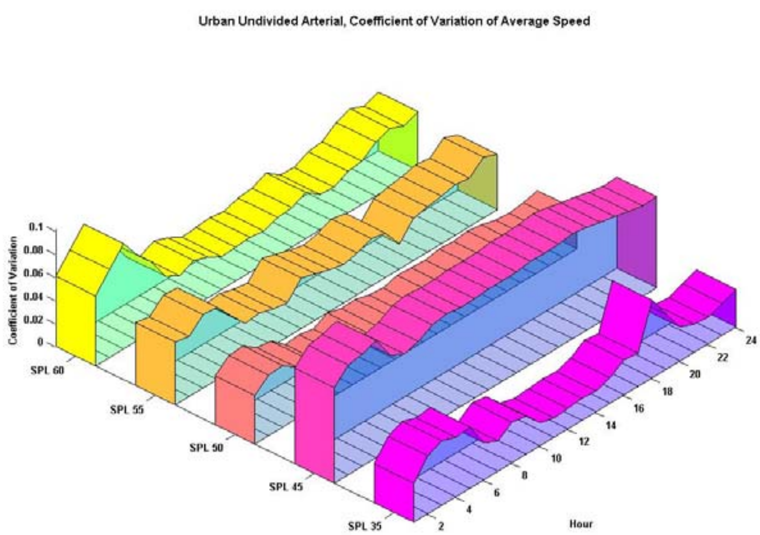

Figure B.12. Coefficient of Variation of Average Speed in Urban Undivided Arterials

APPENDIX C – PLOTS OF URBANIZED SPEEDS AND VOLUMES

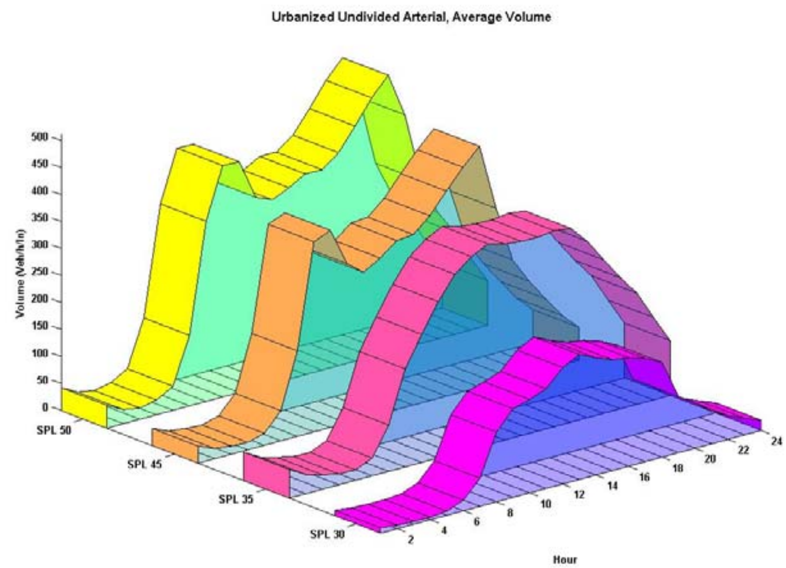

Figure C.1. Hourly Volume by Speed Limit in Urbanized Undivided Arterials

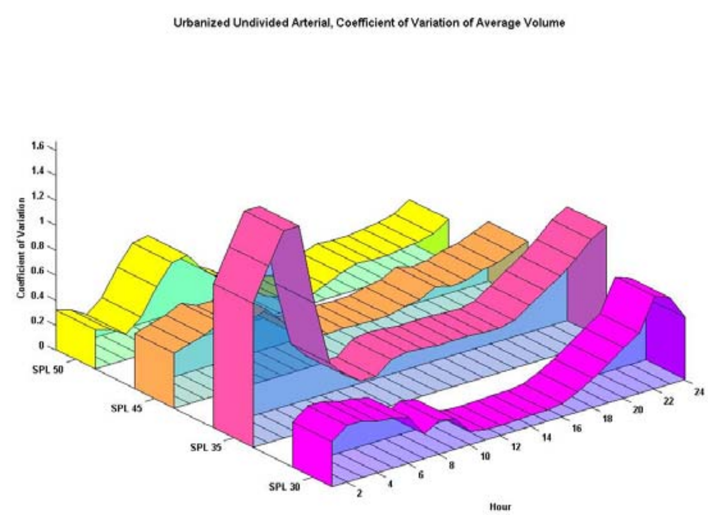

Figure C.2. Coefficient of Variation of Hourly Volume in Urbanized Undivided Arterials

APPENDIX D – SURFACE PLOTS OF VOLUME AND SPEED DATA

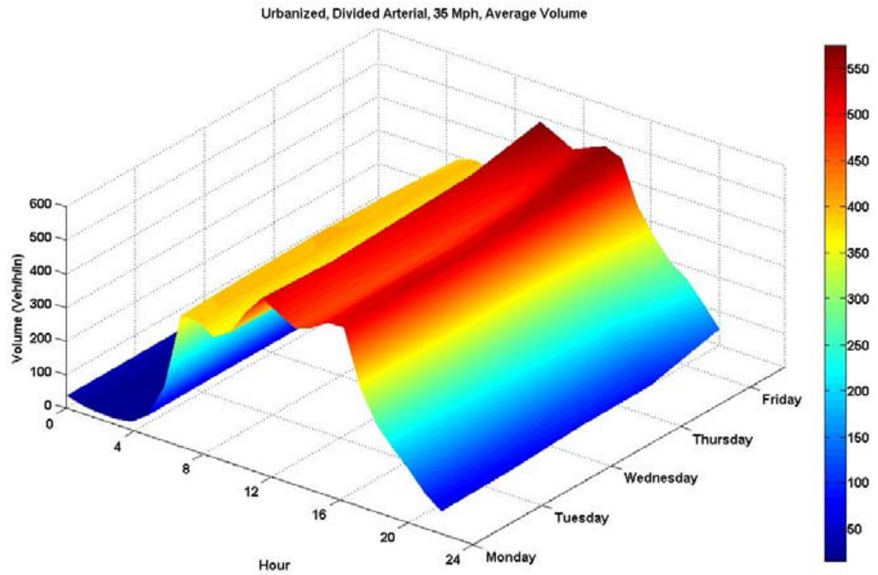

Figure D.1. Hourly Volume by Week Day in Urbanized Divided Arterials with Speed Limit 35 MPH

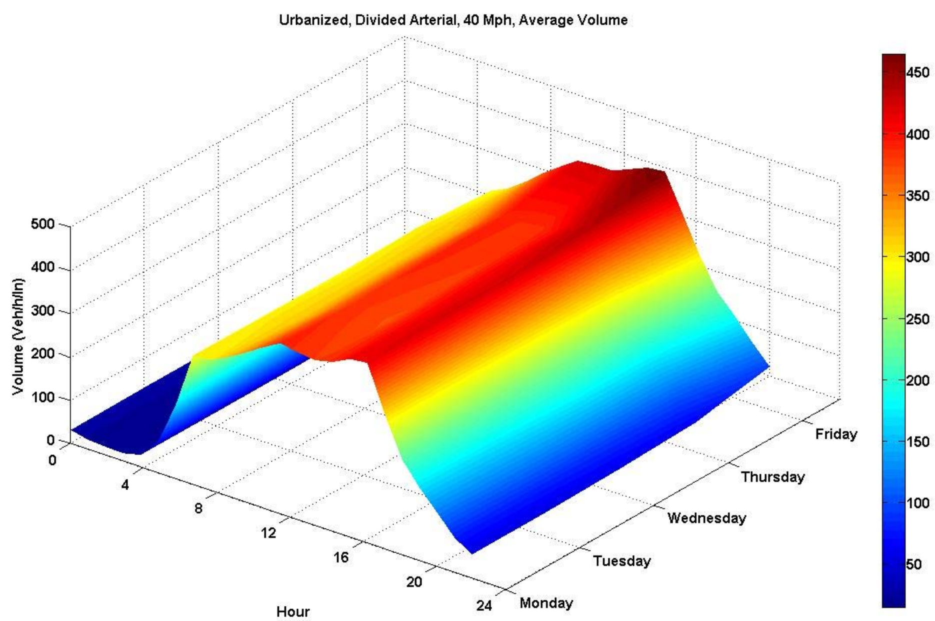

Figure D.2. Hourly Volume by Week Day in Urbanized Divided Arterials with Speed Limit 40 MPH

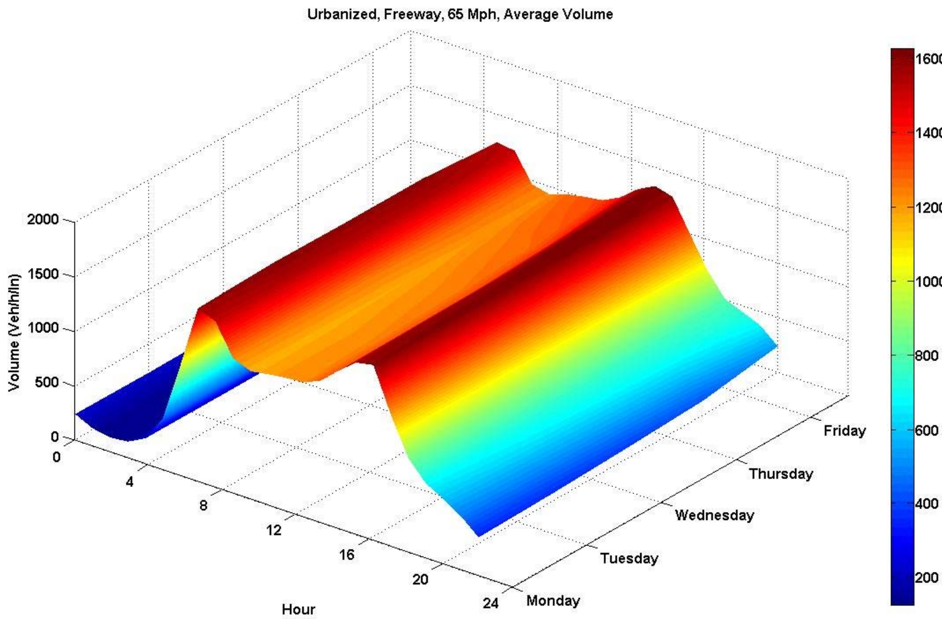

Figure D.3. Hourly Volume by Week Day in Urbanized Freeways with Speed Limit 65 MPH

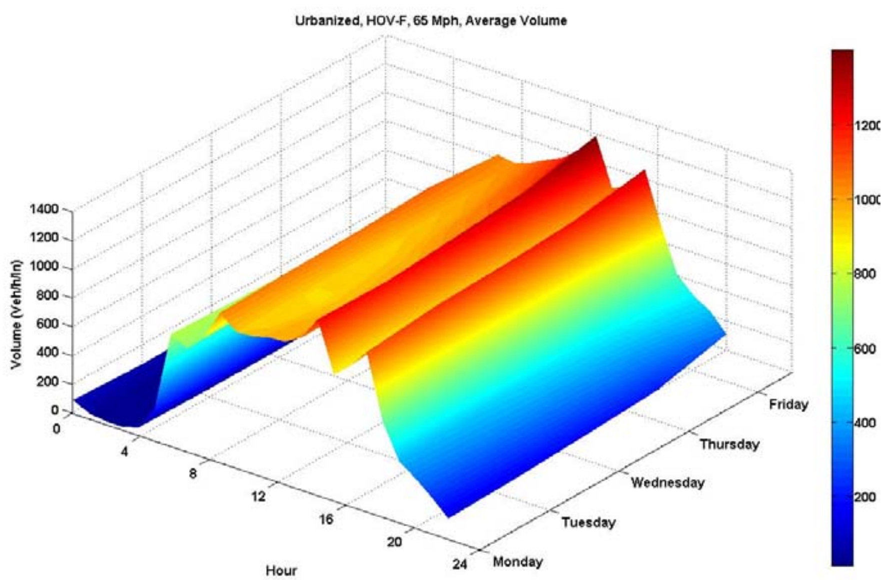

Figure D.4. Hourly Volume by Week Day in Urbanized HOV Lanes with Speed Limit 65 MPH

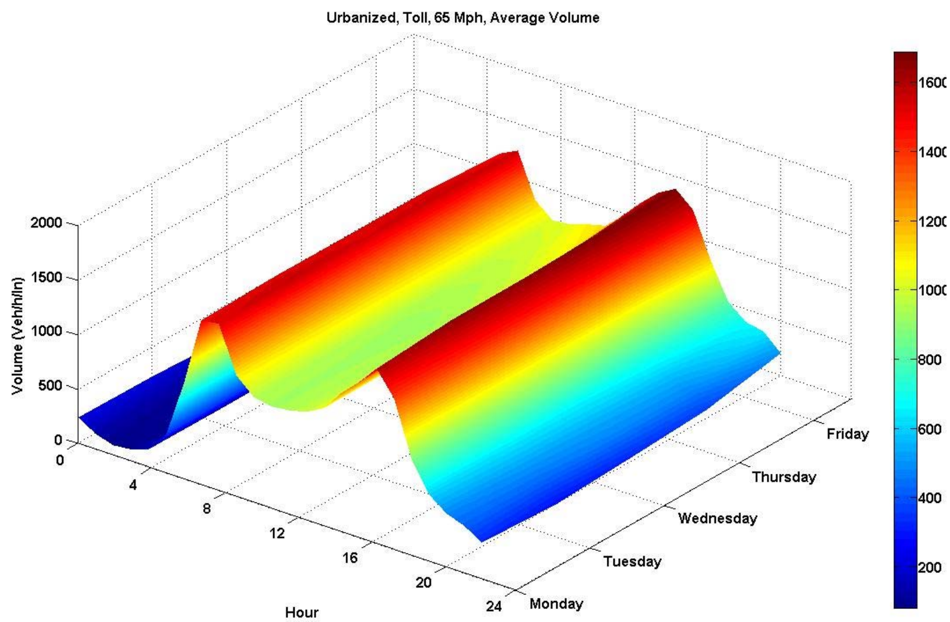

Figure D.5. Hourly Volume by Week Day in Urbanized Toll Roads with Speed Limit 65 MPH

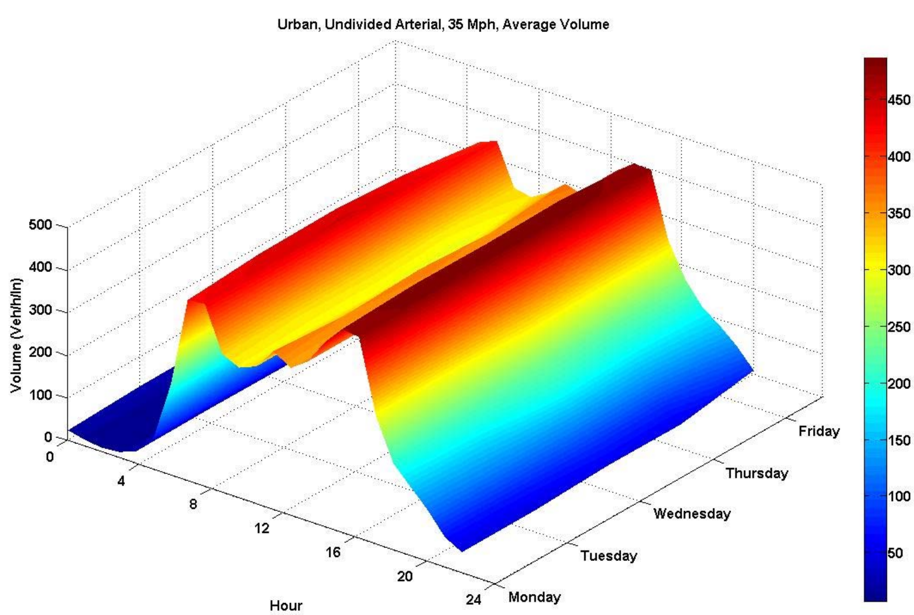

Figure D.6. Hourly Volume by Week Day in Urban Undivided Arterials with Speed Limit 35 MPH

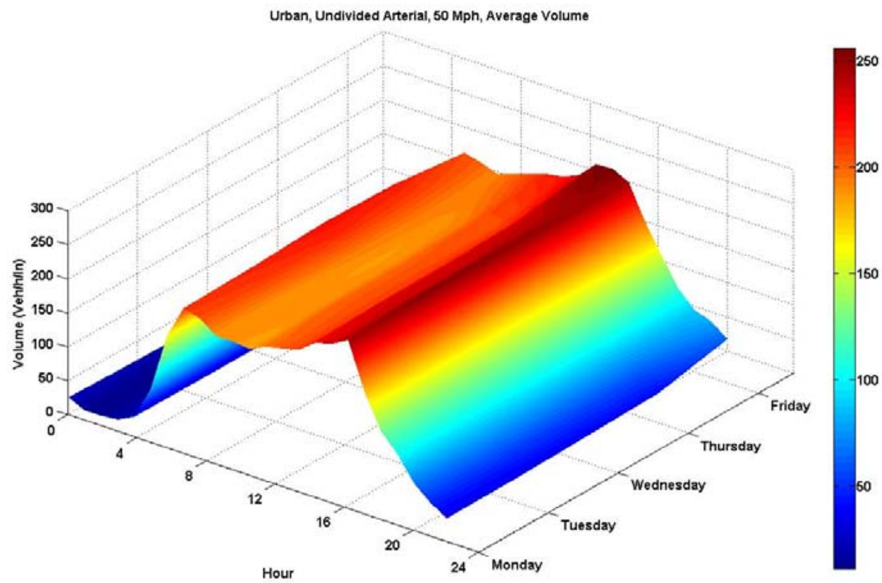

Figure D.7. Hourly Volume by Week Day in Urban Undivided Arterials with Speed Limit 50 MPH

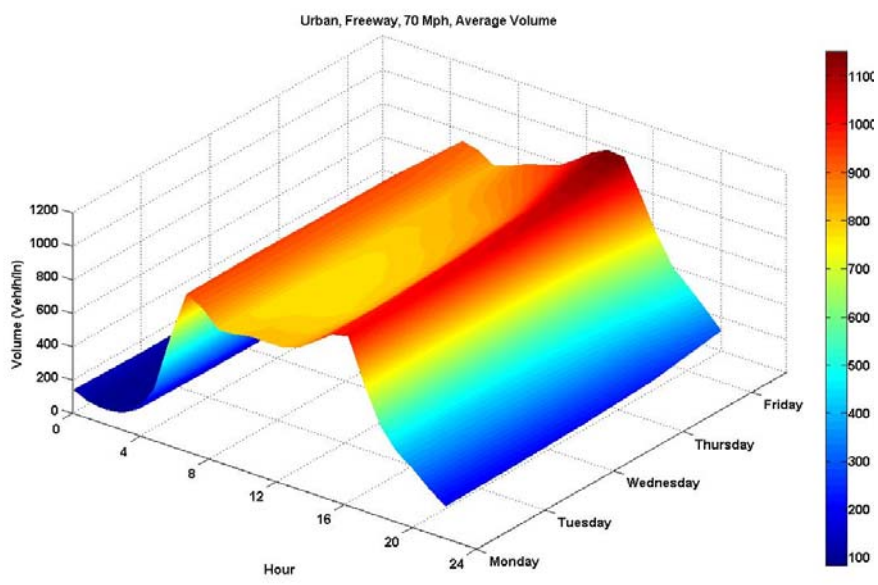

Figure D.8. Hourly Volume by Week Day in Urban Freeways with Speed Limit 70 MPH

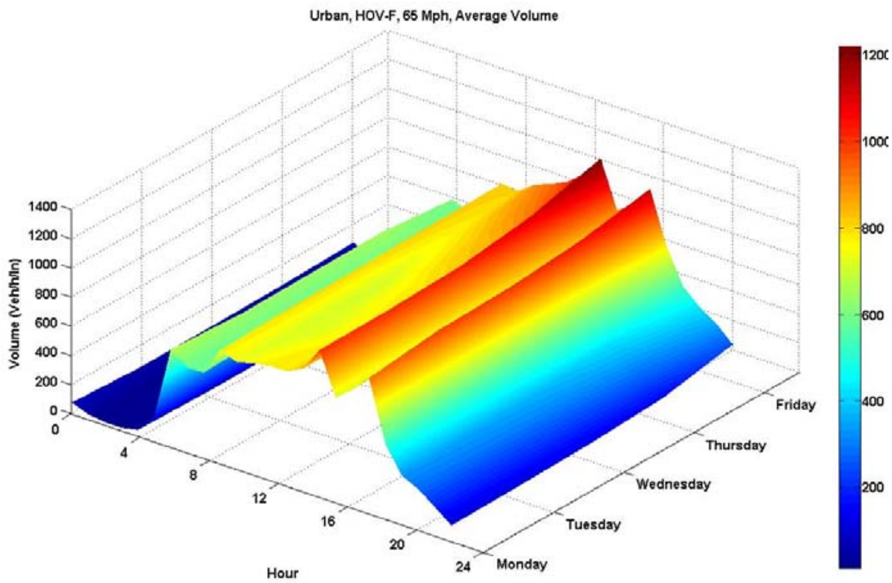

Figure D.9. Hourly Volume by Week Day in Urban HOV lanes with Speed Limit 65 MPH

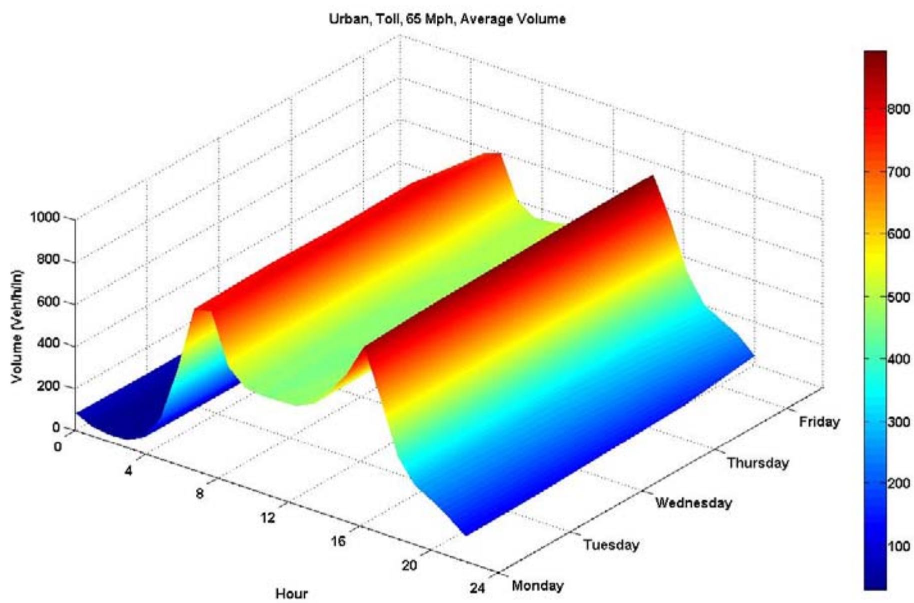

Figure D.10. Hourly Volume by Week Day in Urban Toll Roads with Speed Limit 65 MPH

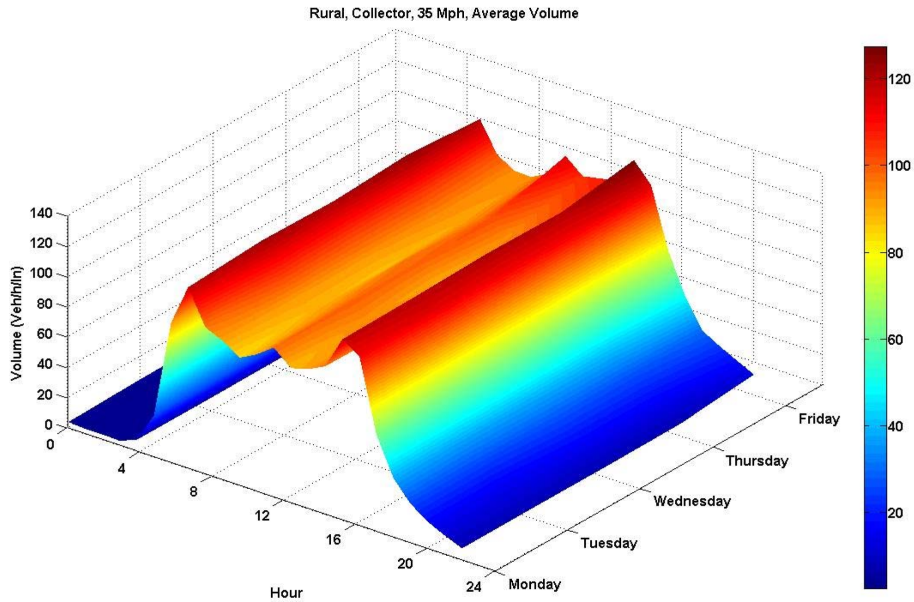

Figure D.11. Hourly Volume by Week Day in Rural Collectors with Speed Limit 35 MPH

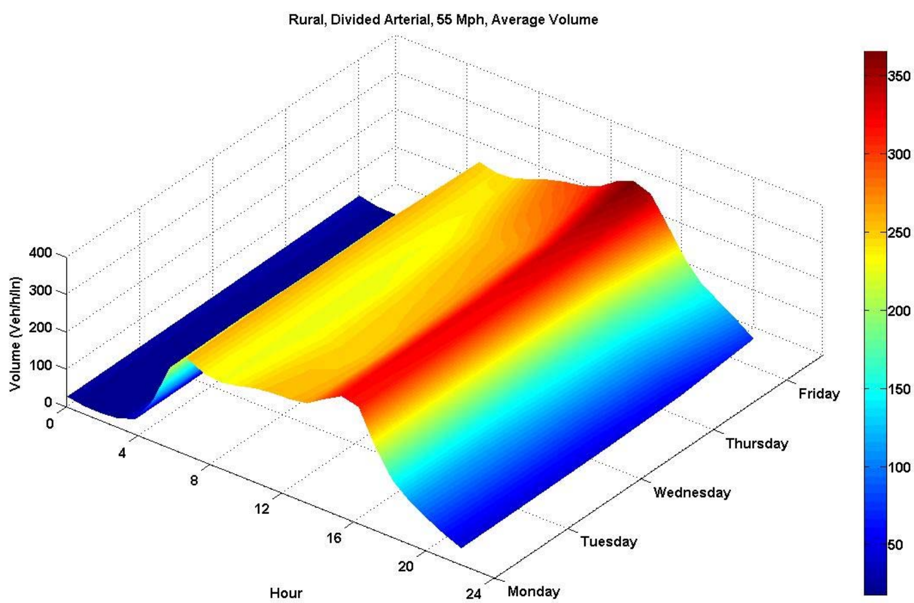

Figure D.12. Hourly Volume by Week Day in Rural Divided Arterial with Speed Limit 55 MPH

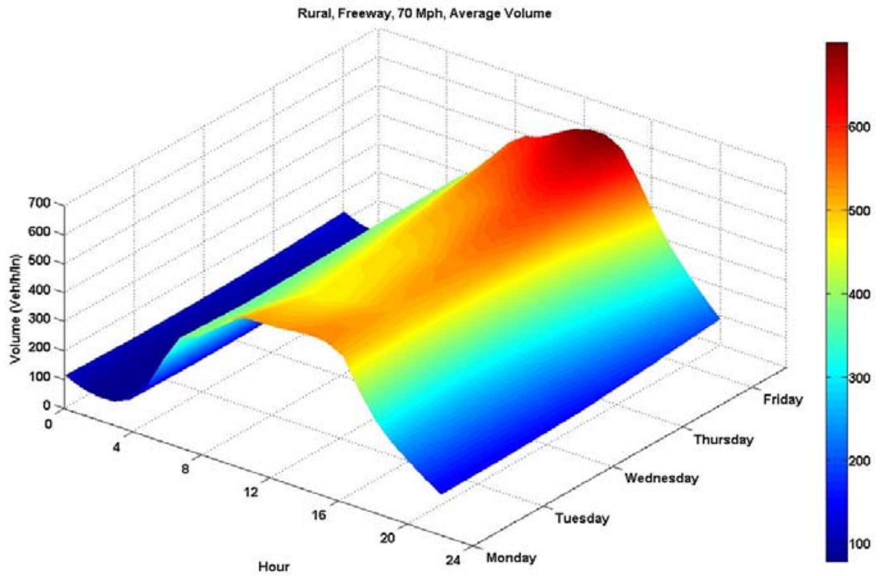

Figure D.13. Hourly Volume by Week Day in Rural Freeways with Speed Limit 70 MPH

APPENDIX E – CONGESTION LEVEL PLOTS

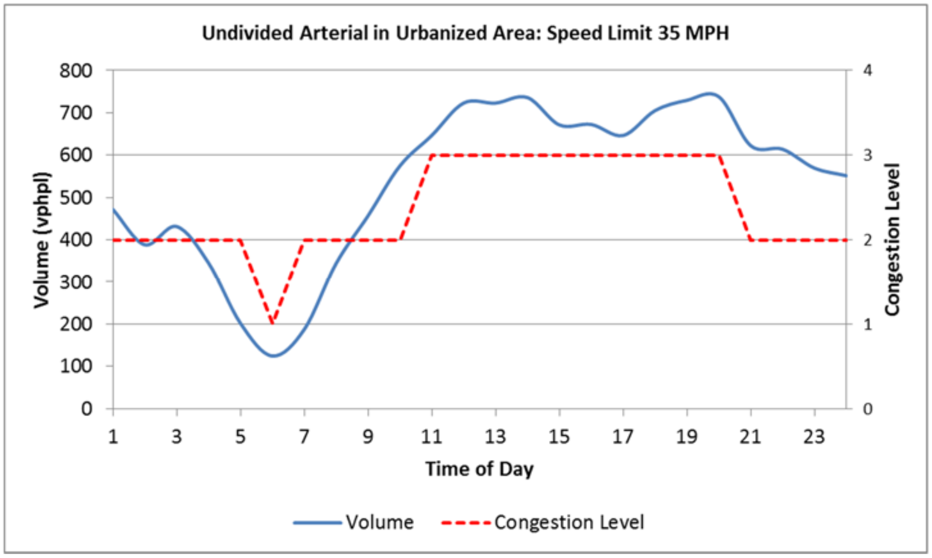

Figure E.1. Time of Day Relationship between Hourly Volumes and Congestion Levels in Undivided Urbanized Arterials with Speed Limit 35 MPH

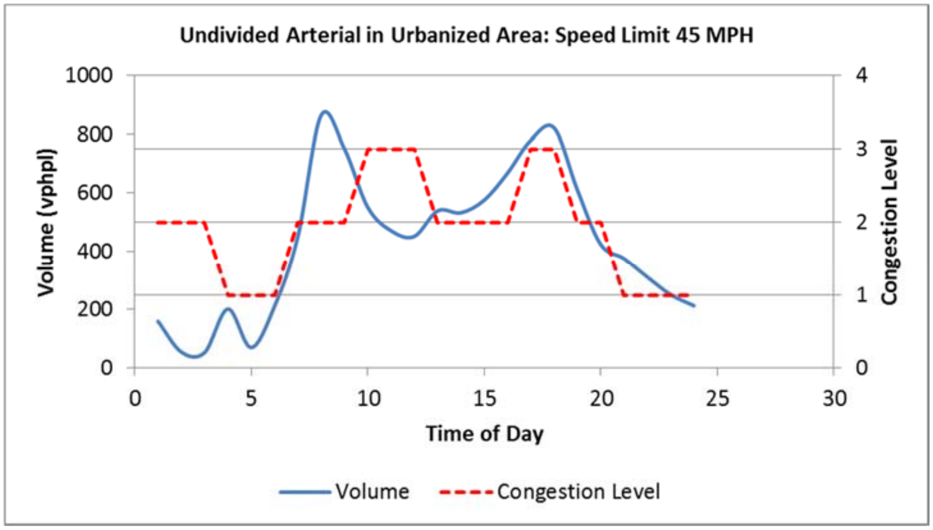

Figure E.2. Time of Day Relationship between Hourly Volumes and Congestion Levels in Undivided Urbanized Arterials with Speed Limit 45 MPH

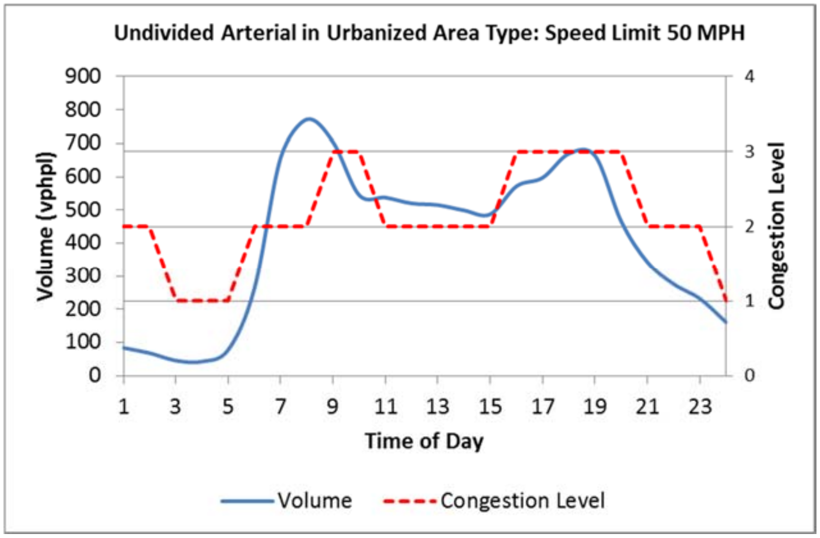

Figure E.3. Time of Day Relationship between Hourly Volumes and Congestion Levels in Undivided Urbanized Arterials with Speed Limit 50 MPH

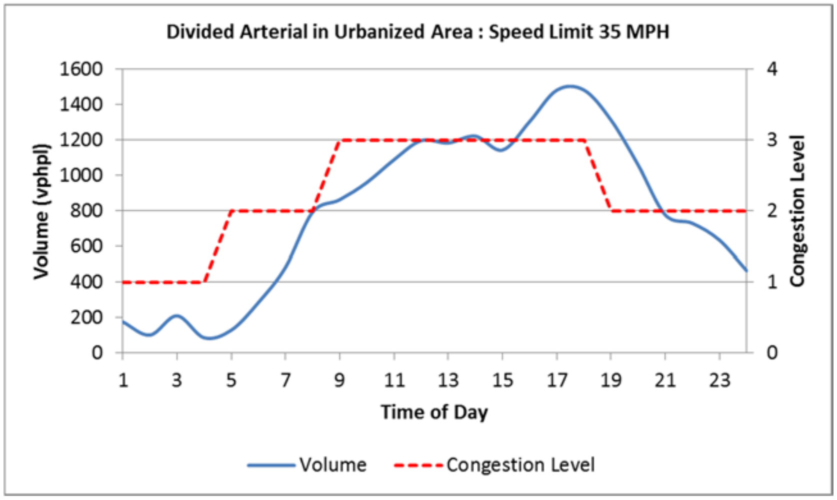

Figure E.4. Time of Day Relationship between Hourly Volumes and Congestion Levels in Divided Urbanized Arterials with Speed Limit 35 MPH

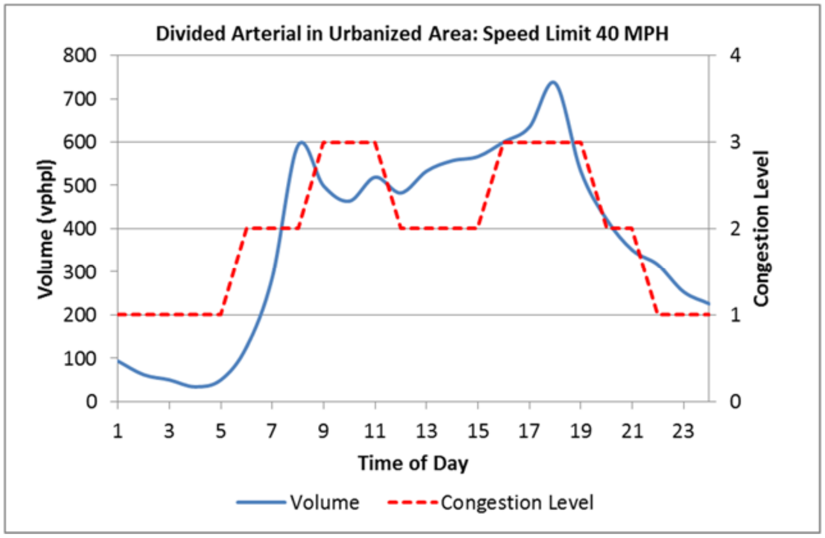

Figure E.3. Time of Day Relationship between Hourly Volumes and Congestion Levels in Divided Urbanized Arterials with Speed Limit 40 MPH

APPENDIX F – TRAFFIC PEAKING CHARACTERISTICS

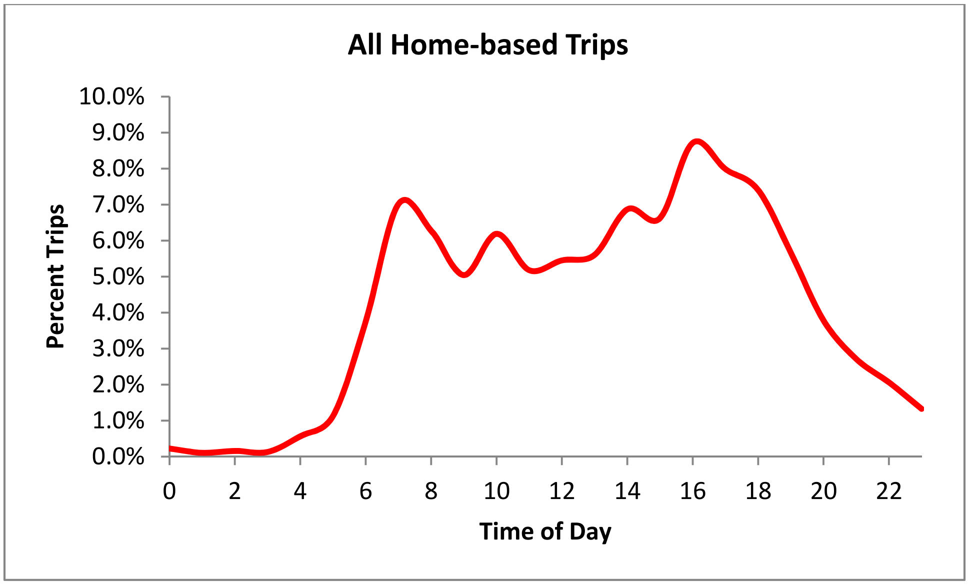

Figure F.1. Proportions of Trips by Time of Day for All HB Trips

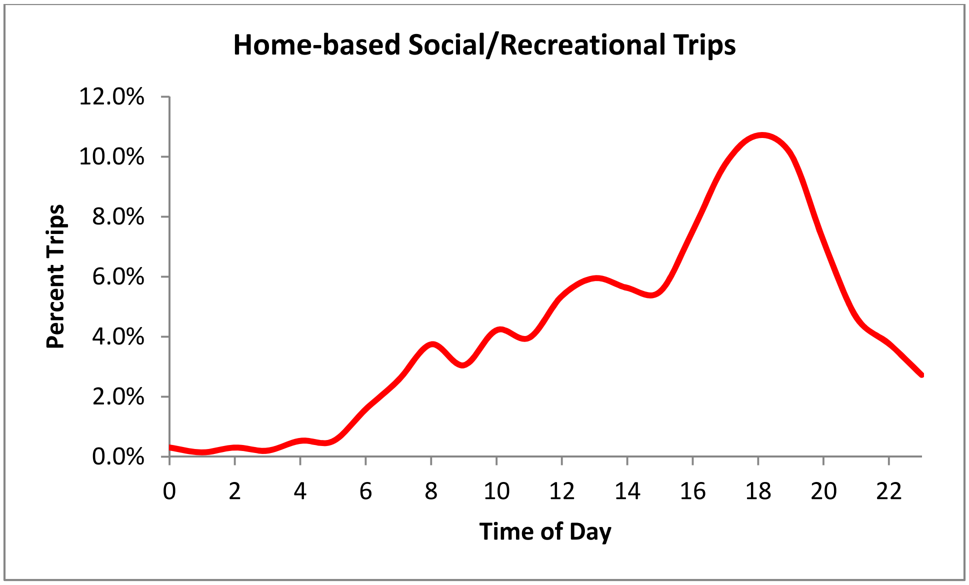

Figure F.2. Proportions of Trips by Time of Day for HBSocRec

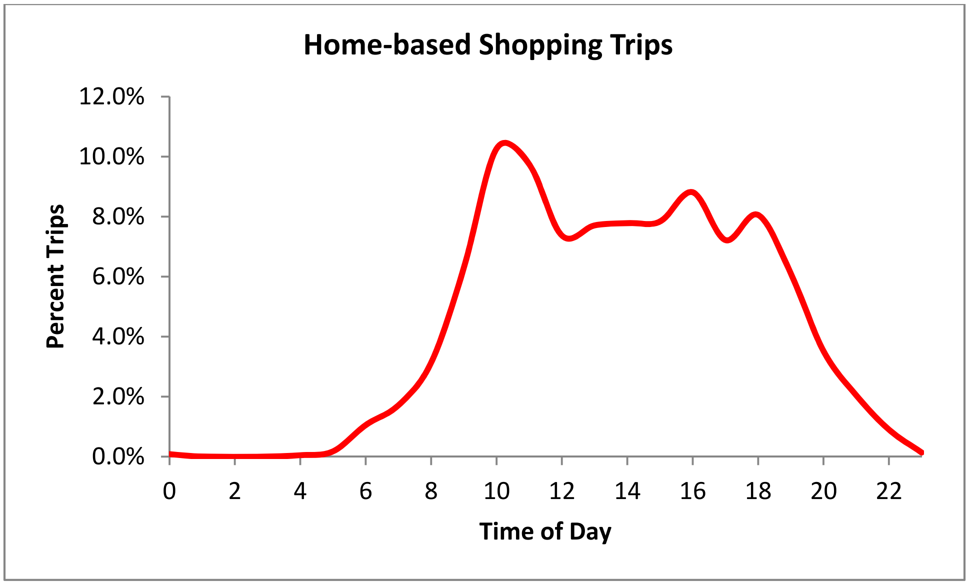

Figure F.3. Proportions of Trips by Time of Day for HB Shopping Trips

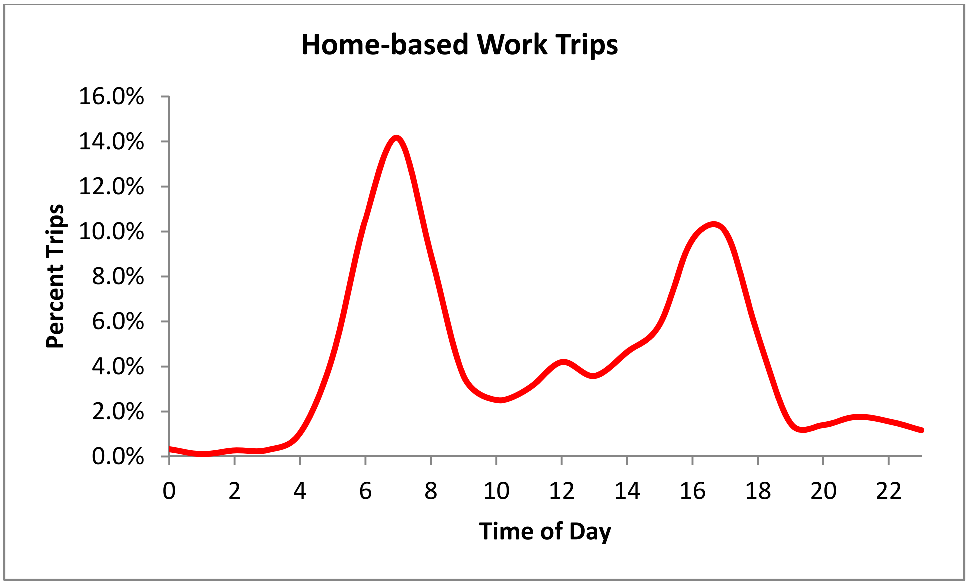

Figure F.4. Proportions of Trips by Time of Day for HBW Trips

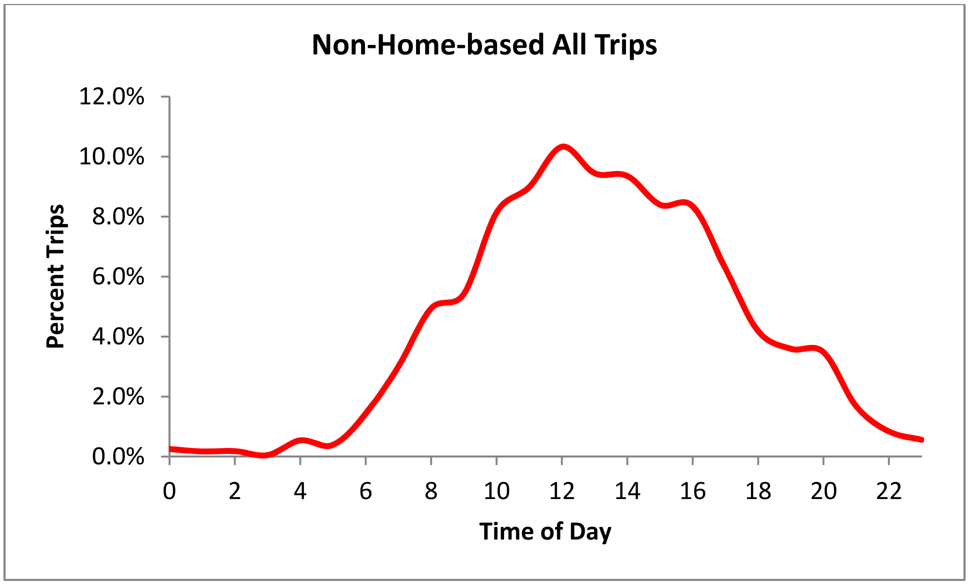

Figure F.5. Proportions of Trips by Time of Day for All NHB Trips

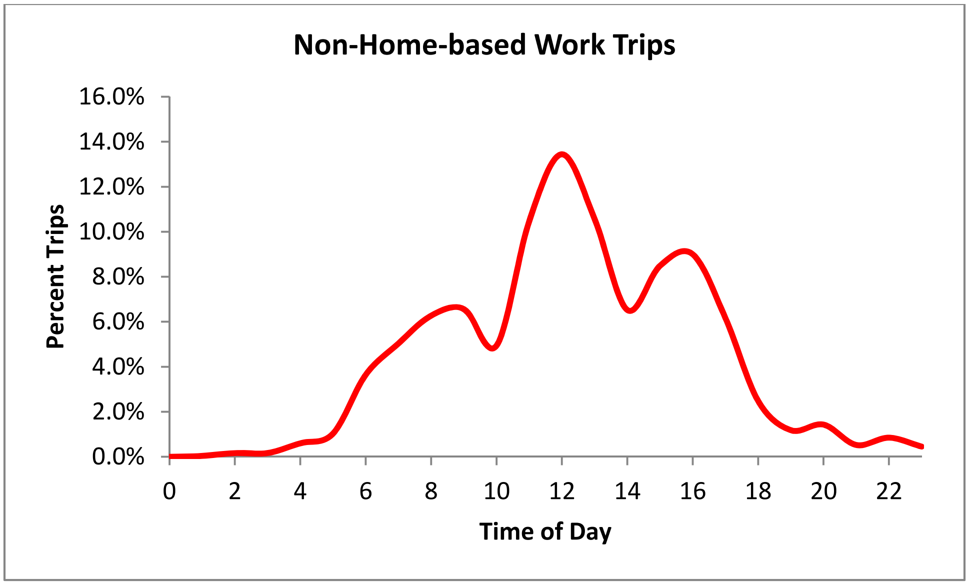

Figure F.6. Proportions of Trips by Time of Day for NHBW Trips

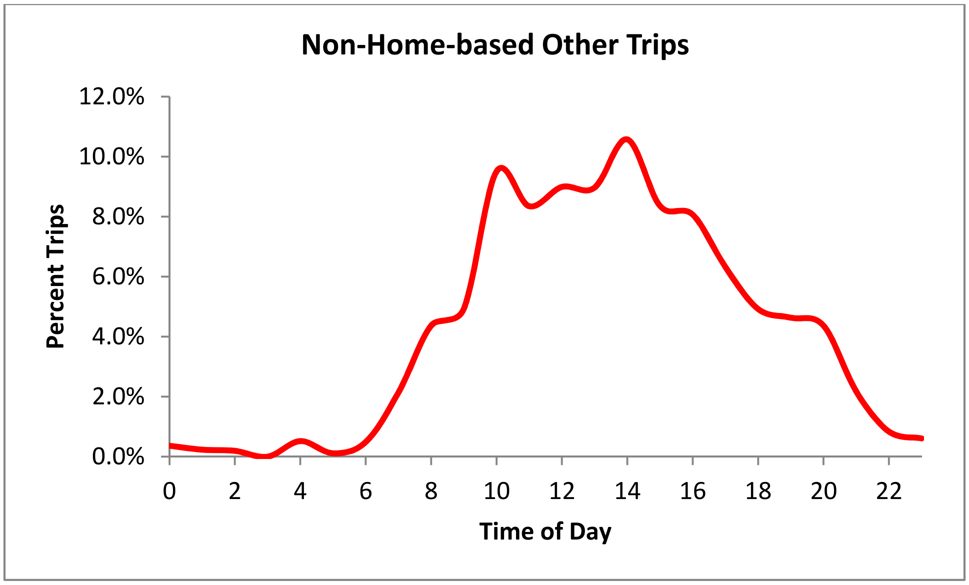

Figure F.7. Proportions of Trips by Time of Day for NHBO Trips

APPENDIX G – TRIP LENGTH DISTRIBUTION

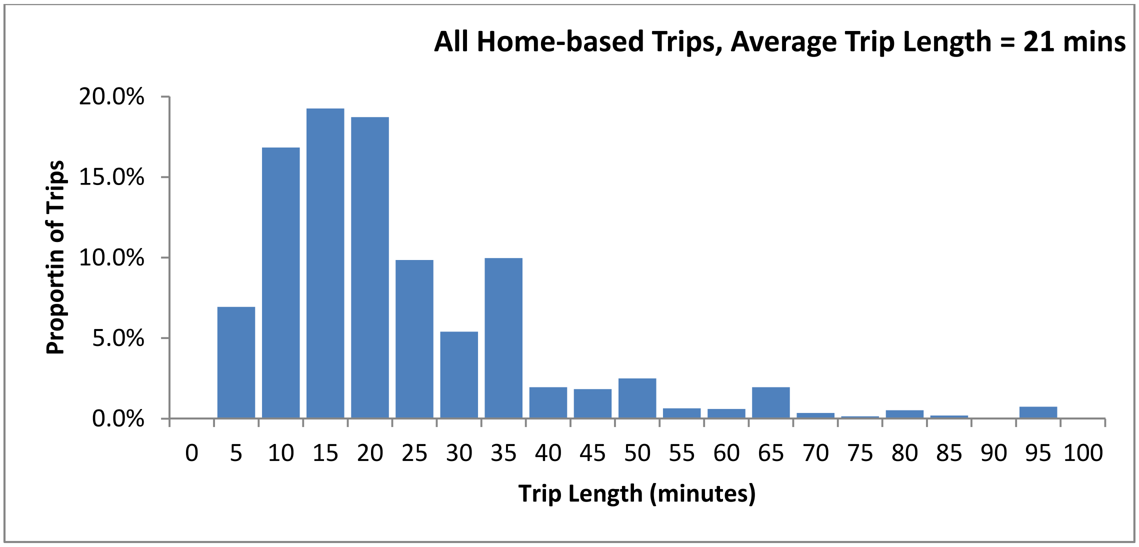

FIGURE G.1 Distribution of Trip Length for All HB Trips

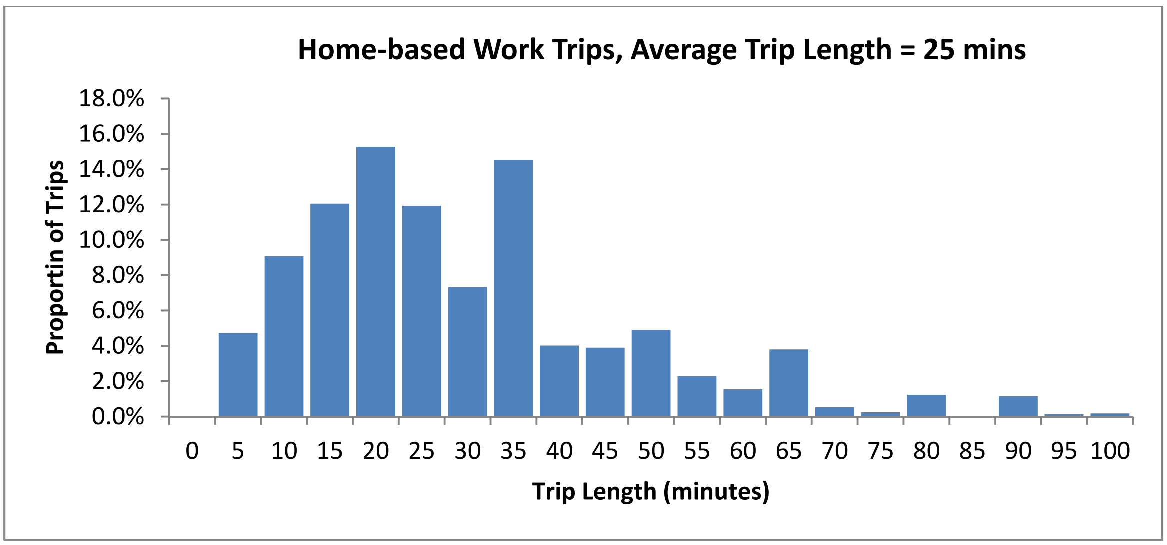

FIGURE G.2 Distribution of Trip Length for HBW Trips

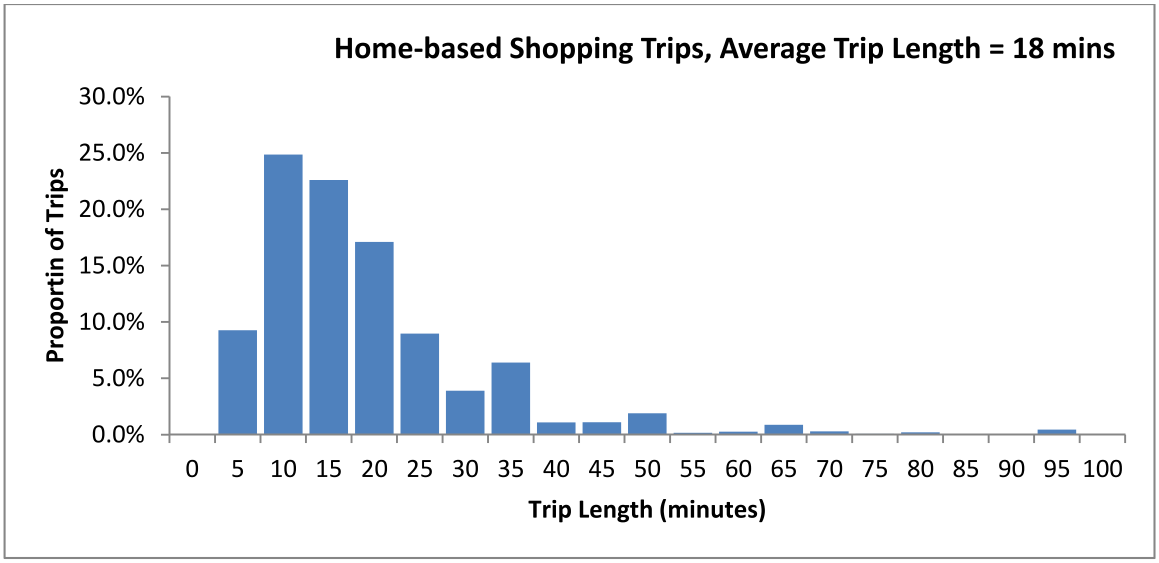

FIGURE G.3 Distribution of Trip Length for HB Shopping Trips

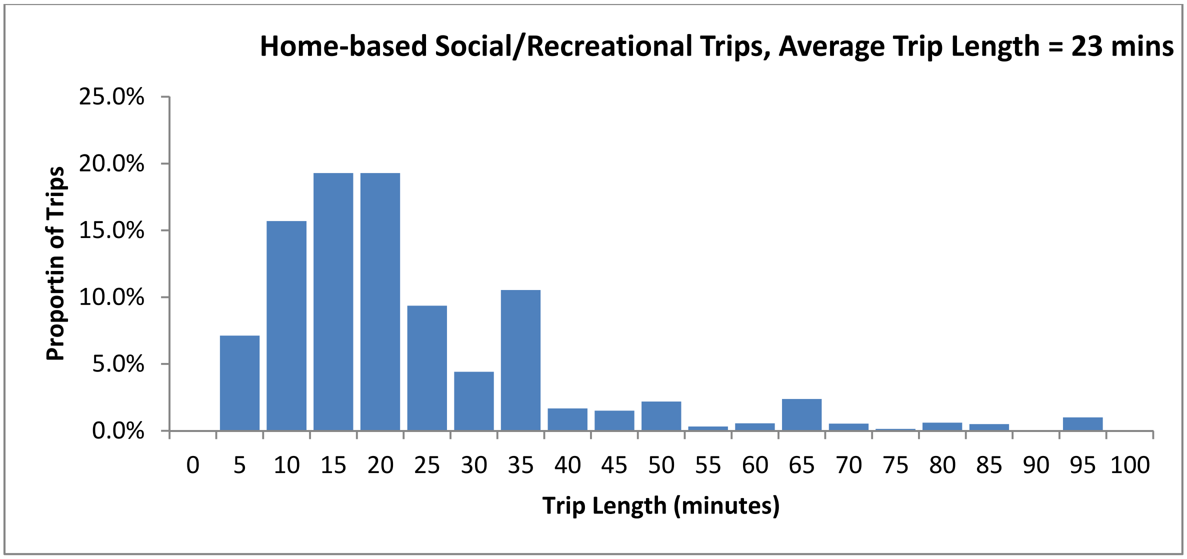

FIGURE G.4 Distribution of Trip Length for HBSocRec Trips

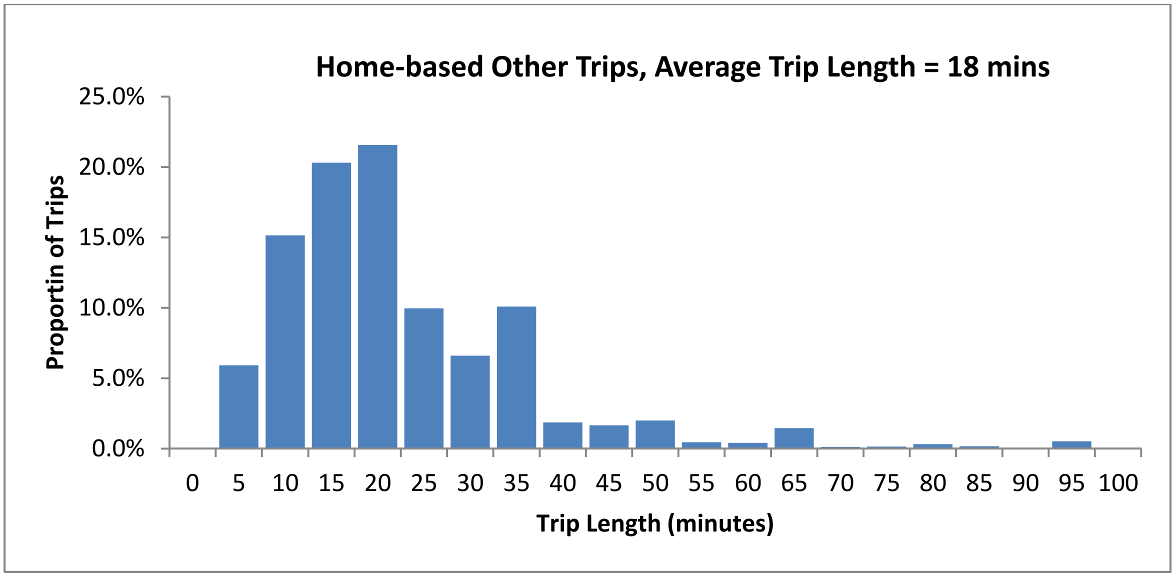

FIGURE G.5 Distribution of Trip Length for HBO Trips

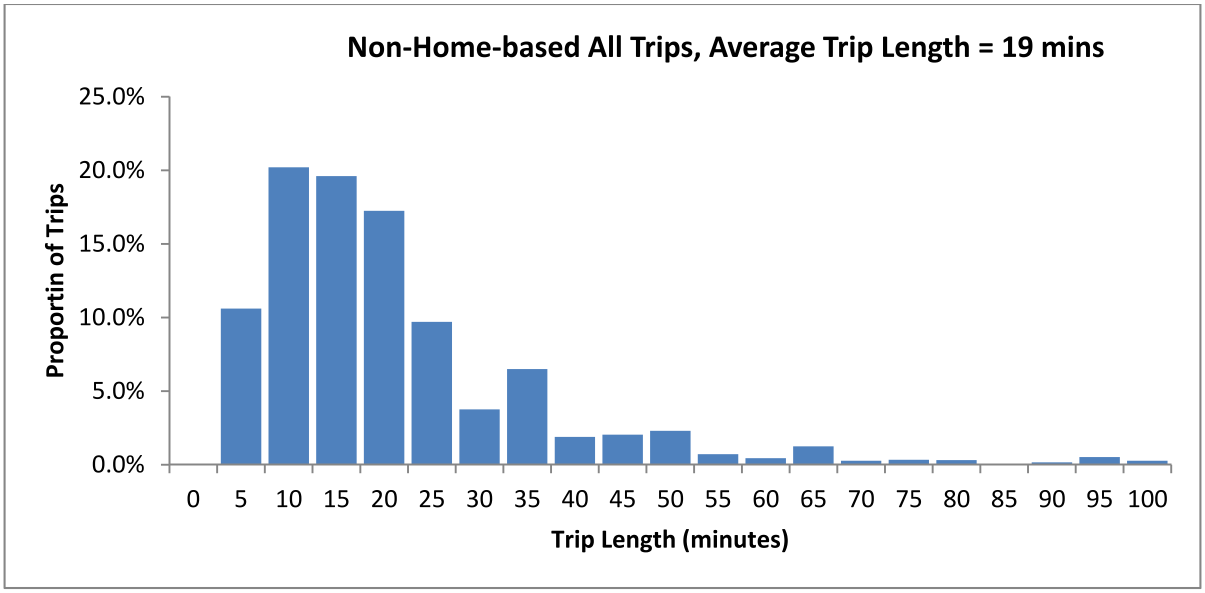

FIGURE G.6 Distribution of Trip Length for All NHB Trips

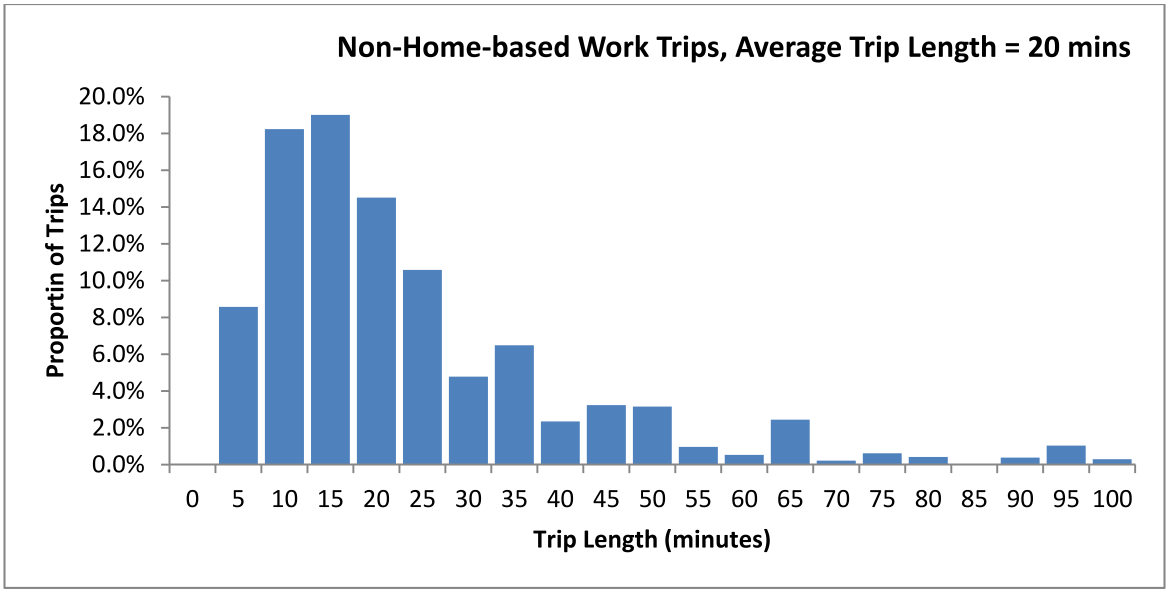

FIGURE G.7 Distribution of Trip Length for NHBW Trips

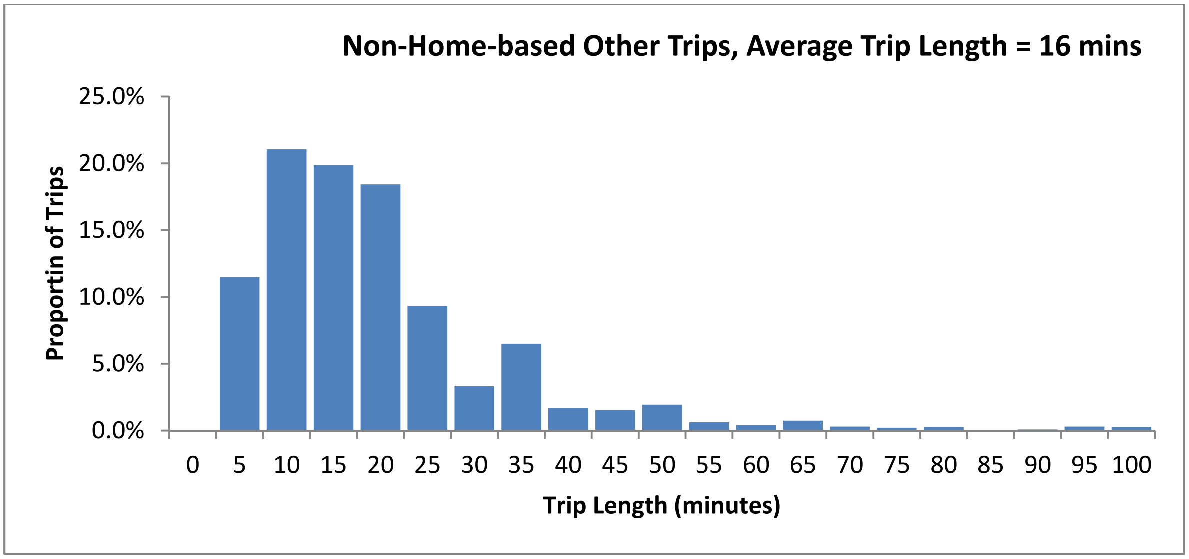

FIGURE G.8 Distribution of Trip Length for NHBO Trips