ASSESSING THE FEASIBILITY OF SUPPLYING VEHICLE ACTIVITY DATA TO MOBILE6 USING THE GLOBAL POSITIONING SYSTEM (GPS)

A Thesis

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Abstract

MOBILE6 is a software program developed by the U.S. Environmental Protection Agency (EPA) to estimate current and future vehicle emissions. The EPA requires all states to develop emission inventories for State Implementation Plans (SIPs) and to demonstrate conformity in non-attainment areas. The primary objective of the MOBILE models is to develop emission inventories in compliance with EPA's regulations.

The research reported in this study is primarily a proof-of-concept study of the feasibility of the Global Positioning System (GPS) to supply vehicle activity data to MOBILE6. However, it also deals with identifying vehicle registration input to MOBILE6 using non-GPS sources. Input data obtained from GPS and non-GPS sources are graphically and statistically compared with the EPA's national default values.

1. Introduction

1.1. Background

MOBILE6 is a software program designed by the U.S. Environmental Protection Agency (EPA) to estimate current and future vehicle emissions under different conditions. MOBILE6 is the latest in a series of MOBILE models and is the first update in MOBILE after the release of MOBILE5b in 1996. The primary objective of the MOBILE model is to develop emission inventories for State Implementation Plans (SIPs) and for conformity determinations. Emission inventories are the estimates of total emissions from the highway motor vehicle fleet on a regional level. The MOBILE6 model calculates in-use fleet emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) generated by gas or diesel-fueled cars, trucks, buses, and motor cycles.

MOBILE6 is based on substantial new test data and accounts for changes in vehicle technology and regulations. It incorporates many new features, including new input and output options that make it more flexible and effective. Some of the new features in MOBILE6 include updated information on basic emission rates, more realistic driving patterns, separation of start and running emissions and changes in fleet composition (EPA, 2002). Using the new input options, MOBILE6 can estimate emissions by roadway type, time of day, vehicle category, and other characteristics that allow detailed modeling of specific local situations. New input options in MOBILE6 create a significant information burden on states preparing submissions for SIP and conformity determinations. The EPA provides national default values for a wide range of conditions that affect emissions. If the input data is unavailable, users may elect to use the national default values. However, the EPA recommends that local values be used whenever possible.

The input requirements of MOBILE6 can be broadly classified into four types, namely external conditions, vehicle gasoline specifications, vehicle fleet characteristics, and vehicle activity data. Procedures for supplying input data for the first two categories are relatively straightforward. Although, this research focuses primarily on supplying vehicle activity data to MOBILE6, because of their high importance, the vehicle fleet characteristic inputs were also developed. Vehicle activity data include data on distribution of vehicle starts during the day, soak distribution, hot soak activity, weekday and weekend trip length distributions, and so on.

Traditionally, vehicle activity data are supplied by travel demand models, traffic count data, instrumented vehicle studies or personal travel surveys. However, there is always a question of accuracy of these data sources because these methods are not developed for air quality modeling purposes and are seldom accurate enough for detailed level emissions modeling required in MOBILE6. Developing accurate travel related input data for air quality models like MOBILE6 is becoming a major challenge for the transportation planners involved in air quality modeling. Research is ongoing in this field and there is a keen interest to test the use of Global Positioning System (GPS) data as an alternative means of estimating vehicle activity. More accurate and extensive travel information available through the use of GPS makes it an attractive alternative means of data acquisition. However, this field is new and the concept of using GPS instruments to obtain data for air quality models like MOBILE6 has not been fully tested.

Although, MOBILE6 is a macroscopic air quality model, it needs input data to be supplied in detailed level. Some of these detailed input requirements include VMT data for each facility class, hour of the day, speed intervals, vehicle start and stop information in each hour of the day and vehicle soak distributions. Although, microscopic air quality models like VT-MICRO and CMEM exist in the air quality modeling field, the EPA still requires all agencies to use the MOBILE6 as their air quality model, while preparing emission inventories.

The use of microscopic GPS data in macroscopic models like MOBILE6 may not be cost effective, but still this study focuses on the feasibility of using this data for the following reasons.

- Different vehicle activity input options of MOBILE6 require different data sources. The EPA itself suggests the use of instrumented vehicle studies for obtaining vehicle starts and stops information. Instead of using these instruments, which collect vehicle start and stop information, if GPS instruments are used, the need for collecting data from multiple data sources may be eliminated.
- Data collected from GPS survey is more accurate than the data from other types travel surveys. Although, conducting the GPS survey is expensive than other types of travel surveys, the data accuracy makes it an attractive option.
- The EPA is conducting a lot of research to develop the microscopic air quality models in the future. The procedures used in deriving the input data to MOBILE6 from the GPS data can also be useful in deriving the input data for the microscopic models.

1.2. Study Objective Background

The input requirements of MOBILE6 create significant information burden on agencies preparing emission inventories. EPA encourages states and agencies to develop innovative methods for supplying the local input data to MOBILE6, as there are limitations for the procedures using the traditional data sources. Travel surveys are one of the primary data sources to MOBILE6. Traditionally in travel surveys vehicle activity data is captured by self-reported information using a telephone recall method or some kind of diary. Data collectors and other transportation professionals construe that people likely omit very short trips using self-reported methods and the data accuracy completely depends on the respondents reporting the travel activity. These self reported methods couldn't be accurately used in obtaining the accurate vehicle start and stop information. Use of automated data collecting technique like GPS can minimize these errors and provides accurate travel behavior required for MOBILE6 inputs.

In conducting a GPS travel survey, the major tasks involve obtaining a suitable sample size to represent the entire population in the area of modeling, processing the obtained data and deriving information in the required MOBILE6 format. Another task is to compare the obtained input data with the national default values. This comparison is important in the process of testing the obtained input data from the GPS. The default data is the only available source of testing the input data obtained from the GPS. Default input data provide a possible input values to MOBILE6 and their distributions provide general trends of different vehicle activity data. Comparing the default data distributions with the local input data distributions helps in understanding the variation of local vehicle fleet and vehicle activity with respect to those of the national averages. A statistical comparison of the local input data with the default data helps in identifying the vehicle activity inputs, which are different from the default values. This helps the agencies preparing the emission inventories to choose either local values or the default values for supplying data to a particular input option.

1.3. Research Objectives

The specific objectives of this research study are to:

- Develop a methodology using GPS data to derive vehicle activity inputs to MOBILE6.
- Compare the derived inputs with the national default values and test the validity of supplying travel-related inputs to MOBILE6 using GPS.
- Using the results of this research demonstrate a procedure for obtaining a suitable sample size for a future GPS survey aimed at supplying vehicle activity inputs to air quality modeling.

The findings of the study are expected to help the researchers in conducting a GPS survey, processing the data to obtain the required input data of MOBILE6 and thereby producing locality specific vehicle activity inputs to MOBILE6 using a single data source.

2. Literature Review

MOBILE6 is the latest in a series of air quality models, first produced in 1978. The EPA's User's Guide (EPA, 2002) and its various other technical documents are the primary literature source for supplying input data to MOBILE6. Before reviewing the published literature, EPA's Users Guide to MOBILE6 was reviewed with specific emphasis on identifying the input requirements for MOBILE6.

2.1. Input Requirements of MOBILE6

The User's Guide to MOBILE6 (EPA, 2002) finally gives a detailed explanation for each input requirement. MOBILE6 requires that input to be supplied using individual or composite vehicle classifications, depending upon what input data is being supplied. In the individual vehicle type classification, vehicles are divided into 28 vehicle types based on their weight, type and fuel type. This classification is also known as the complete MOBILE6 vehicle classification and is shown in Table 2.1. The composite vehicle classification combines gasoline and diesel vehicles. In this vehicle classification vehicles are divided into 16 vehicle types as shown in Table 2.2. Vehicles are further distinguished by age up to 25 years of age. That is, MOBILE6 requires information by model year from the current year to 25 years earlier than the current year. Models older than 25 years are all grouped together with 25-year old models.

The following subsections describe each input requirement briefly.

2.1.1 Vehicle Fleet Data

Fleet characteristic commands require information on the number of vehicles by vehicle type, vehicle age and fuel type. The research reported in this study focuses on two important vehicle fleet characteristic input options, namely the distribution of vehicle registrations and annual mileage accumulation rates.

- The distribution of registered vehicles by vehicle age must also be supplied by vehicle type as specified in Table 2.2.

Table 2.1: Complete MOBILE6 vehicle classification
(Source: EPA, 2002)

Vehicle Type	Individual Vehicle Type - Description
LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3750 lbs. LVW)
LDGT2	Light Duty Gasoline Trucks 2 (0-6,001 lbs. GVWR, 3751-5750 lbs. LVW)
LDGT3	Light Duty Gasoline Trucks 3 (6,001-8500 lbs. GVWR, 0-3750 lbs. LVW)
LDGT4	Light Duty Gasoline Trucks 4 (6,001-8500 lbs. GVWR, 3751-5750 lbs. LVW)
HDGV2B	Class 2b Heavy Duty Gasoline Vehicles (8501-10,000 lbs. GVWR)
HDGV3	Class 3 Heavy Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
HDGV4	Class 4 Heavy Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
HDGV5	Class 5 Heavy Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
HDGV6	Class 6 Heavy Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
HDGV7	Class 7 Heavy Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
HDGV8A	Class 8a Heavy Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
HDGV8B	Class 8b Heavy Duty Gasoline Vehicles (>60,000 lbs. GVWR)
LDDV	Light Duty Diesel Vehicles (Passenger Cars)
LDDT12	Light Duty Diesel Trucks 1 (0-6,000 lbs. GVWR)
HDDV2B	Class 2b Heavy Duty Diesel Vehicles (8501-10,000 lbs. GVWR)
HDDV3	Class 3 Heavy Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
HDDV4	Class 4 Heavy Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
HDDV5	Class 5 Heavy Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
HDDV6	Class 6 Heavy Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
HDDV7	Class 7 Heavy Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
HDDV8A	Class 8a Heavy Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
HDDV8B	Class 8b Heavy Duty Diesel Vehicles (>60,000 lbs. GVWR)
MC	Motorcycles (Gasoline)
HDGB	Gasoline Busses (School, Transit and Urban)
HDDBT	Diesel Transit and Urban Busses
HDDBS	Diesel School Busses
LDDT34	Light Duty Diesel Trucks 1 (6,001-8500 lbs. GVWR)

**GVWR: Gross Vehicle Weight Rating: The maximum weight of the vehicle when it is fully loaded as specified by the manufacturer*
**LVW: Loaded Vehicle weight (weight of vehicle sitting empty (or vehicle curb weight) plus 300lb)*
**ALVW: Alternative Loaded Vehicle Weight :(An adjusted weight obtained by the numerical average of vehicle curb weight and gross vehicle weight)*

Table 2.2: Composite Vehicle Types for MOBILE6
(Source: EPA, 2002)

Number	Abbreviation	Description
1	LDV	Light-Duty Vehicles (Passenger Cars)
2	LDT1	Light-Duty Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDT2	Light-Duty Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDT3	Light-Duty Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW*)
5	LDT4	Light-Duty Trucks 4 (6,001-8,500 lbs. GVWR, 5,751 lbs. and greater ALVW)
6	HDV2B	Class 2b Heavy-Duty Vehicles (8,501-10,000 lbs. GVWR)
7	HDV3	Class 3 Heavy-Duty Vehicles (10,001-14,000 lbs. GVWR)
8	HDV4	Class 4 Heavy-Duty Vehicles (14,001-16,000 lbs. GVWR)
9	HDV5	Class 5 Heavy-Duty Vehicles (16,001-19,500 lbs. GVWR)
10	HDV6	Class 6 Heavy-Duty Vehicles (19,501-26,000 lbs. GVWR)
11	HDV7	Class 7 Heavy-Duty Vehicles (26,001-33,000 lbs. GVWR)
12	HDV8A	Class 8a Heavy-Duty Vehicles (33,001-60,000 lbs. GVWR)
13	HDV8B	Class 8b Heavy-Duty Vehicles (>60,000 lbs. GVWR)
14	HDBS	School Buses
15	HDBT	Transit and Urban Buses
16	MC	Motorcycles (All)

- This involves specifying vehicle registration data for 25 vehicle ages in the 16 composite vehicle types. Age distribution factors can be obtained using the following formula.

  Age distribution factor of age *x* = Number of vehicle in age *x*/Total number of vehicles of all ages in that composite vehicle type.

- The annual mileage accumulation rates must be provided by vehicle age for all 28 individual vehicle types, shown in Table 2.1. The mileage accumulation rate represents the total annual travel accumulated per vehicle of a given age and vehicle type. The mileage accumulation rates are estimated by dividing the average mileage accumulation of each vehicle type in each age category by 100,000. For example, if vehicle of a certain type and a certain age accumulates 10,000 mile per year on average, the mileage accumulation rate for that vehicle type and age category will be 0.100.

2.1.2 Vehicle Activity Data

Vehicle activity input requirements relate to vehicle miles traveled distributions (VMT), vehicle engine start distributions, vehicle trip length distributions, soak length distributions, etc. Details of these input requirements are described below.

- The VMT must be allocated to various roadway or facility types (4 types) by each of the 28 vehicle classes for each of the 24 hours of the day. The facility types used in this input requirement are freeway, arterial, local streets and ramps. For each vehicle class, there are four of 24-value VMT input data sets corresponding to the four facility types (freeway, arterial, local, and ramp) for each hour of the day.
- The VMT by hour command requires information, which is an aggregation of the information in the previous subheading. When the extensive data required for above command is unavailable this command can be used. The fraction of total VMT that occurs each hour of the day is specified in this command. This command requires values that are independent of facility type. 24 VMT fractions, one for each of the 24 hours of the day must be supplied.
- The VMT by speed command specifies VMT by average speed (pre selected ranges) on freeways and arterial roads for each of the 24 hours of the day. Within each facility type and each hour of the day, travel in terms of VMT is divided into 14 speed bins. The 14 speed ranges are allocated as follows. The first bin is "idle" which is below 2.5 mph. The second bin consists of speeds in between 2.5 mph to 5 mph. From 5 mph to 60mph there are 11 speed bins, at 5mph intervals. The last speed bin contains all speed values greater than or equal to 65 mph.

- In the ‘distribution of vehicle starts during the day’ input option, engine starts by hour of the day are specified separately for weekdays and weekends. 48 values are supplied, each value representing the average fraction of all engine starts that occur in each hour of a 24-hour day, for weekdays and weekends. The sum of the fractions of each set of 24 values must equal one.
- The soak time command in MOBILE6 requires the cold soak inputs. The soak time affects exhaust start and exhaust running emissions. A vehicle is considered to be soaking if its engine is not running. Soak time is the length of time between the engine turn off time and engine start time. Cold soak time in MOBILE6 determines the percentage of vehicles that have been soaking for a given amount of time prior to an engine start, for each hour of the day. There are 70 cold soak intervals for each of the 24 hours of the day as specified by EPA as shown in Table 2.3. Soak time distributions represent the proportion of vehicles experiencing a cold soak of a given duration at each hour of the day. Soak times are established separately for weekdays and weekends. Within the weekday and weekend groups, soaking vehicles are distributed into 24 hours of the day and within each hour of the day soaking vehicles are subdivided into 70 soak time intervals. Soak time factors are obtained for each hour of the day so that all 70 fractions add up to one. Each fraction in a particular hour of the day is obtained by dividing number of soaking vehicles in a particular soak bin by total number of soaking vehicles in all 70 soak bins.
- When fuel vapors escape from a hot vehicle that has just been turned off, hot soak emissions occur. MOBILE6 assumes that vehicles emit harmful vapors from a

vehicle up to 60 minutes after it is turned off and, therefore, hot soak durations ranging from 1 minute at minimum to a maximum of 60 minutes are required as input. The hot soak time distributions represent the proportion of vehicles experiencing a hot soak of a given duration at each hour of the day. This option requires the user to specify a hot soak duration distribution for each of 14 daily time periods separately for weekdays and weekends. MOBILE6 divides a typical day into 14 time periods: one for each hour between 6 AM and 7 PM, plus one for the hours from 7 PM through 6 AM the next day. Within each of 14 hot soak intervals, the user must distribute hot soak emissions into 60 classes with each class representing 1 minute with the exception of the last class, which includes hot soak durations of 60 minutes or more. Within each hot soak interval, 60 hot soak fractions should be obtained as MOBILE6 input, so that all 60 fractions add up to one. Each fraction in a particular hot soak interval should be obtained by dividing number of soaking vehicles in a hot soak class by total number of soaking vehicles in all 60 hot soak classes.

Table 2.3: Cold Soak Time Intervals for MOBILE6
(Source: EPA, 2002)

Interval number	**Interval Range (N=interval number)**
1	(Greater than 0.1) to 1.0 minutes
2 to 30	(Greater than N-1) to N minutes
31 to 45	(Greater than 2N-32) to (2N-30) minutes
46 to 67	(Greater than 30N-1320) to (30N-1290) minutes
68	Greater than 720 minutes
69	(Greater than 0) to 0.01 minutes (restarts)
70	Zero minutes (stalls, not used)

2.2. Review of Past Studies in MOBILE6 Data Inputs

Past studies of the input requirements for MOBILE6 were reviewed and the useful information is presented in this section. Information on external conditions and vehicle gasoline specifications can usually be obtained from local agencies with relatively little effort. The most time consuming part of obtaining data for MOBILE6 is getting vehicle fleet characteristic and vehicle activity data. Hence most of the literature available deals with obtaining information on vehicle fleet characteristics and vehicle activity data.

2.2.1 Vehicle Fleet Data

EPA used the data analysis conducted by Arcadis and his colleagues to prepare vehicle registration default values for MOBILE6; Arcadis reviewed the following primary data sources to obtain vehicle registration distributions for the 16 composite vehicle types shown in Table 2.2.

- Truck Inventory and Use Survey by the U.S Bureau of Census.
- Nationwide Personal Transportation Survey, 1995.
- Federal Transportation Administration data.

The data prepared by Arcadis represented a "snapshot" in time. The vehicle fleet characteristics reflect the economical and political conditions at that time and the use of this "snap shot" data to represent vehicle fleet in any year other than the year in which the data was collected will not provide accurate results. Hence there is no reason to expect the same economical and political conditions that existed at the time of input data preparation will exist in the future (EPA, 2001d).

The EPA developed default vehicle registration distributions from the 1996 vehicle registration data produced by Arcadis, and then adjusted the individual distributions using curve fitting equations shown in Table 2.4. Several types of curves such as linear, polynomial, exponential and Weibull curves were explored to find the best fit (EPA, 2001d). The equation for motorcycles is not shown in the table 2.4, as the EPA did not prepare curve-fitting equations for that class.

Table 2.4: Curve Fitting Equations Used in Default Registration Data Preparation
(Source: EPA, 2001d)

Aggregate Vehicle Category	Equation	Ages
LDV	y= (8,517,910*e (-((age/16.10050554) ^ 4.45489164)))	1-12
LDV	y = 112855609.5568e (-0.2321*age)	13-25
LDT(0-6,000 lbs)	y= (3,386,682*e (-((age/14.38211814) ^ 3.04037069)))	1-18
LDT (0-6,000 lbs)	y = 805298.7399e (-0.0409*age)	19-25
LDT (6001-8500 lbs)	y = 1305324.4e (-0.070863*age)	1-25
HDV classes 2b-3	y = 732326.5e (-0.09455*age)	1-25
HDV classes 4-8	y = 404143.88e (-0.066843*age)	1-25
HDBS	y = 38982e(-0.068092*age)	1-25
HDBT	y= (3462*e (-((age/17.16909475) ^ 12.53214119)))	1-17
HDBT	y = 24987.0776 e(-0.2000*age)	18-25

Comparisons of the vehicle registration distributions produced by Arcadis and curves fitted by the EPA are shown in the figures 2.1 to 2.7 for all the 16 vehicle types. The EPA combined some of the 16 vehicle categories because of data constraints. The following are the vehicle groups developed from 16 composite classes (see Table 2.2). Individual vehicle classes in each of these groups have the same set of default values

- LDV

- LDT1 and LDT2
- LDT3 and LDT4
- HDV classes 2a-3
- HDV classes 4-8
- All school buses as HDBS
- All transit buses as HDBT
- MC

The EPA encourages the use of alternative data sets and modeling efforts to provide local information on vehicle registration distributions (EPA, 2001d). The graphs shown in Figures 2.1 to 2.7 could be useful for comparison purposes for agencies preparing vehicle registration distribution inputs using various methods.

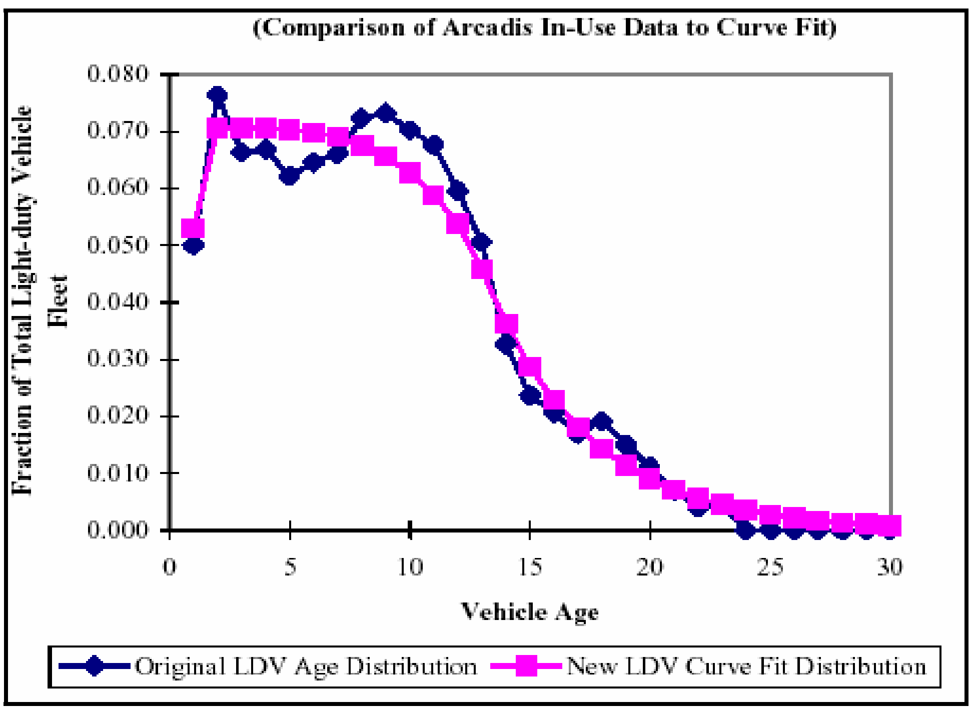

Figure 2.1: Comparison of Arcadis Data to Curve Fit for LDV
(Source: EPA, 2001d)

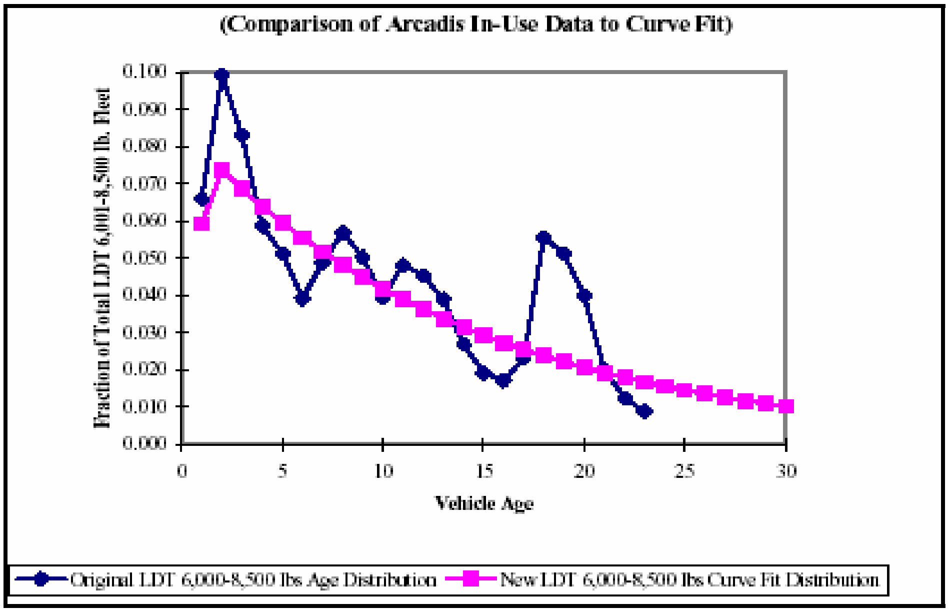

Figure 2.2: Comparison of Arcadis data to Curve Fit for LDT 1, 2
(Source EPA, 2001d)

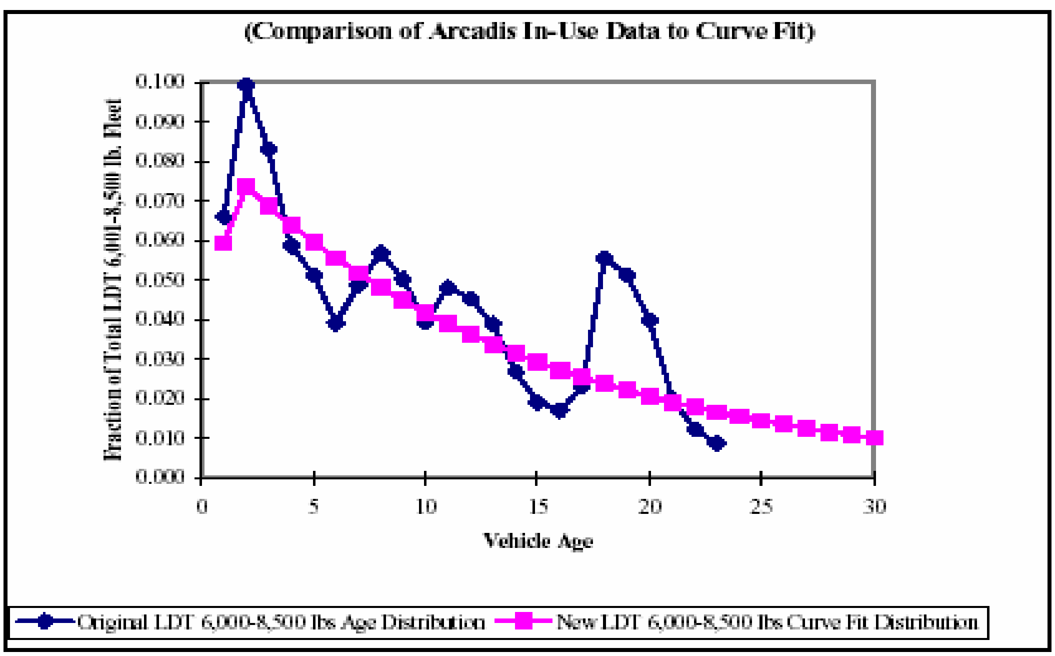

Figure 2.3: Comparison of Arcadis Data to Curve Fit for LDT 3, 4

(Source: EPA, 2001d)

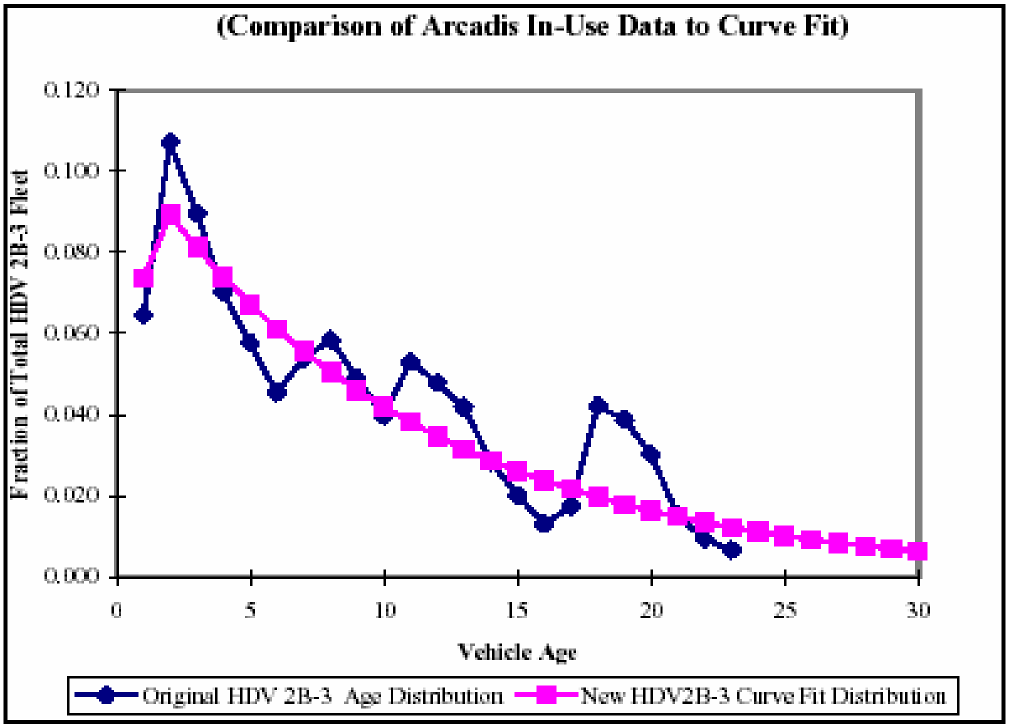

Figure 2.4: Comparison of Arcadis Data to Curve Fit for HDV2b-3
(Source: EPA, 2001d)

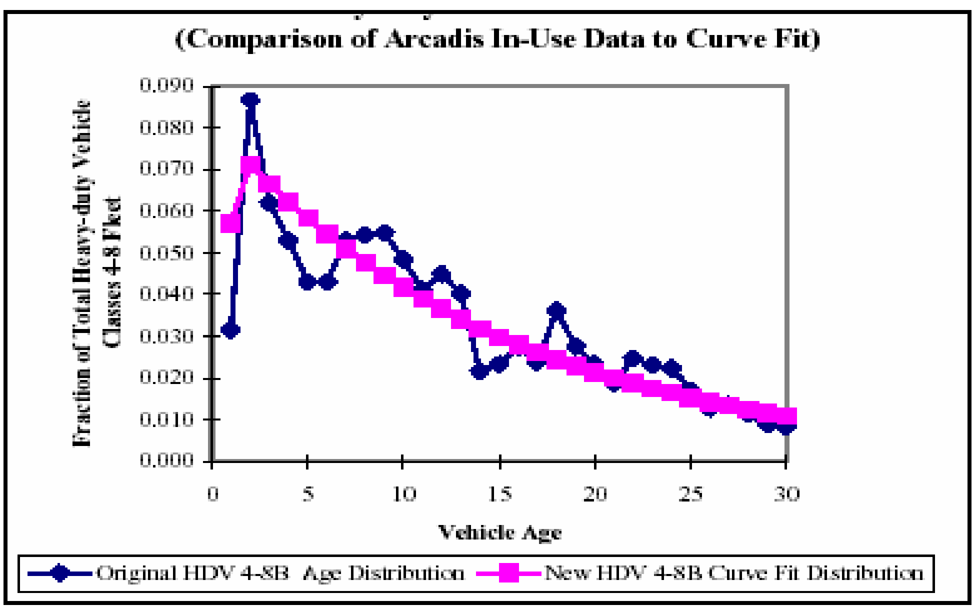

Figure 2.5: Comparison of Arcadis Data to Curve Fit for HDV4-8
(Source: EPA, 2001d)

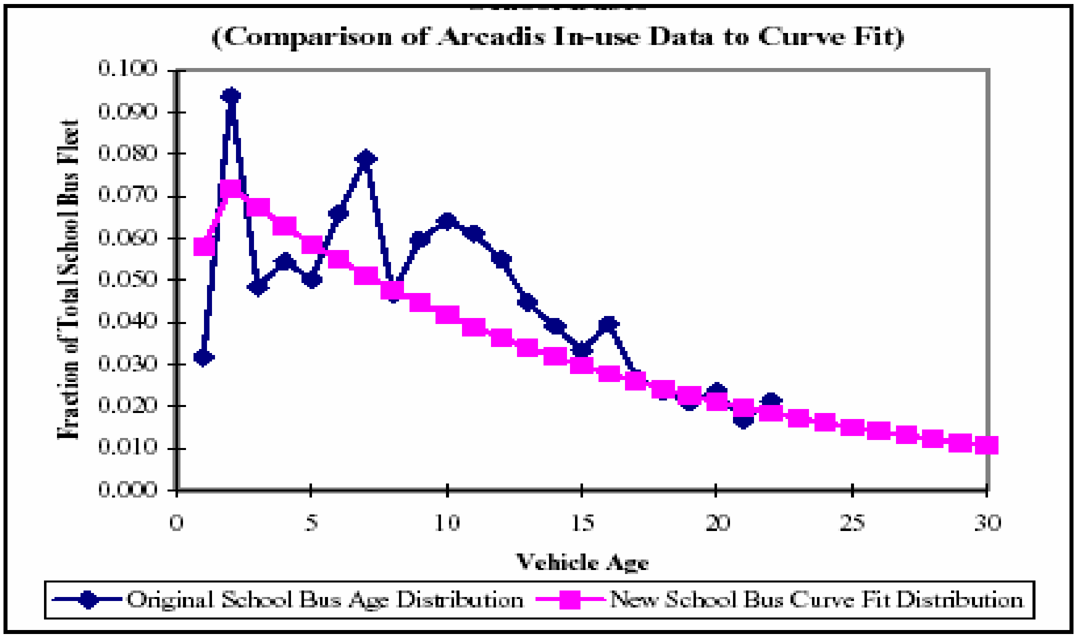

Figure 2.6: Comparison of Arcadis Data to Curve Fit for HDBS
(Source: EPA, 2001d)

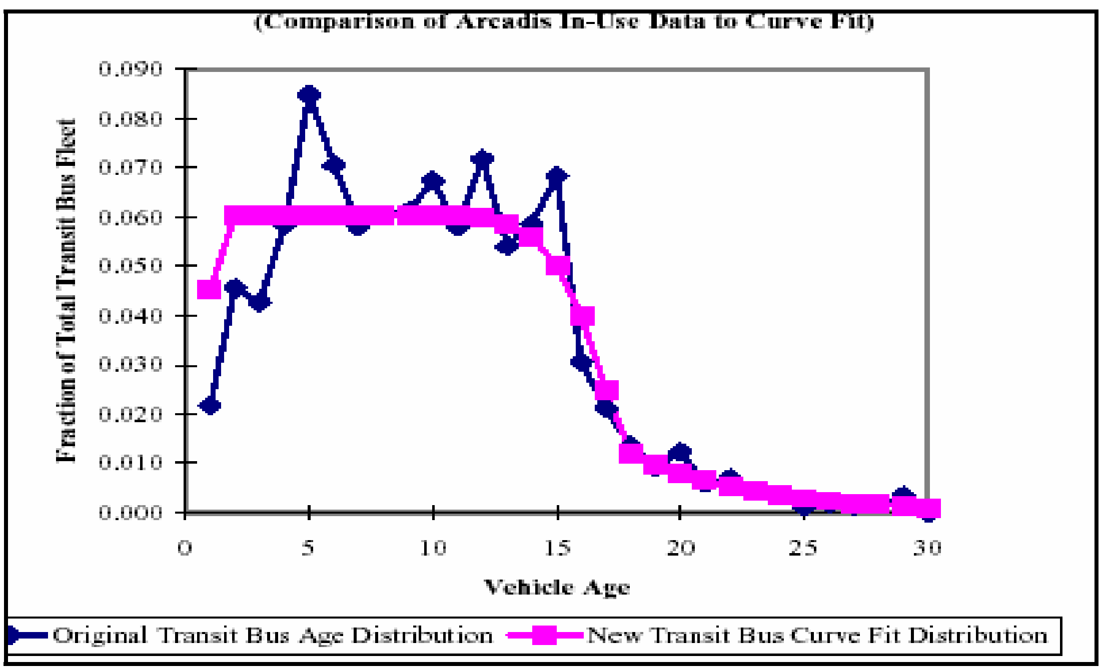

Figure 2.7: Comparison of Arcadis Data to Curve Fit for HDBT
(Source: EPA, 2001d)

Qiao, et al. (2001), developed models and corresponding software to forecast the age distribution of vehicles for specific localities. They developed two types of models to predict vehicle age distribution. Model Type1 (MT1) models the proportion of vehicles in each age category for each vehicle type, and then transfers the results to forecast the future age distribution. Model Type 2 (MT2) models the future age distribution directly. Both model types contain a family of linear models, non-linear models and time series models. These models require considerable local information including socioeconomic indexes and the current distribution of vehicle ages by vehicle type in the area and it is not simply a matter of extending the current trends of vehicle age distribution. The basic idea in this effort was to develop a relationship between socioeconomic indexes and vehicle age distribution. Age distributions for the eight counties in the Houston-Galveston Area Council (HGAC) in Texas were used for the validation of model structures and parameters. Emission factors generated by MOBILE based on default age distribution values and those based on forecasts from the models were compared and considerable differences were found. Hence the authors suggested using the proposed model to generate locality-specific MOBILE emission factors. The authors also developed a computer program, which can serve as standard software for the Texas cities in generating age distribution inputs for MOBILE.

Miller, et al. (2001), proposed that county level income could be used to estimate vehicle age distribution and emissions. Vehicle registration data were analyzed on a county-by-county basis in the process of performing a statewide emission inventory of on-road mobile sources in Tennessee. It was observed that median vehicle age correlated strongly with average personal income for each county. It was observed that counties with the lowest income had oldest vehicle fleets, while the counties with highest income had the newest vehicle fleets. The authors suggested that personal income might be a good surrogate for vehicle age.

A recent study by Granell et al. (2001) describes the problems in current practice in using the locality-specific fleet distributions and proposes some alternatives. They reported that the Emissions Inventory Improvement Program (EIIP) provides methodologies to estimate vehicle characteristics using Inspection and Maintenance (I/M) programs and license plate readings from video cameras used in large remote sensing programs. As part of EIIP, the EPA published guidance documentation focusing on data sources development for use in emission inventories. They also reported on the use of Department of Revenue registration data in Georgia, where Vehicle Identification Numbers (VINs) of all the vehicles registered in the state were obtained from the database. The results of VIN decoding gave important information like vehicle model, body, engine type, model year etc.

For annual mileage accumulation rates, default values produced by EPA were drawn from data sets processed by Arcadis et al., (1998). They used different data sets for obtaining annual mileage accumulation rates for different vehicle types. These data sets were:

- 1995 Nationwide Personal Transportation Survey - for LDV class
- The U.S. Bureau of Census' "1992 Truck Inventory and Use Survey" - for all trucks and non bus heavy duty vehicles
- Bobit Publication's "School Bus Fleet 1997 Fact Book Issue" – for school buses
- Federal Transportation Administration Data – for transit buses

The processing of the data involved the calculation of annual mileage rates for all the vehicle types and development of linear and exponential curve fitting equations. The curve fitting equations are shown in Table 2.5. Using these curves, default mileage accumulation rates were estimated based on the model year of the vehicles (EPA, 2001d). Figure 2.8 shows the default annual mileage accumulation rates obtained in that study for LDVs including the curve fitting results and MOBILE5a default values.

Table 2.5: Annual Mileage Accumulation Rate Curve Fit Equations
(Source: EPA, 2001d)

Aggregate Vehicle Category	Equation	Age
Light-duty vehicle	y= (8,517,910*e (-((age/16.10) ^ 4.45)))	1 to 12
Light-duty vehicle	y = 112855609.55e (-0.23*age)	13 to 25
Light-duty truck 0-6,000 lbs	y= (3,386,682*e (-((age/14.38211814) ^ 3.04)))	1 to 18
Light-duty truck 0-6,000 lbs	y = 805298.73e (-0.0409*age)	19 to 25
Light-duty trucks 6,001-8,500 lbs	y = 1305324.4e (-0.070863*age)	1 to 25
Heavy-duty vehicles classes 2B-3	y = 732326.5e (-0.09455*age)	1 to 25
Heavy-duty vehicles classes 4-8	y = 404143.88e (-0.066843*age)	1 to 25
Heavy-duty school buses	y = 38982e(-0.068*age)	1 to 25
Heavy-duty transit buses	y= (3462*e (-((age/17.16) ^ 12.53)))	1 to 17
Heavy-duty transit buses	y = 24987.07 e(-0.20*age)	18 to 25

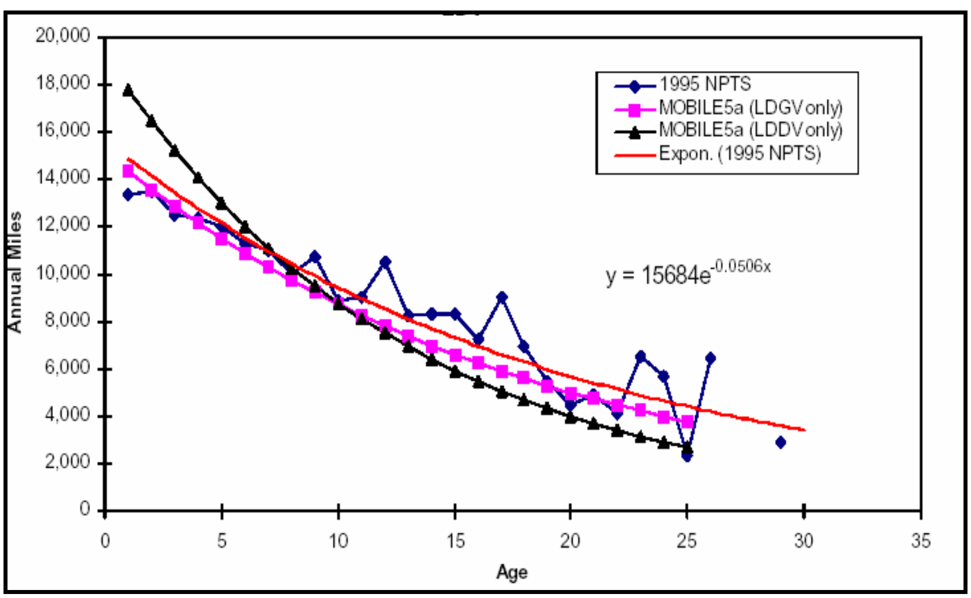

Figure 2.8: Arcadis Annual Mileage Accumulations Rates for LDV
(Source: Arcadis et al., 1998)

2.2.2. Vehicle Activity Data

Vehicle activity data includes information on vehicle miles traveled (VMT) distributions, and soak length distributions. For each input option, EPA's methodologies for obtaining the default values and the EPA's suggestions and the other published research studies are briefly discussed in this subsection.

For VMT fractions by functional class, speed and hour of the day the default values were developed by aggregating the data obtained in different locations from travel demand studies and traffic count data sets. The individual areas have different functional classification systems. Hence the EPA had to merge these classes into four functional classes required for MOBILE6. The data obtained from 5 urban areas namely, Chicago, Houston, Charlotte, Ada county (Boise region) and New York were used to develop VMT default values for MOBILE6. Results for Chicago, Houston and Boise were obtained from travel demand models while, the results for Charlotte and New York were obtained from traffic counts. These cities were used as prototypes and the EPA developed an aggregation procedure to develop VMT by speed, facility class and hour of the day to obtain the national default values. The EPA suggests the use of travel demand models or traffic count data for agencies preparing data for VMT requirements of MOBILE6, and these methods are briefly discussed in the following paragraphs.

Most state and local transportation agencies have sizable bodies of traffic count data available to them. Some of these counts may be collected as part of the Highway Performance Monitoring System (HPMS), but typically agencies have their own traffic count databases. Traffic count data are generally maintained at hourly or daily resolution and in some cases they are available at 15-minute intervals (EPA, 2001a).

The following are the VMT by facility class estimation steps suggested by EPA (EPA, 2001a).

1. Calculate the sum of counts in each functional class
2. Determine the sample size in each functional class
3. Determine the average volume by dividing the total count by the sample size
4. Obtain miles of facility in each class (from DOTs or GIS databases)
5. Calculate VMT by class as average volume multiplied by number of miles of facility.

MOBILE6 requires VMT for arterials and freeways be further disaggregated by speed. EPA suggests the use of the Bureau of Public Roads (BPR) method for this process. In this method, the volume/capacity relationship expressed in the BPR curves is used to estimate the speed on each link.

Another source of estimating vehicle activity by functional class, time of day and speed is travel demand models. Land use data, network data and data of diurnal factors are the inputs to the four-step process in travel demand modeling. Land use forecasting models are used to allocate future population and employment growth based on accessibility measures and attractiveness of each zone. Only the major roadways represent the highway network and all inter-zonal travel is assumed to occur on this network. The diurnal factors describe the variation in traffic flow by hour of the day. Estimates of these factors are obtained from traffic counts on travel surveys. The estimated factors from traffic counts are usually classified by facility/area type and orientation of link. The factors based on travel survey data are distinguished by trip purpose (TMIP, 1994).

The following data are available from travel demand models:

1. Link specific traffic volumes. From these volumes, VMT can be calculated by multiplying link volumes by link length.
2. Average speed on each link. This can be obtained by dividing the link length by the travel time on the corresponding link.
3. Zone to zone trips by purpose.

The EPA suggests the following steps in using travel demand models for VMT estimation (EPA, 2001a).

1. Distribute link level volumes by hour of the day
2. Calculate hourly VMT by multiplying link distance by hourly volume.
3. Find the v/c ratio, using link specific capacities.
4. Apply the BPR curve, using link specific free flow speed or look up tables, to arrive at hourly-congested speeds.

Bhat and Nair, (2001), developed a model that predicts the VMT by vehicle type on links as a function of the functional classification, physical attributes, operating conditions of the links, and the attributes of the traffic analysis zone in which the link lies. They did an empirical analysis to estimate a model for the Dallas-Fort Worth region in Texas. Five sets of independent variables were included in the model to predict the VMT mix on links. These are: a) link specific functional classification, b) link physical attributes, c) link free speed variables, d) degree of urbanization of zone, e) zonal land use characteristics. The results of the proposed model and those of the default model in use by the Metropolitan Planning Organizations were compared with the actual observed

VMT distribution values. The model evaluation results indicated that proposed model provided better predictions of VMT distribution values on links than the default model.

Battelle team estimated the VMT by facility class using the Lexington GPS data. A map matching algorithm developed by Transcore (formerly JHK& Associates) was used in breaking down the travel into facility classes. This algorithm used specific nodes and links of the street network to convert the GPS data file into a GPS match database with coordinate adjusted and link referenced time points. However, this breakdown of VMT into individual facility classes was not detailed enough to supply VMT by facility class input to MOBILE6 (Battelle, 1997).

Soak analyses require information on soak durations, time of soak, trip lengths, time of trip, day of trip and other information. The EPA recommends that this information be gathered from vehicles specially instrumented to collect this information. In studies conducted by the EPA, 168 vehicles were randomly selected while undergoing routine inspection at Inspection and Maintenance (I/M) stations and then fitted with instruments that recorded start and stop information. The motorists selected were asked to travel for a week using the instrumented vehicles and then to return to have their instruments removed. Information from more than 8500 vehicle trips was recorded in this manner. The raw data was collected, processed and a trip characteristic file was developed using this processed file (EPA, 2001b, c).

Because of the relatively small sample size on which the EPA based estimation of its default values, default soak-related inputs are not differentiated according to model year and vehicle type criteria. The EPA investigated the hot soak and cold soak activity parameters such as number of trips per day and the distribution of the soak time by vehicle type and vehicle age. Slight differences were observed between cars and trucks in terms of number of trips per day and hourly distribution of soaks, but the differences were small. The EPA suggests that this may be due to cars and trucks being used in a similar manner in urban areas, although differences probably exist between their use in industrial and rural areas. Little difference was found between older and newer vehicle soak lengths. This result was unexpected as older vehicles could be expected to be used less than newer vehicles and, therefore, to have longer soak lengths. However, the EPA felt the result may be due to the relatively small sample of older vehicles rather than that there is no difference between the soak lengths of older and newer vehicles (EPA, 2001b, c).

EPA's document on technical guidance to MOBILE6 lists some of the data sources for obtaining soak-related inputs. Travel demand models, that are suitable for activity input data, are not suitable for soak information. Trip diaries and surveys can be used, but these rely on the correct reporting of values by the vehicle owners and may exclude starts that occur at intermediate destinations (EPA, 2001b). Venigalla and Pickrell, (2002), derived soak times using reported data from the 1995 NPTS data. They conducted detailed analysis to relate soak time variability to geographic, trip purpose and time of day variables. The study offers an alternative procedure to accurate and more expensive local surveys if it is assumed that urban areas of similar population display similar soak time characteristics. Soak time data were developed at various geographic levels such as Metropolitan Statistical Area (MSA), Census Region, Census Division and National level. The study suggests the use of the next geographic level of aggregation if the MSA sample size is inadequate or unavailable. The study did find that the default soak time values are, in general, different to the MSA soak time values derived from NPTS data (Venigalla and Pickrell, 2002).

Everett and Sacs, (2001), proposed an alternative methodology for collecting local vehicle start information for use in MOBILE6. They suggested use of an inexpensive ($100 each) data logger that records stop/start data in a vehicle. To reduce the recruitment costs, the survey was linked to the Knoxville MPO's planned household travel survey. In total, the study collected data from 377 vehicles from 200 households in Knoxville, Tennessee. They found that considerably fewer stops and starts were observed in their survey than the EPA default data. The total cost of gathering the data and performing the initial analysis was approximately $36,000 or about $85 per vehicle.

There have been some efforts to model soak time durations. Nair and Bhat (2000) estimated models based on vehicle trip data, obtained from household surveys and supplementary land-use data. Zone specific soak time distributions by time of day and origin activity purpose were obtained. Sivakumar (2000) used soak time models developed by Nair and Bhat, and implemented soak time distribution models in a GIS framework. Given the zone-to-zone production attraction matrices by trip purpose, the number of trip starts by the zone of origin, activity purpose prior to trip start and time of day were obtained. Based on this information, the zone specific soak time distributions were computed using the soak time distribution models.

2.3. Summary

EPA provides extensive documentation, which is helpful for understanding the input requirements to MOBILE6, the methodologies developed by the EPA in preparing the national default values. EPA used the different data sets from different regions and aggregated the results to obtain the national default values. Travel demand models, traffic counts, and travel surveys are some of the primary data sources in preparing the national default values. However, these sources are not exclusively developed for the purpose of air quality modeling and are not accurate in supplying the detailed vehicle activity data required for MOBILE6. EPA suggests the agencies preparing emission inventories to use local data in MOBILE6 and encourages innovative methods and modeling efforts for supplying vehicle activity data to MOBILE6.

Several alternative methods were developed in supplying accurate vehicle activity data to MOBILE6. For developing vehicle age distribution, use of county level income, modeling vehicle age distribution using socio economic indices and the use of VIN decoding were some of the alternative methods. Some authors modeled VMT by vehicle type as a function of functional classifications, operating conditions on link and zonal characteristics. For developing the soak distribution inputs research efforts were available in using the travel survey data and instrumented vehicle study data.

The major limitations in using the traditional data sources can be described as follows. Speed estimates of travel demand models are inaccurate. Hence the VMT by facility class values obtained by these models are erroneous. The VMT estimates by the travel survey data are subject to error, as they primarily depend on the respondents. The soak distribution inputs and vehicle start/stop inputs obtained by the travel survey data are also prone to error, as the respondents generally forget to report short trips and they sometimes fail to report accurate trip start/stop information. EPA suggests the use of instrumented vehicle studies to obtain the vehicle start/stop information and soak related inputs. However, this procedure will not be cost effective, as the agencies preparing emission inventories generally will not be interested in conducting an instrumented vehicle study for obtaining data for few inputs. Hence the use of the GPS can be an attractive alternative to other instruments that record information of vehicle starts/stops only. Using GPS eliminates the difficulties in collecting the data from multiple data sources and also reduces the errors in the obtained vehicle activity data.

3. Methodology

Based on the literature collected, methodologies were developed to supply vehicle fleet and vehicle activity input data to MOBILE6. To supply distribution of vehicle registrations, a methodology was developed using the Louisiana vehicle registration data as a demonstration database. In supplying all other input data, methodologies were developed using data collected from Global Positioning System (GPS) instruments. Although the GPS and vehicle registration data were obtained from two different locations, the differences in locality-specific conditions were not considered, as this study mainly focuses on demonstrating the procedures to supply input data to MOBILE6.

The vehicle registration data of all vehicles registered in the State of Louisiana by year 2001 was obtained from the Louisiana Department of Transportation and Development (LA DOTD). These data were representative of the type of data the EPA recommends be used to estimate the distribution of vehicle registrations. Typically, data for a particular non-attainment area would be estimated from the entire database and processed to determine the distribution by type and age in the area. This was done in this case where the data for the state of Louisiana was used to demonstrate the process of establishing the input data in the required input format. The Louisiana vehicle registration data contains information such as parish name, weight of the vehicle, vehicle model year, vehicle type and body type for all the registered vehicles in Louisiana. All vehicles were distributed into the 16 composite vehicle types based on the vehicle type and vehicle weight information as stipulated in Table 2.2.

The main objective of this research was to test the feasibility of using GPS to get estimates of vehicle activity inputs to MOBILE6. However, rather than conduct a survey in which GPS instruments are placed in a sample of vehicles and travel is recorded in the instruments, use was made of an existing set of data of this type. The survey was conducted in Lexington, Kentucky, in 1996 when GPS instruments were installed in a random sample of vehicles.

The Lexington study was the first study to collect in-vehicle GPS data and involved a survey period of six days, with 100 households participating. The specific objective of the survey was to test the feasibility of GPS in improving personal travel survey data. Each household participated in the survey was provided with a single GPS instrument to be installed in a vehicle used by the household. Along with the primary driver, other drivers in the households were also allowed to use the vehicle outfitted with the GPS instrument (Battelle, 1997).

The raw GPS data collected in Lexington were 'absolute' GPS points. That is, they were not differentially corrected for selective availability. Selective availability, which was in operation at the time of the Lexington study, was a purposeful degradation of the GPS signals which could move GPS readings as much as 100 meters in a random manner. Because of this inaccuracy in the GPS data, it needed further processing to match it to roadway nodes and links and to identify the accurate distance traveled by the vehicle based on the link length (Battelle, 1997).

The map-matching analysis was performed on the Lexington data using software developed by TransCore (formerly JHK & Associates). The results of the map matching analysis (referred to as 'processed data' hereafter) provided valuable information such as day of travel, time of day, link ID, distance traveled within that link, travel time, speed, latitude and longitude, user ID, trip number, trip purpose, and the location of the trip.

Matched data for all the households was unavailable because of some problems with the equipment and with the use of the equipment such as, the malfunction of the equipment, signal losses, and occasional failure to switch on the equipment. Out of the 100 vehicles, data from 80 vehicles were found to be useful for this analysis. Processed data from all six days of the survey period were available for only 50 percent of the cases. Out of the 80 vehicles, 40 vehicles had 6 days of travel data, 12 vehicles had 5 days of data, 14 vehicles had 4 days of data, 11 vehicles had 3 days data, and 3 vehicles had 2 days of data.

Another problem encountered with the GPS data was that some of the GPS trips extended out of the Lexington street network. These 'out-of-area' trips were deleted from the database because they constituted trips that would not normally be included in an air quality analysis of a non-attainment area. The GPS layer was attached to the Lexington network and all the travel lying outside the network area was highlighted. A total of 3.21% of GPS observations were 'out-of-area travel' and this travel was deleted from the parent file and the remaining data was used for further analysis.

3.1. Vehicle Fleet Data

3.1.1. Distribution of Vehicle Registrations

There are 358,468 records of in the Louisiana registration data, each record representing a registered vehicle in the state. The MS Access database was used for manipulating the data records. A new data column named 'composite vehicle type' was added and the determined composite vehicle type numbers were assigned to all the vehicles under this field. Similarly, the age of the vehicles was also assigned creating a separate column in the database. The proportions of vehicles in each age group, under each vehicle class were then estimated.

3.1.2. Annual Mileage Accumulation Rates

As explained earlier, mileage accumulation rates are required in MOBILE6 to provide a measure of the degree of use vehicles have undergone. The amount of use a vehicle has experienced is expected to impact the effectiveness of emission control systems and the wear and tear of the engine. In this study, to estimate the annual mileage accumulation rates GPS data was used.

Using the Lexington, Kentucky data, the distance traveled by individual vehicles in the survey period was extrapolated to get annualized estimates of the vehicle travel. This process involved multiplying the average daily travel of a particular vehicle with 365. The mileage estimates obtained by this method were rough estimates of annual travel and did not account for the variations in travel across the year because of the data constraints. Since this study is a demonstration of the use of GPS travel for the use in MOBILE6 with existing GPS data, further attempts to account for different variations across the year were not undertaken. For capturing the daily variation in vehicle travel the survey period could be increased and for capturing the seasonal variation in travel, the survey could be conducted in different seasons of the year.

In the GPS data all the recruited vehicles for the survey were classified into five vehicular types namely, automobile, van, utility vehicle, pickup truck and other type of truck. However, because the sample was so small (80 vehicles) classifying these vehicles into MOBILE6 individual vehicle classes would have resulted in very small sub-samples. Hence, all vehicles in the GPS data set were classified as Light Duty Gasoline Vehicles

(LDGV) in the classification system used in MOBILE6. A column representing the age of the vehicle was added to the GPS database and the 25 values representing age were then assigned to all of the records. Annual mileage values under each age group were calculated and the fractions were obtained for LDGV class.

3.2. Vehicle Activity Data

3.2.1. VMT by Facility Class

The Lexington data contains all the required information except the functional classification. To classify the VMT according to functional class, a methodology was developed using the 'overlay' feature in GIS. Using this procedure, the street network properties can be assigned to the GPS layer, based on bandwidth provided by the user. Bandwidth is the width of the strip around the street network, based on which the GIS assigns the street network properties to the GPS layer. In the 'overlay' process a suitable bandwidth must be chosen, so that the attributes of the street network can be added to the GPS layer properly. However, the functional classification in the Lexington base map is not in the required MOBILE6 format. The base map does not include freeway ramps. Hence, since freeway ramp links were relatively few in number, they were selected manually using GIS selection tools and classified as ramps. This allowed the GPS trips in the data to be classified by functional classification required in MOBILE6.

The GPS database with functional classification information was opened in the Access database for further analysis. To obtain the hourly VMT values under each functional class, the data set needs the hour of the day information. The hour of the day information in the required MOBILE6 format was added to the database using the time information of the GPS data. Then, the file was split into four parts based on the functional class. An SQL query was written which aggregates the VMT values of each GPS record by hour of the day in each functional class. The VMT fractions were obtained in each hour of the day, by dividing the VMT of a specific facility class by total VMT of all the facility classes.

3.2.2. VMT by Hour

The data file established above containing VMT by functional class was aggregated to obtain VMT by hour of the day.

3.2.3. VMT by Speed

As explained earlier, in MOBILE6, VMT must be specified by speed bin among two of the four facility classes (arterials and freeways). This was achieved by taking the speed values in the GPS data and subdividing them into 14 speed bins at 5mph intervals, from 0 to 65 mph with the final bin catering for speeds 65mph and above. A separate field called 'speed bins' was added to the data file and the speed bin numbers were assigned for all the records. Then the VMT that comes under arterials and freeways were distributed separately using the hour of day values. Under each hour of the day, 14 VMT fractions for 14 speed bins were finally obtained using SQL queries in M.S. Access database.

3.2.4. Soak Distribution

Before developing the methodology for deriving the soak distribution inputs, it is necessary to know the difference between a cold soak (soak time) and a hot soak. Emissions from hot soaks are highest immediately after engine shutdown and decrease gradually over time until an assumed cutoff time of 1 hour. If the engine starts before the cutoff time occurs, hot soak emissions are truncated. For cold soaks, shorter soaks result in fewer emissions as the engine is still warm. No cold soak emissions occur with zero times and maximum emissions occur after six hours.

The illustration of the definition of cold and hot soaks can be seen Figure 3.1, where a soak occurs between two trips. The first trip starts at 8 a.m. and ends at 8:55 a.m. and the second trip starts at 10 a.m. and ends at 10:45 a.m. The hot soak occurs at the end of the first trip and has duration of 60 minutes because that is the maximum that it can have. The cold soak occurs at the beginning of the second trip and is the length of time the vehicle engine was stopped before that particular trip started. Hence, in this particular case, the cold soak for the second trip is 65 minutes.

To convert the GPS data into soak time data, the records were first divided into weekday and weekend travel, based on the day of the travel information. Within each of these data sets, each new trip was identified and the individual trips were placed in a separate Excel file for further analysis. 70 soak time intervals were developed by adding 70 columns to the trip data file. Cold soak times were calculated by writing formulas in Excel on the basis of information in Table 2.3. The formulas written were used in assigning a binary value to each vehicle trip record. A value of true or false was assigned for each vehicle trip record in all the soak bins. This data file was then transferred into an Access database, for obtaining number of soaking vehicles in each soak bin for all 24 hours of the day. A computer program was developed in Visual Basic, to count the number of soaking vehicles in each soak bin under each hour of the day. Finally, a matrix containing 24 columns representing hour of the day and 70 rows representing soak interval was obtained. Each cell value represents the total number of soaking vehicles in a particular hour of the day and particular soak interval. The soak time fractions were then computed so that all 70 fractions in a particular hour of the day add up to one.

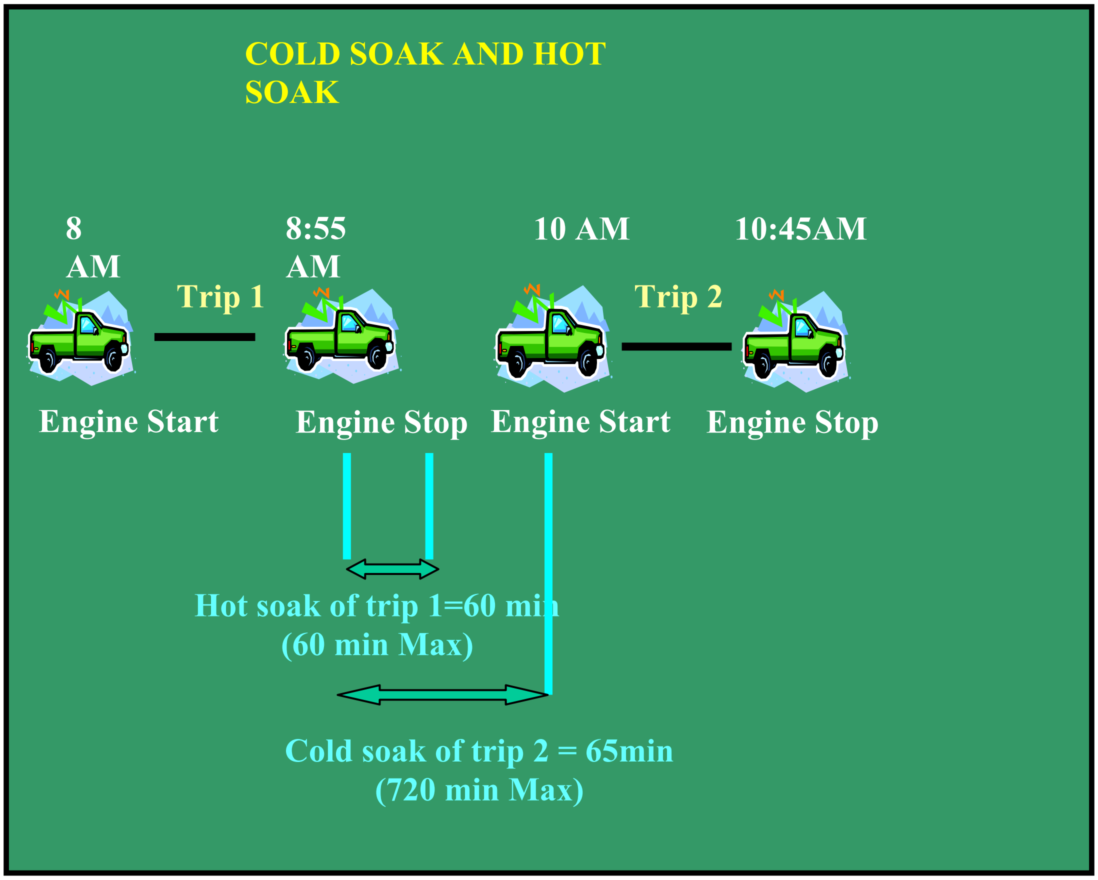

Figure 3.1: Illustration of Cold Soak and Hot Soak
(Source: Chalumuri, 2003)

3.2.5. Hot Soak Activity

Data files developed in the cold soak analysis were used in this section also. The only difference was in developing the formulas for hot soak intervals. Similar analysis was conducted to assign binary values to soak intervals. The computer program written for cold soak analysis was used here with minor modifications. Finally, a matrix containing 14 columns and 60 rows was obtained. Each column represented a hot soak hour of the day, and each row represented a hot soak interval. Each cell in the matrix represented the proportion of vehicles soaking in a particular hot soak hour of the day and in a particular hot soak interval.

3.2.6. Distribution of Vehicle Starts during the Day

The GPS soak distribution data files developed for weekdays and weekends were used for further analysis on this input option. This command also requires information to be supplied separately for weekdays and weekends. First of all in the weekday trip data file, the trip start and hour of the day columns were used as parameters in an SQL query, which supplies number of trip starts in each hour of the day. After obtaining the number of trip starts, fractions of trip starts were obtained by dividing number of trip starts in a particular hour of the day by the total number of trip starts. This process was repeated in the weekend trip data file also and the distribution of vehicle starts was obtained.

4. Analysis and Results

4.1. Vehicle Fleet Data

4.1.1. Distribution of Vehicle Registrations

As explained in the previous sections this input command requires all the registered vehicles to be classified into 16 composite vehicle types and within each vehicle type the vehicles are required to be classified by age. For this purpose the model year and the vehicle weight information is needed.

The EPA suggests the use of vehicle registration data or the Vehicle Identification Number (VIN) data for obtaining distribution of vehicle registrations (EPA, 2002). In this study, the vehicle registration data obtained from Louisiana Department of Transportation and Development (LA- DOTD) was used to obtain the distribution of vehicle registrations. A methodology developed for classifying all the vehicles into 16 composite vehicle types and under each vehicle type sub grouping the vehicles according to their model year was applied on the registration data and the results were compared with the national default values.

The Louisiana vehicle registration data contains 3,458,467 vehicles registered as of year 2001. The data contains important information like parish number, vehicle weight, vehicle type, body type and model-year. The tasks in drawing the required input from this data are establishing vehicle ages from the model year information and classifying each vehicle into MOBILE6 composite vehicle type based on the vehicle weight and vehicle type information.

Vehicle ages were obtained with little effort based on the model year information. In establishing vehicle ages from model year information, all the vehicles registered in year 2001 were classified as being one year old. Vehicles ages were increased by one year for each year earlier than 2001 until model year 1977. Vehicles registered in 1977 and earlier were classified as being 25 years old vehicles.

To develop registration distributions using the vehicle registration data, assumptions were made following the EPA's guidelines. EPA developed vehicle registration distributions by aggregating the 16 vehicle classes into 8 vehicle classes as described in section 2.2.1. This aggregation also included aggregating LDT1, 2 and LDT3, 4. In this study, trucks were aggregated, as done by the EPA and vehicle registration distributions for 14 vehicle classes were obtained.

All automobiles with vehicle weights less than 8,500lb were classified as Type 1 vehicles. All trucks with vehicle weights less than or equal to 6,000lb were classified as LDT1, 2 vehicles. All trucks with vehicle weights greater than 6,000lb and less than or equal to 8,500lb were classified as LDT3, 4 vehicles. All automobiles and trucks with vehicle weights greater than 8,500lb and less than or equal to 10,000lb were classified as HDV2b vehicles. All automobiles and trucks with vehicle weights greater than 10,000lb and less than or equal to 14,000lb were classified as HDV3 vehicles. All automobiles and trucks with vehicle weights greater than 14,000lb and less than or equal to 16,000lb were classified as HDV4 vehicles. All automobiles and trucks with vehicle weights greater than 16,000lb and less than or equal to 19,500lb were classified as HDV5 vehicles. All automobiles and trucks with vehicle weights greater than 19,500lb and less than or equal to 26,000lb were classified as HDV6 vehicles. All automobiles and trucks with vehicle weights greater than 26,000lb and less than or equal to 33,000lb were classified as HDV7 vehicles. All automobiles and trucks with vehicle weights greater than 33,000lb and less than or equal to 60,000lb were classified as HDV8a vehicles. All automobiles and trucks with vehicle weights greater than 60,000lb were classified as HDV8b vehicles. All school buses were classified as HDBS and buses for all other purposes were classified as HDBT category. All motorcycles were grouped into the MC category. Motorcycles were classified into 12 age groups only, because in preparing this part EPA followed the methodology adopted for MOBILE5 registration distribution.

After assigning the vehicle classes to the registration data, the vehicle registration data file was divided into 14 parts based on their new vehicle classes. Data files of each vehicle class were analyzed separately to classify the vehicles in a particular class into 25 age categories. SQL queries were used in Access database to classify the vehicles according to their age category. After obtaining the number of vehicles in each age category, fractions of MOBILE6 inputs were developed by dividing the number of vehicles in a particular age group by total number of vehicles in that particular vehicle class. Visual comparison of the results with the default values is difficult, as there are age distributions of vehicles in 14 vehicle classes. Hence, the results are interpreted graphically in Figures 4.1 to 4.14. From the graphs there appears to be a great deal of similarity in distributions between the Louisiana values and those in the default data.

The figures show that older vehicles are fewer in number than newer vehicles. It appears that the distributions of Louisiana vehicles start with comparatively lower values. These are the proportion of one-year old vehicles. The vehicle class that displays distinctly different distribution to that in the default data is school buses as shown in figure 4.12. School buses are on average much older in Louisiana than in the rest of the country.

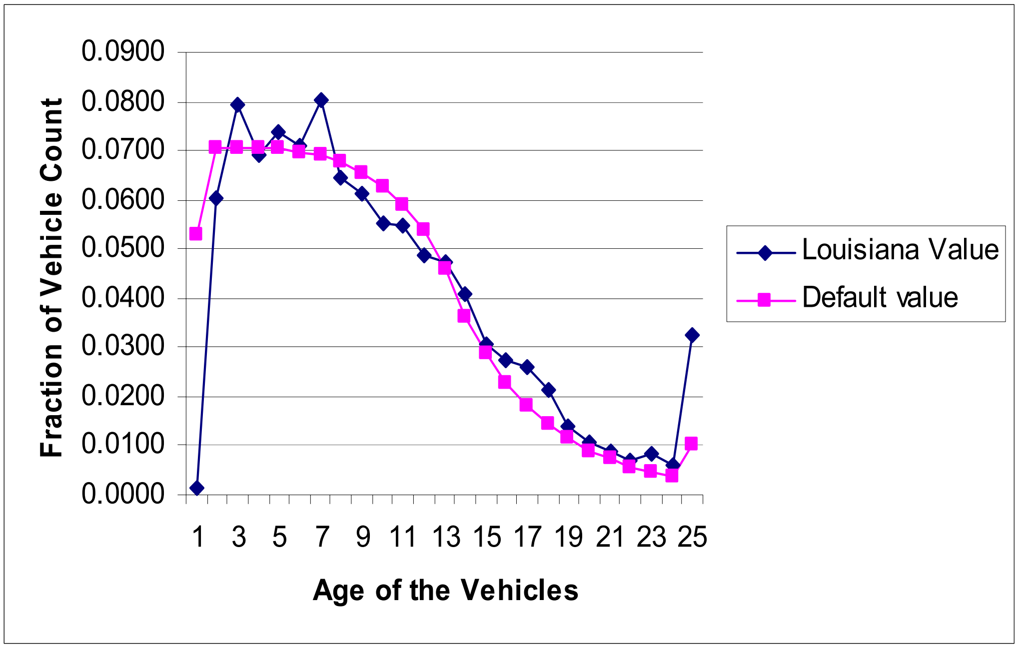

Figure 4.1: Distribution of Vehicle Registrations for LDV

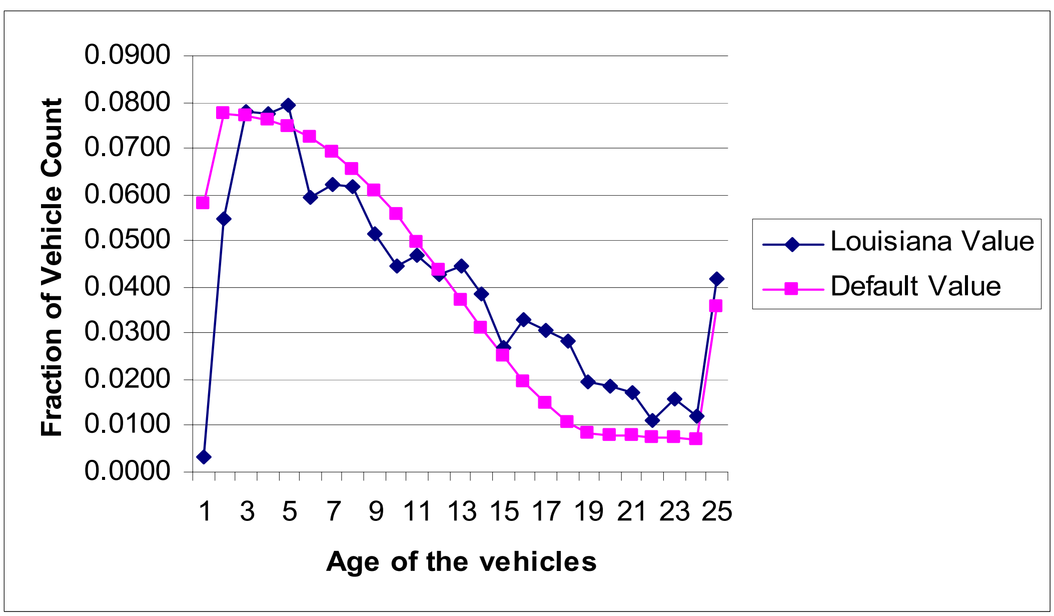

Figure 4.2: Distribution of Vehicle Registrations for LDT1 and LDT2

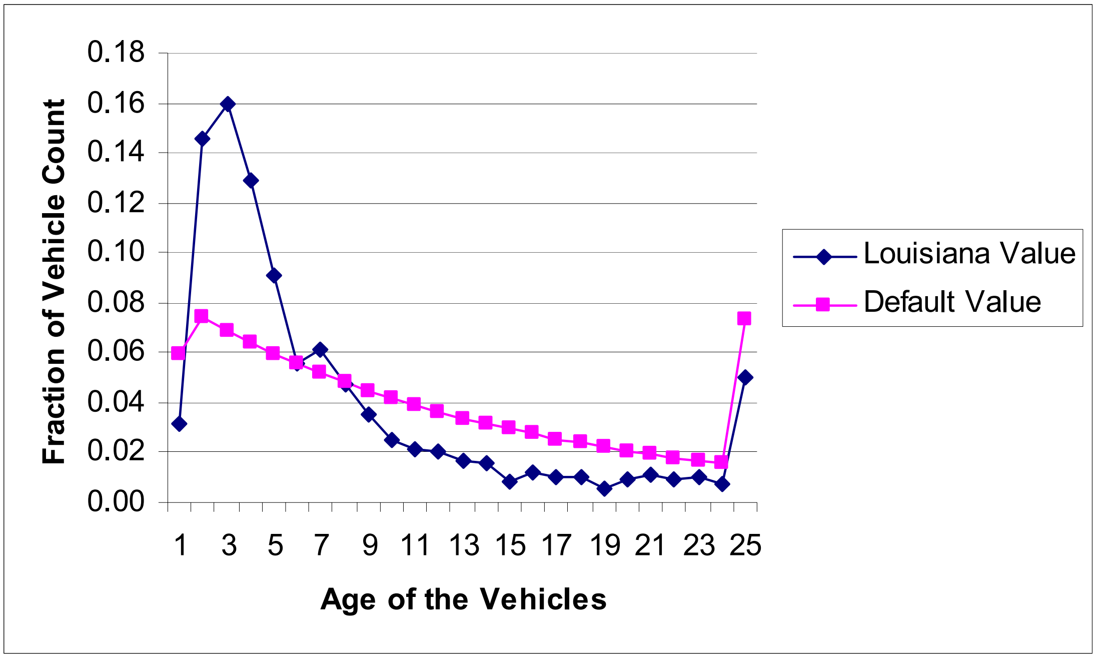

Figure 4.3: Distribution of Vehicle Registrations for LDT3 and LDT4

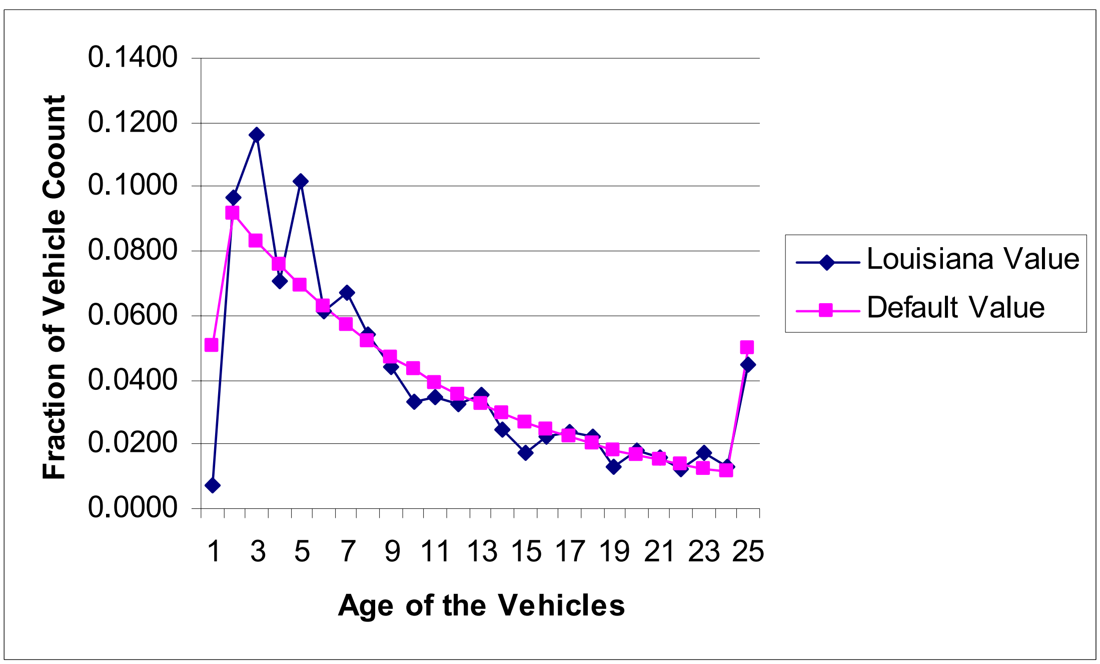

Figure 4.4: Distribution of Vehicle Registrations for HDV2b

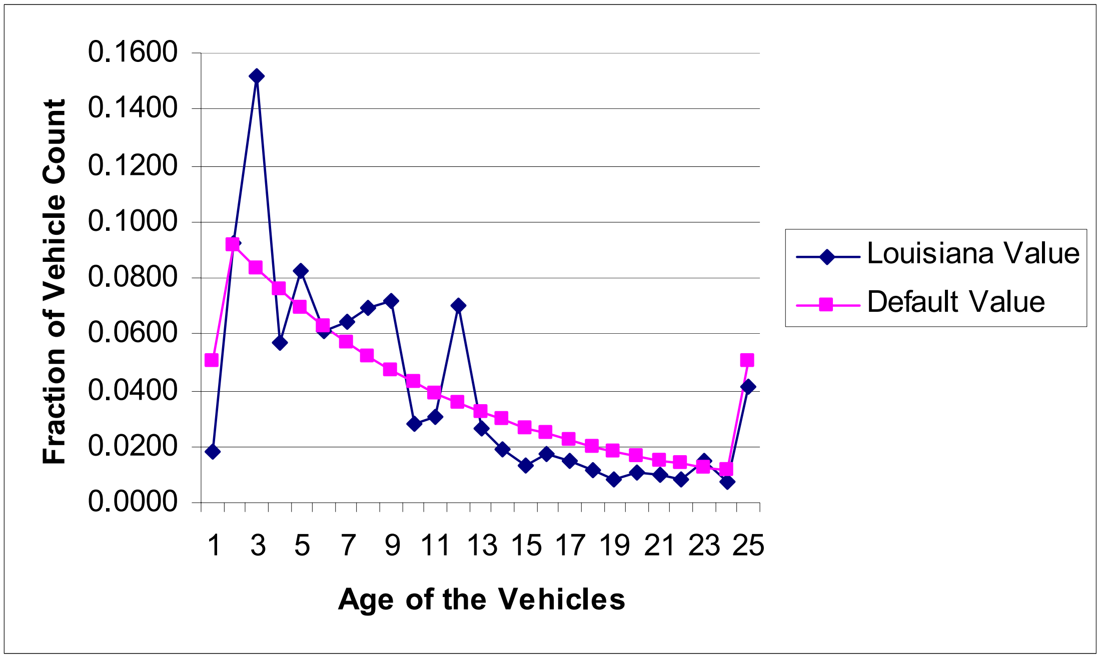

Figure 4.5: Distribution of Vehicle Registrations for HDV3

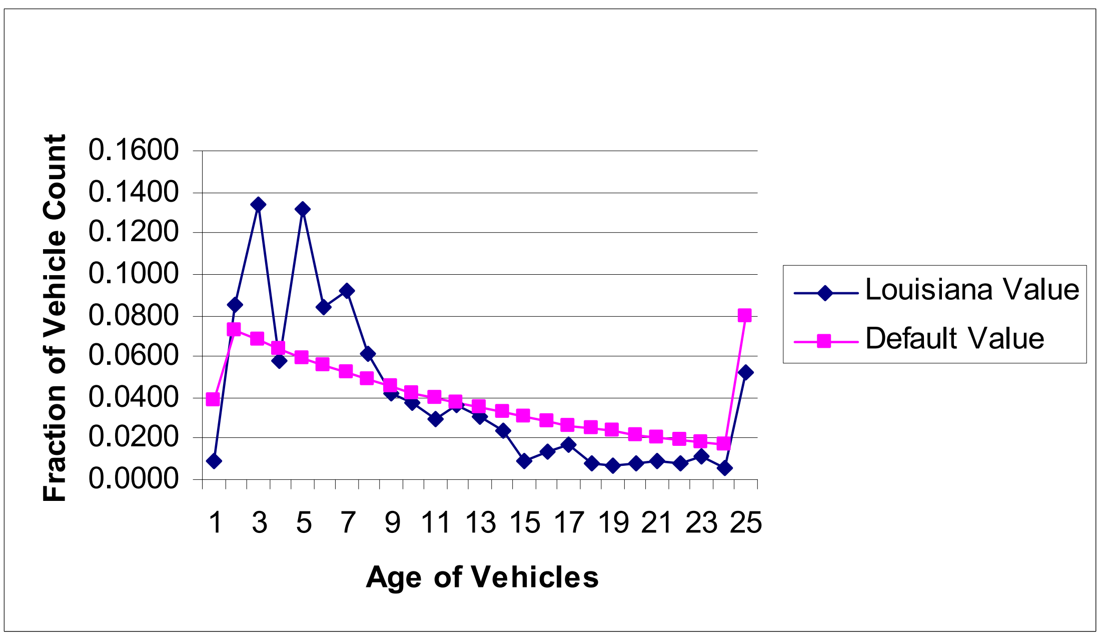

Figure 4.6: Distribution of Vehicle Registrations for HDV4

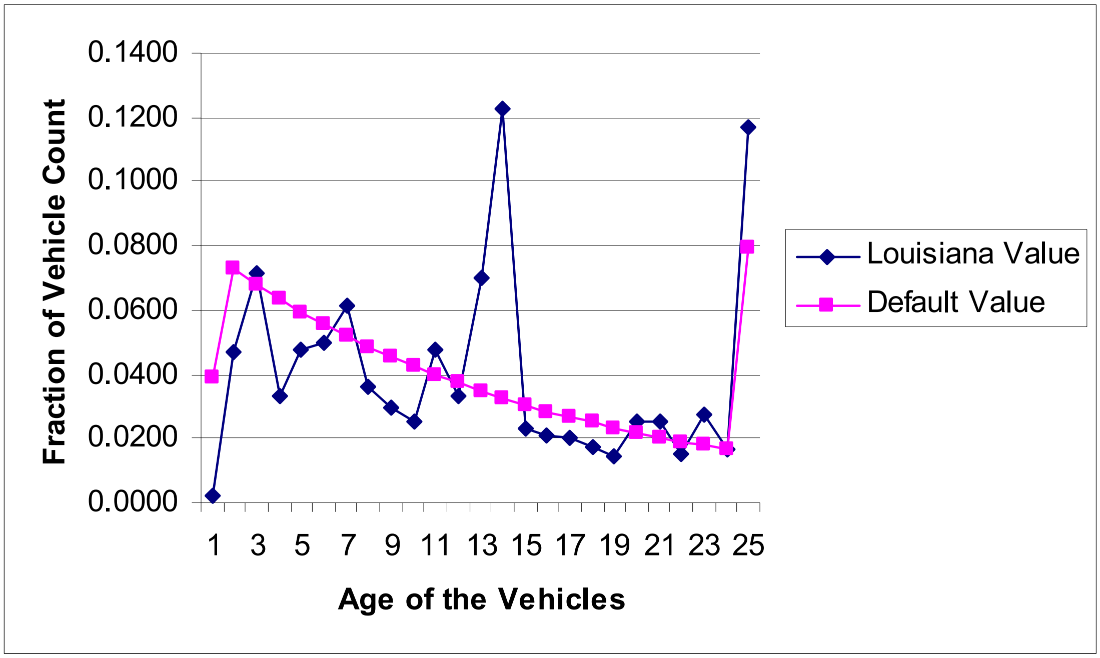

Figure 4.7: Distribution of Vehicle Registrations for HDV5

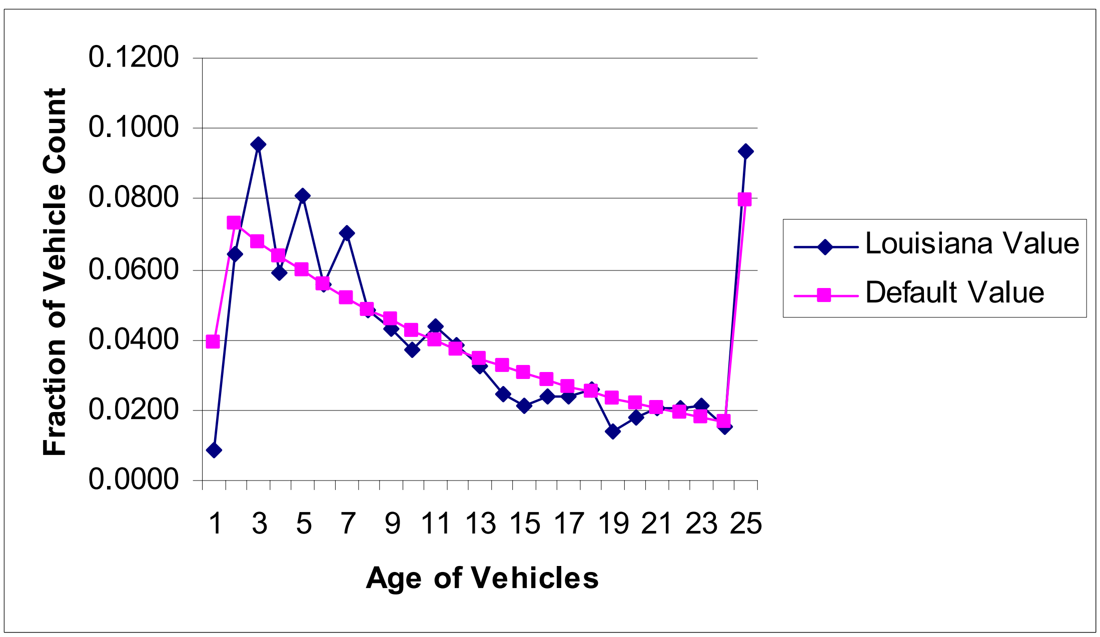

Figure 4.8: Distribution of Vehicle Registrations for HDV6

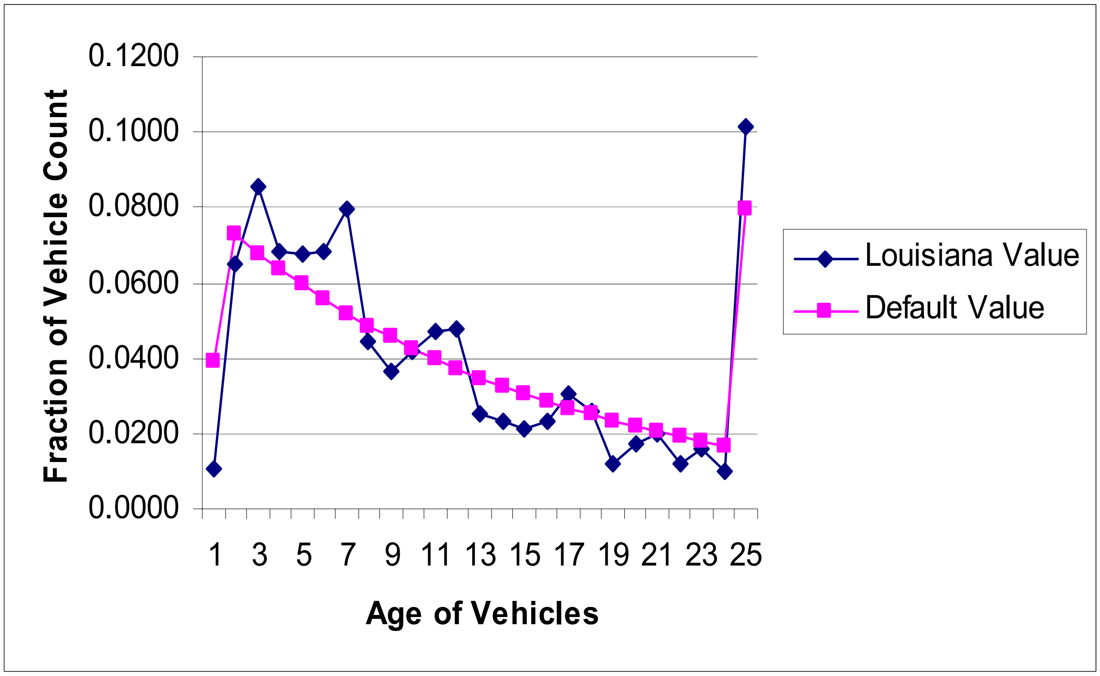

Figure 4.9: Distribution of Vehicle Registrations for HDV7

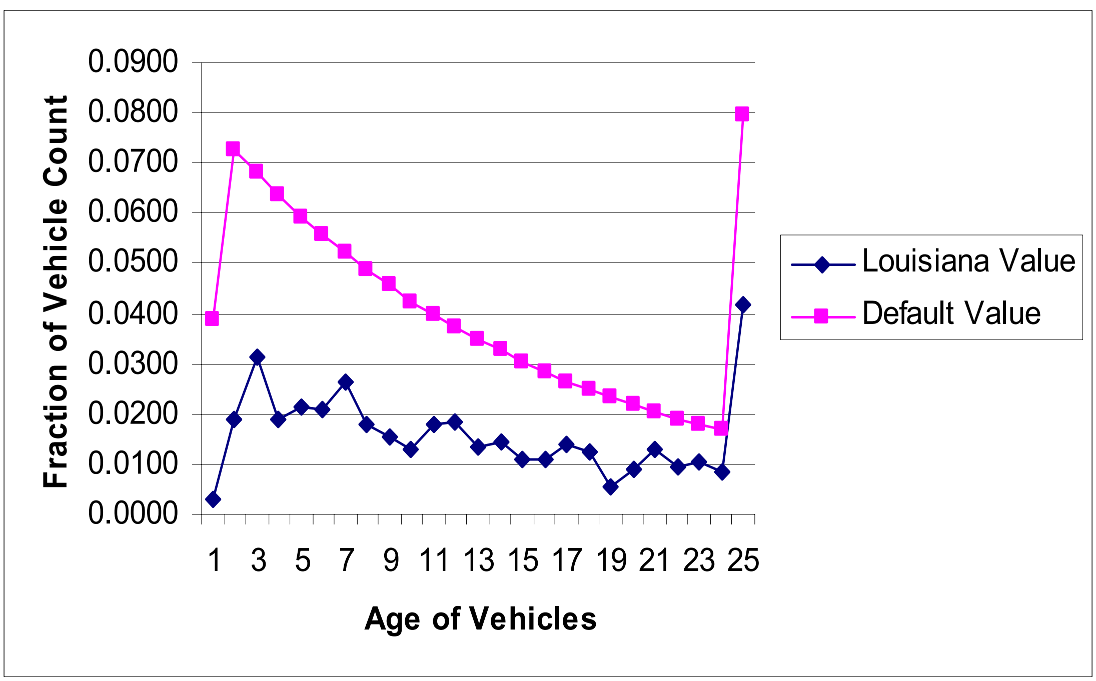

Figure 4.10: Distribution of Vehicle Registrations for HDV8a

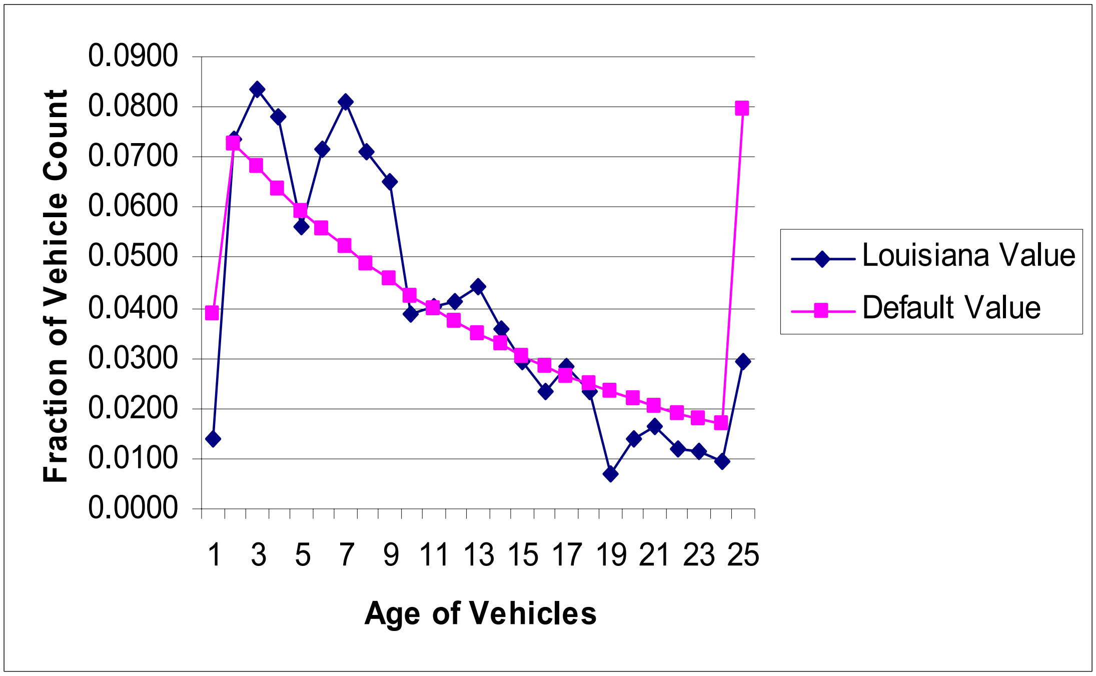

Figure 4.11: Distribution of Vehicle Registrations for HDV8b

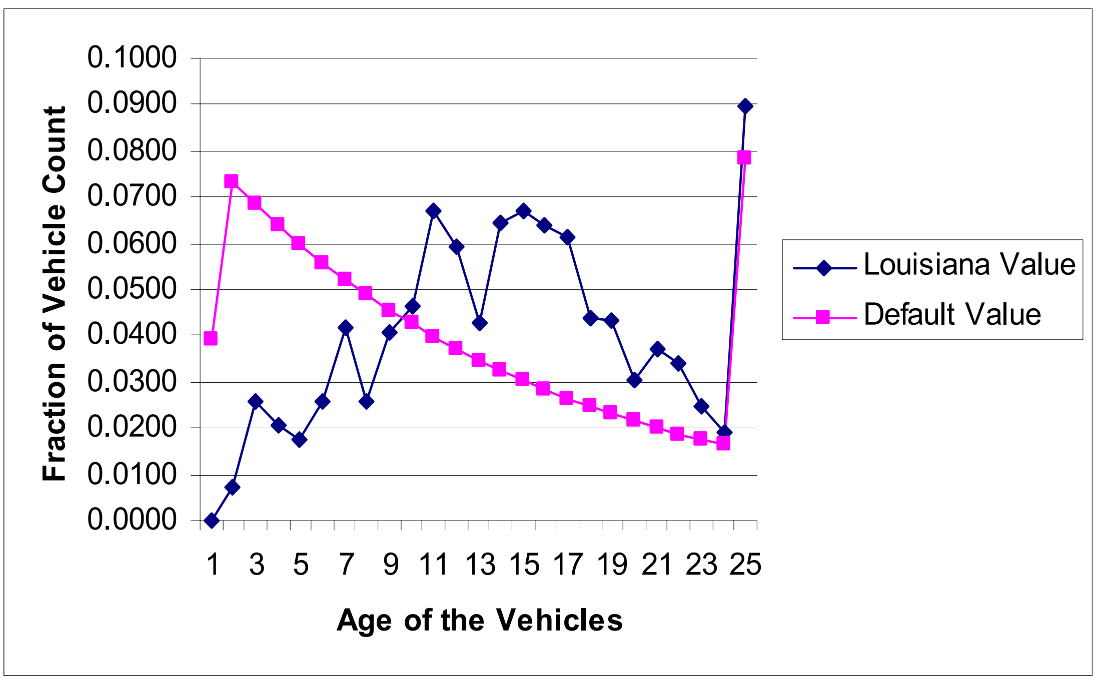

Figure 4.12: Distribution of Vehicle Registrations for HDBS

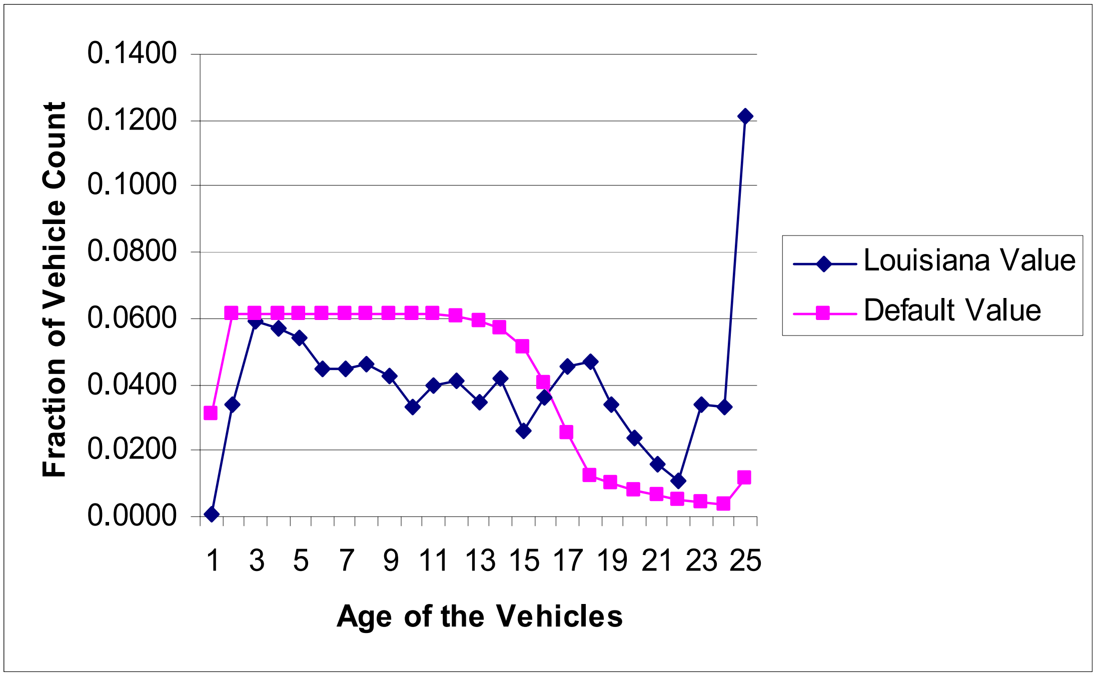

Figure 4.13: Distribution of Vehicle Registrations for HDBT

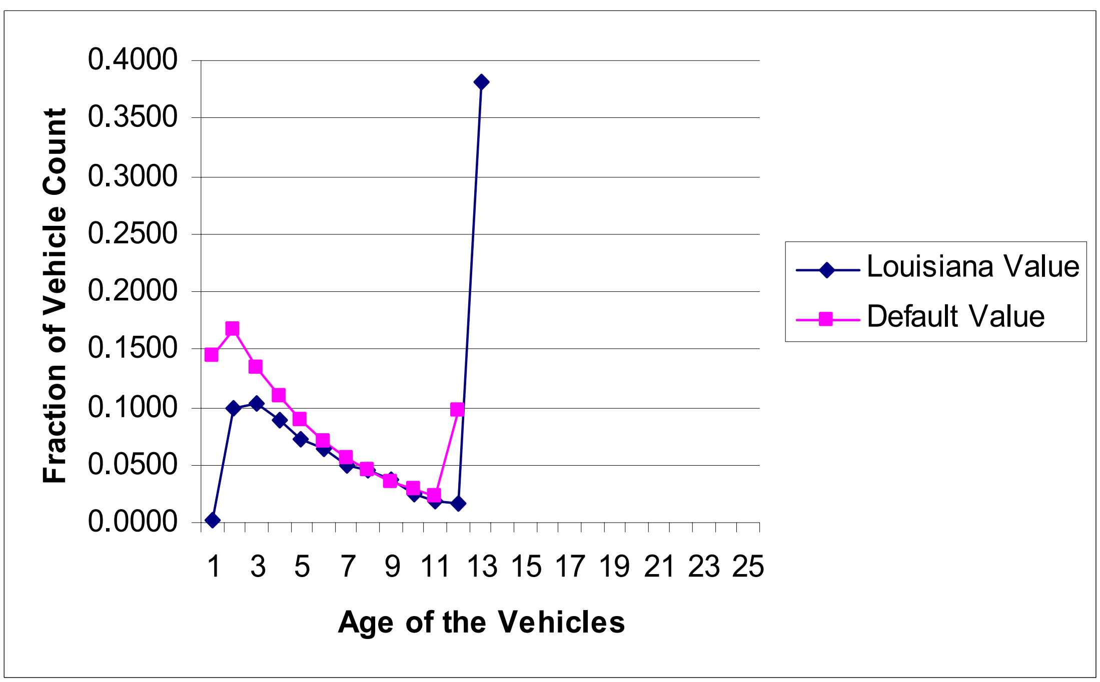

Figure 4.14: Distribution of Vehicle Registrations for MC

Hypothesis testing was conducted using a Chi-square test at 5% level of significance. The null hypothesis was that the Louisiana and the default values are equal, while the alternative hypothesis was just the opposite. Chi-square test statistic, in M.S. Excel software was used in this study. The software calculates the chi-square value and provides a chi-squared probability value for the given degrees of freedom. If the chi-squared probability value does not exceed 0.05, then it can be stated that the expected and observed values are different at 95% confidence limit. The software calculates the chi-square value using the following formula.

$$\chi^2 = \sum_{i=1}^{r} \frac{(A_{ij} - E_{ij})^2}{E_{ij}}$$

Where,

A_{ij} = Actual observations in the i-th row (Louisiana registration distribution values)

E_{ij} = Expected observations in the i-th row (Default registration distribution values)

r = number of rows

To apply Chi-square test on the results, each cell value in the expected observations should be greater than 5 and there should not be any null values. However, the results obtained were fractions that add up to one under each vehicle class. Hence, rather than applying the test on the fractions, it would be appropriate to compare the number of vehicles in each cell from which the fractions were obtained. However, the number of vehicles in each vehicle class for the default values were not available. To obtain these values, it was assumed that the total number of vehicles in each vehicle class were the same in the Louisiana and the default data sets. Then, the number of observations for the default data in each age stratum of a particular vehicle class were obtained by multiplying the fractions in the default data by the total number of vehicles in that particular vehicle class.

The Chi-square test was applied on each vehicle class separately. A chi-squared probability value of 0 was obtained, with 24 degrees of freedom for the registration distribution results of all vehicle classes excepting the motorcycle vehicle class. The chi-squared probability value of 0 was obtained for the motorcycle vehicle class with 11 degrees of freedom, as it has 12 age groups only. Since Chi-Squared probabilities for the mileage accumulation rates were less than 0.05, the null hypothesis was rejected for the results of all vehicle classes. Hence the Louisiana and the default values are different at 5% level of significance for all vehicle classes.

4.1.2. Annual Mileage Accumulation Rates

In the processed GPS data file, distance values are available in feet for all data records. The total travel by each vehicle was obtained by simple summation of all the distance values. Each vehicle's data could be distinguished from the other vehicles, based on the 'User ID'. Each number in the 'User ID' column shows the vehicle in use.

To obtain annual mileage accumulation rate values in MOBILE6 format, the vehicle age and vehicle type information is also needed. Household information like vehicle age, vehicle type, number of drivers etc. was also collected at the time of recruitment and stored in a separate file. This external data was joined to the processed GPS data file using the 'User ID' as key.

The Lexington study was conducted in 1996 and hence all the vehicles with 1996 as the vehicle model year were considered to be one year old. The vehicle year 1996 was considered as the 'calendar year' for the present study. All vehicle ages were determined based on the following simple equation.

Vehicle age = (Calendar Year – Vehicle Model Year) +1

In the Lexington data, all the vehicles were classified into five vehicle types. To classify these vehicle types into MOBILE6 individual vehicle classes, the following assumptions were made. All the automobiles, vans and the utility vehicles were classified into the Light Duty Gasoline Vehicle (LDGV) class. Pickup truck and other type of truck classes were grouped as the Light Duty Gasoline Truck (LDGT1) category assuming that these are household trucks. Only 16 vehicles out of the 80 vehicles were identified in LDGT1 category, as the remaining vehicles fall in LDGV category. To reduce sampling errors in this analysis all the vehicles were assumed to be in LDGV class.

Total mileage values were estimated for each vehicle and extrapolated to annual mileage values based on the number of days of travel observed. As mentioned earlier data was generally not available for all 6 days of travel for each vehicle and hence the number of days of travel differed from household to household. Annual mileage rates were calculated using the following equation

Annual Mileage = {(total travel in survey period in miles)/number of days of travel}*365

The obtained annual mileage by this type of aggregation may not result in accurate representation of travel, as the annual mileage generally varies with the season of the year. Possible solution to this problem could be conducting the survey for more number of days, and if possible conducting the survey at different seasons of the year.

The obtained annual mileage accumulation rates were classified into 25 vehicle ages using SQL queries in M.S. Access database. The results are shown in Table 4.1. Default values suggested for MOBILE6 are included for comparison purposes. Values are not shown for vehicle ages 15, 16 and 19-25 because no vehicles of these ages were present in the GPS data. The table also shows available sample sizes in individual age classes. The GPS and default values are also depicted graphically in Figure 4.15.

Table 4.1: Annual Mileage Accumulation Rates for MOBILE6

Vehicle Age	Sample Size	Annual Mileage	
		GPS	Default
1	5	9621.668	14910
2	13	10021.45	14174
3	8	8921.415	13475
4	5	12283.35	12810
5	7	17352.64	12178
6	7	8484.959	11577
7	8	12793.43	11006
8	7	9270.061	10463
9	5	14335.04	9947
10	7	8815.811	9456
11	3	11721.67	8989
14	2	7929.64	7723
17	2	5674.125	6636
18	1	14176.54	6308

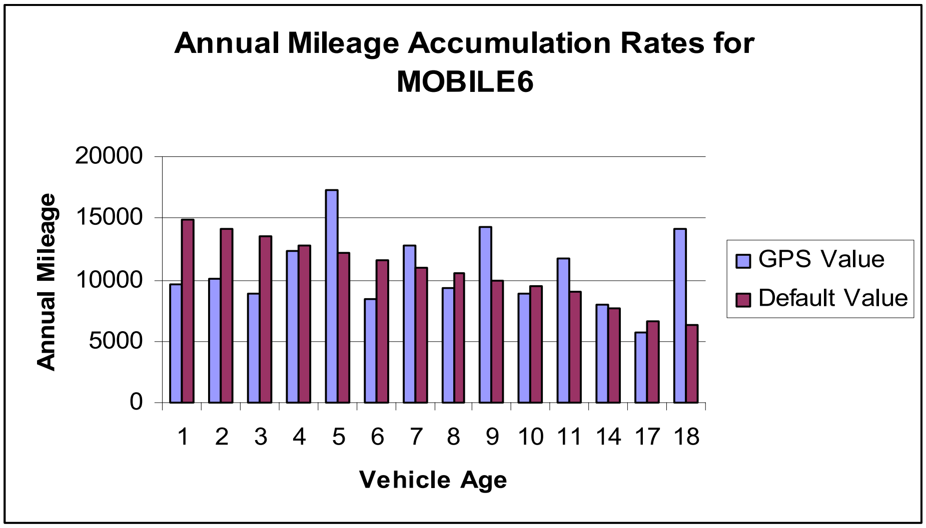

Figure 4.15: Annual Mileage Accumulation Rates for MOBILE6.

The results show that the GPS values do not follow the trend followed by the default values although sample sizes in the individual age categories are very small in some cases. The mileage accumulation rates for the default values decrease with the increase in the age of the vehicles although this trend is not entirely apparent in the GPS values. One possible explanation is that, the vehicle fleet in the Lexington area is different to those of the national estimates in that vehicles are generally older and greater use is made of older vehicles since they are the only vehicles available to a household. Another possible reason for this result could be the sampling error due to the small sample size in the Lexington study. The available GPS data of the 80 vehicles stratified into 14 age groups creates very low sample size in each stratum. Another possibility is that the method adopted for obtaining the default data could be erroneous. As explained earlier, the default values for the LDGV class were obtained from the NPTS data. The NPTS data is collected by telephone survey in which the respondents are asked how many miles they drove in a particular vehicle the previous year. Respondents tend to give very common replies such as 10,000 miles or 15,000 miles and may tend to underestimate for older vehicles.

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. A Chi-squared probability value of 0 was obtained, with 13 degrees of freedom for the mileage accumulation results. Since Chi-Squared probabilities for the mileage accumulation rates were less than 0.05, the null hypothesis was rejected in this particular case. That means the GPS and default values are different at 5% level of significance.

In this study, an effort is made to estimate the sample size for future GPS surveys in which mileage accumulation rates must be estimated. The sample size estimated in this process could be useful for obtaining mileage accumulation data for MOBILE6 using GPS survey. The variance of the observed mileage accumulation values in the individual cells were used to estimate a sample size that would be required to estimate mean values at the 95% level of significance with a maximum tolerable error of 10%. Out of the estimated sample sizes in each vehicle age category, the largest value must be considered as the required sample size. The following steps were undergone, for estimating sample sizes in individual vehicle age categories.

- Let the acceptable percentage error in the estimate of each category value be ‘d’
- The tolerable deviation is then $d*M$, where ‘M’ is the sample mean of individual vehicle category.

- The standard error of the estimate (S.E.E) is $\frac{S}{\sqrt{n}}$, where 'S' is the standard deviation of the observations in each vehicle category and 'n' is number of observations over which the standard deviation is calculated.
- The confidence interval at the 95% level of confidence is (S.E.E) * (Z)
- Since the estimated mean should fall within the confidence interval, the new sample size 'N' for an infinite population can be estimated from the following equation.

$$\text{Sample size} \quad N = \left(\frac{1.96 * S}{d * M} \right)^2$$

Table 4.2 shows, the mean and standard deviation of all mileage accumulation rates for available individual age categories in which observations were present. The mean and standard deviation values were estimated based on the daily average mileage values accumulated by each vehicle under each age category. For example, eight vehicles were classified into vehicle age 7. The mean and standard deviation values of age 7 were estimated by considering the mean and standard deviation values among the average mileages accumulated by all 8 vehicles. As can be seen, the sample size for individual vehicle categories varies from 5 to 264. One strategy is to require a sample size for the survey that is the largest sample size required in the individual vehicle categories. Thus, in this case a sample size of 264 vehicles surveyed for six days would be required. However, an alternative to this is to use the 85th percentile of the sample sizes required in the individual vehicle categories. For a 10 % tolerable deviation and 95 % confidence level an 85th percentile value of the obtained sample sizes was calculated as 261. Hence a sample size of 261 vehicles over six days of survey period would be sufficient to satisfy 85% of the sample size needs of the MOBILE6 model in terms of annual mileage accumulation rates.

Table 4.2: Sample Size Estimation Using Mileage Accumulation Results

Veh_Age	Mean (M)	Stdev (S)	n	N
1	26.36073	9.0553	5	45
2	27.45602	13.92371	13	99
3	24.44223	10.64924	8	73
4	33.65302	24.25257	5	200
5	47.54149	26.58514	7	120
6	23.24646	7.814513	7	43
7	35.05049	28.87279	8	261
8	25.39743	11.21022	7	75
9	39.27409	19.67961	5	96
10	24.15291	8.854125	7	52
11	32.11417	7.27271	3	20
14	21.72504	18.01724	2	264
17	15.54555	1.846905	2	5
		85th percentile = 261		
		Tolerable deviation = 10%		
		Confidence level = 95%		

*n is the current sample size of the Lexington GPS data
*N is the required sample size

4.2. Vehicle Activity Data

4.2.1. Vehicle Miles Traveled (VMT) by Facility Class

This input option for MOBILE6 requires hourly VMT data to be supplied for each of the four facility classes under each of the 28 vehicle types. However, the EPA supplies the same set of default values for all vehicle types for this input requirement. Hence, all vehicle classes were combined together in the present analysis. This also alleviates sampling error introduced by the small sample size in the Lexington data.

The four facility classes included freeways, arterials, local roads and freeway ramps, respectively. Under each of the facility classes, 24 hourly VMT values were supplied, starting from 6 A.M. onwards. Travel between 6 AM and 7 AM was considered as the first hour of travel; and travel between 5 AM and 6 AM of next day was considered as the 24th hour travel. The hourly values from 2 to 23 were assigned in increasing order for the remaining hours lying in between 7 AM of a day and 5 AM of the next day. GPS time information was used for this purpose and for each GPS record, the corresponding hour of the day was assigned.

To classify the VMT data by facility class, the GPS data needed to be analyzed in a GIS environment. TransCAD GIS software was used for this specific purpose. First of all, the GPS data was geo-coded in TransCAD using the latitude and longitude values. The processed GPS data file was then opened as a 'data view file' in TransCAD. The GPS data file consisted of all the travel information except the facility class information. To add the facility class information to the GPS 'data view' file, a street network with facility class information was needed.

The Lexington street network provided by the Battelle team consists of all the facility class information except the ramp information. It has different facility types namely, freeways, arterial highway, major arterial, minor arterial, collectors and local through streets numbered from 1 to 6 respectively. As mentioned earlier, MOBILE6 requires facility class information in terms of freeways, arterials, local streets and ramps. To achieve this facility class information provided with the network was aggregated to represent freeways, arterials, and local streets. Arterial highways, major arterials, minor arterials and the collectors were grouped together as the 'arterials'. Now the network contained all the functional class information with the exception of the ramp information. To assign the ramp classification to the network, all the ramp links were identified manually and corresponding classification number was assigned. The network with all four functional classes is shown in Figure 4.16.

To transfer the facility class information into the GPS data, the 'Overlay' feature in TransCAD was used. Using this feature, a separate data file containing all the features of the GPS layer and the functional classification information of the street network was obtained. The process of overlaying involved the following steps. First of all the Lexington network with a functional classification in it was opened and then the GPS layer was opened on it. The process involves assigning the features of underlying layer to the top layer using a bandwidth. Bandwidth is the width of the strip that is to be chosen around the street network, based on which the GIS assigns the street network properties to the GPS layer. For example if a bandwidth of 60ft was chosen, the GPS points within 60ft range of the street will be assigned with the properties of the street.

However, this procedure is not accurate under certain conditions. If the bandwidths selected for this purpose are too narrow, GPS observations can be lost. Broad bandwidths on the other hand will assign the information of surrounding streets to the GPS layer. Hence the process involved testing various bandwidths and selecting an optimum one. The process works well provided facilities of different functional classes are not in close proximity to each other. One such problem area is where ramps merge into freeways or where roads of different functional classifications intersect. To minimize these problems, the street network was divided into four separate layers, based on the facility type. This allowed the individual facility class networks to be overlaid separately with GPS layer, using different bandwidths. After experimenting with different bandwidth values, a bandwidth of 60ft was selected for freeways and arterials, and 30ft for local streets and ramps. This minimized the error but did not eliminate it. In these cases, the roads that were wrongly assigned with ramp classification were manually selected by TransCAD's 'Select by shape' feature and assigned with appropriate facility class information.

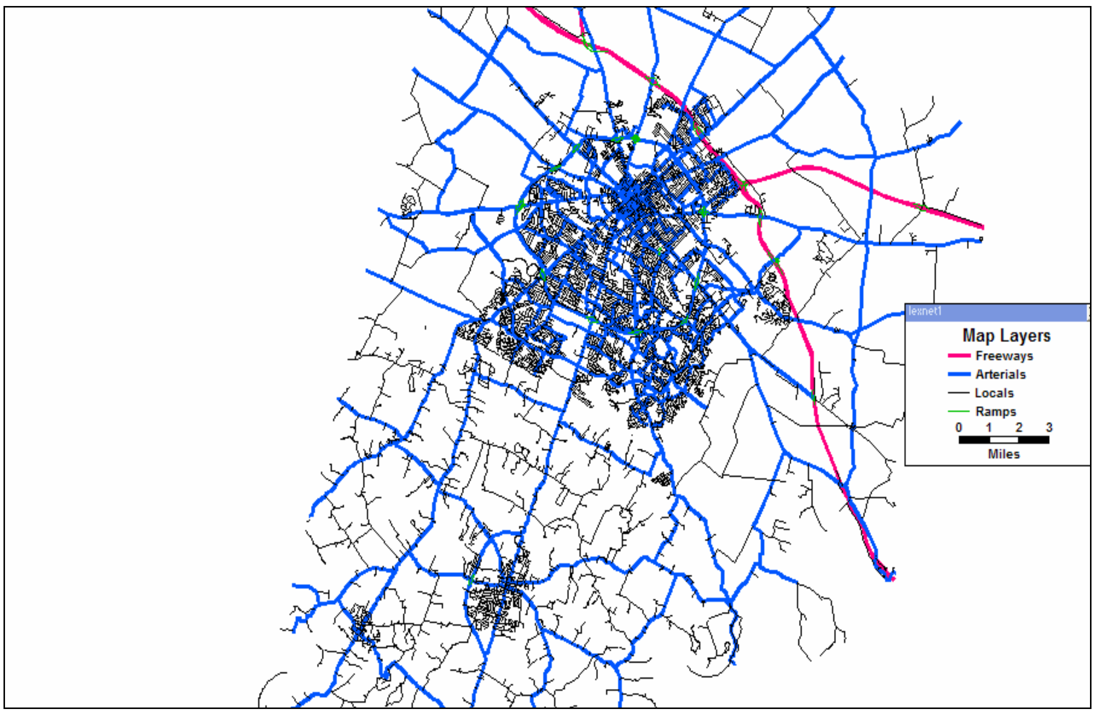

Figure 4.16: Lexington Network Divided into Four Functional Classes

After obtaining the GPS layers with functional classification associated with each, VMT values were distributed based on the hour of the day. For this purpose, all the GPS layers were transferred into Access database and using SQL queries, the hourly VMT values were estimated. In each hour of the day, VMT fractions were obtained for each facility class, by dividing the VMT of a specific facility class by total VMT of all the facility classes. The VMT classification of the GPS data is shown in Figure 4.17.

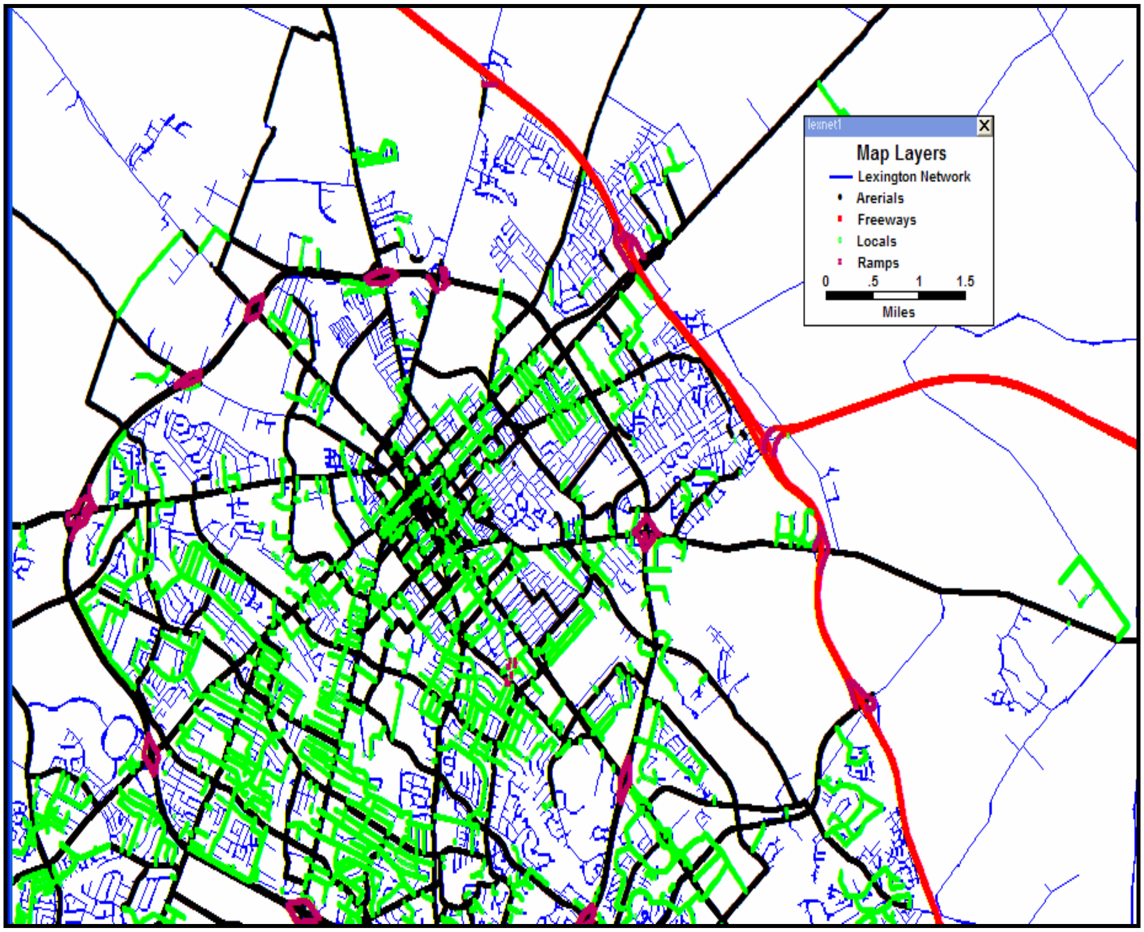

Figure 4.17: Functional classification of the GPS travel in Lexington Area

Table 4.3 shows the VMT breakdown according to functional classes in the Lexington area. The Lexington survey value represents the result obtained from the analysis of Battelle team. The table shows that there is very little freeway miles in the area, which is the reason for the relatively little freeway travel in Lexington.

The overlay procedure produces values that are quite similar to the Lexington survey values. It should be noted that in the Lexington network the ramp values were unavailable at the time of analysis by the Battle team. These values were introduced manually by identifying the ramp links and modifying the network in the present study.

Higher percentages of arterial and freeway travel were found by the Battelle team than those of the current study. This is probably the result of including ramps with the arterials and freeways in their analysis.

Table 4.3: VMT Breakdown by Functional Classes in Lexington

Functional Class	VMT	
	Lexington Survey Value (%)	Overlay Procedure Value (%)
Freeways	2.87	2.31
Arterials	81.62	81.12
Locals	15.5	15.47
Ramps	Unavailable	1.1

In Table 4.4, the VMT by facility class by hour of the day results are shown in MOBILE6 format. The GPS and MOBILE6 default values are shown side by side for easy comparison. The results are graphically interpreted in Figures 4.18 to 4.22. Comparison of the GPS and default values in Table 4.4 and in Figures 4.18-4.22 show that they are considerably different. It can be observed that in Lexington survey most of the travel was conducted on arterials. The freeway VMT distribution graph shows that the GPS values are considerably lower than the default values. The reason could be that there are relatively few freeways in the Lexington area. Higher arterial travel could be attributed to the same reason. It appears therefore that VMT by facility class varies from locality to locality and depends on local network conditions. Travel on local streets and ramps are more or less similar to the default values. Another possibility for the relatively less travel in freeways is that the sample of vehicles surveyed was very small and the sample might not represent the entire population properly.

Table 4.4: VMT Breakdown by Functional Classes for MOBILE6

	Freeway		Arterial		Local		Ramp	
Hour	*GPS*	*Default*	*GPS*	*Default*	*GPS*	*Default*	*GPS*	*Default*
1	0.01	0.39	0.98	0.46	0.01	0.12	0.01	0.03
2	0.01	0.34	0.84	0.5	0.15	0.13	0.01	0.03
3	0.00	0.34	0.85	0.5	0.13	0.14	0.01	0.03
4	0.00	0.35	0.84	0.49	0.16	0.13	0.00	0.03
5	0.04	0.35	0.77	0.5	0.17	0.13	0.01	0.03
6	0.08	0.33	0.76	0.51	0.15	0.13	0.01	0.03
7	0.02	0.32	0.83	0.52	0.14	0.13	0.01	0.03
8	0.03	0.33	0.82	0.51	0.14	0.13	0.01	0.03
9	0.01	0.33	0.84	0.51	0.14	0.13	0.01	0.03
10	0.03	0.32	0.80	0.52	0.16	0.13	0.01	0.03
11	0.01	0.33	0.78	0.51	0.20	0.14	0.01	0.03
12	0.03	0.31	0.80	0.52	0.15	0.14	0.02	0.03
13	0.01	0.3	0.83	0.54	0.15	0.14	0.01	0.03
14	0.02	0.31	0.84	0.53	0.13	0.14	0.01	0.03
15	0.01	0.33	0.82	0.51	0.16	0.13	0.01	0.03
16	0.04	0.34	0.81	0.5	0.14	0.13	0.00	0.03
17	0.03	0.38	0.86	0.46	0.10	0.13	0.01	0.03
18	0.00	0.41	0.90	0.44	0.09	0.12	0.00	0.04
19	0.00	0.43	0.77	0.42	0.21	0.12	0.02	0.04
20	0.00	0.44	0.86	0.4	0.10	0.12	0.03	0.04
21	0.02	0.46	0.94	0.39	0.03	0.11	0.01	0.04
22	0.00	0.46	0.94	0.39	0.06	0.11	0.00	0.04
23	0.00	0.45	0.80	0.4	0.20	0.11	0.00	0.04
24	0.07	0.42	0.86	0.43	0.01	0.11	0.06	0.04

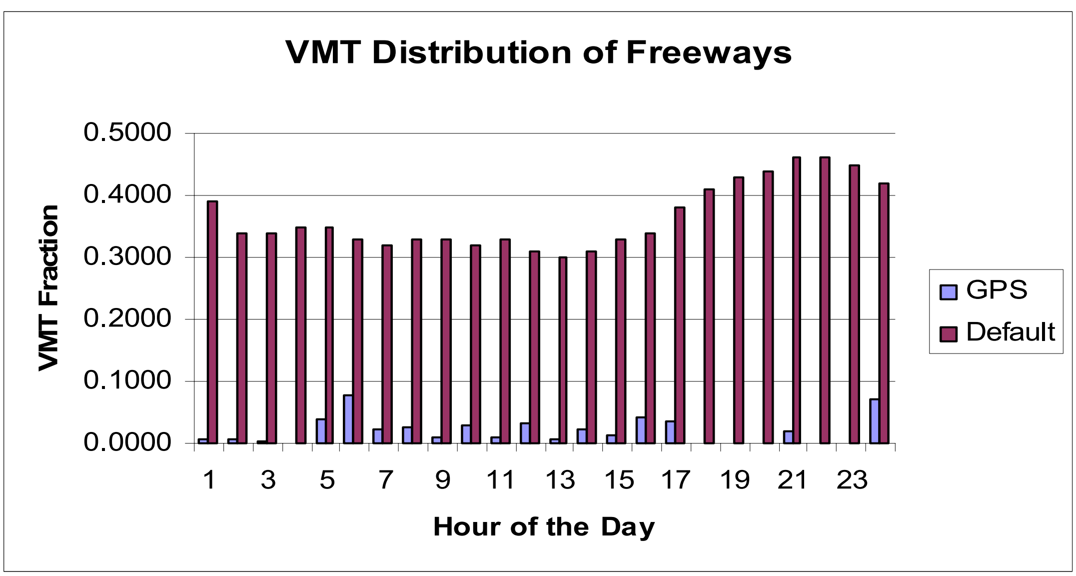

Figure 4.18: Distribution of VMT by Freeways for MOBILE6

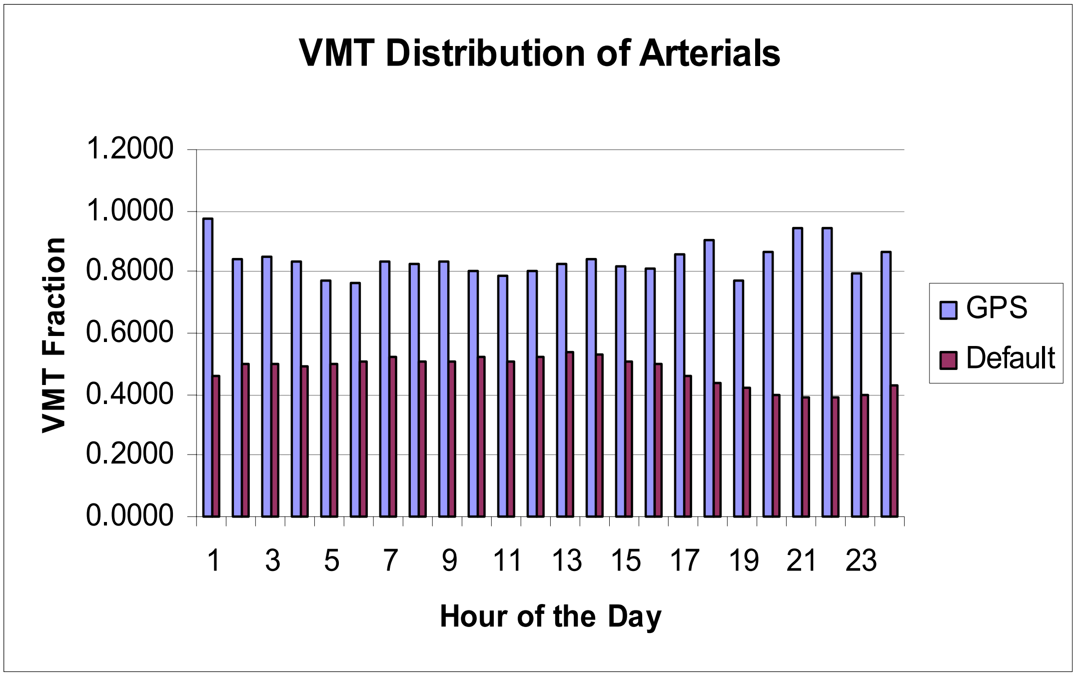

Figure 4.19: Distribution of VMT by Arterials for MOBILE6

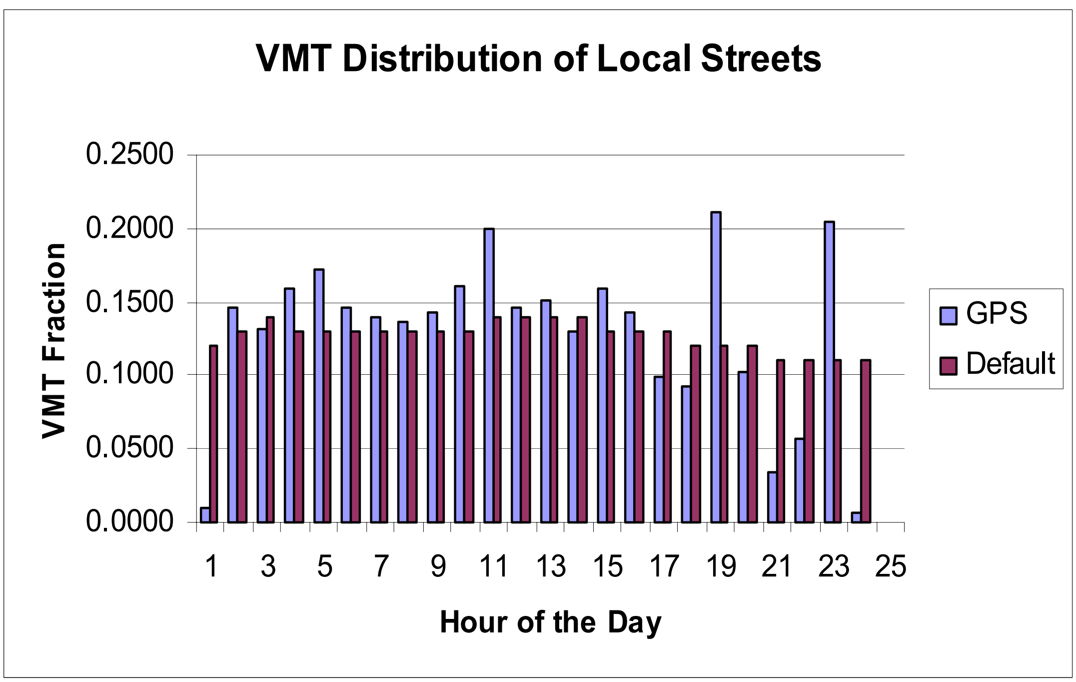

Figure 4.20: Distribution of VMT by Local Streets for MOBILE6

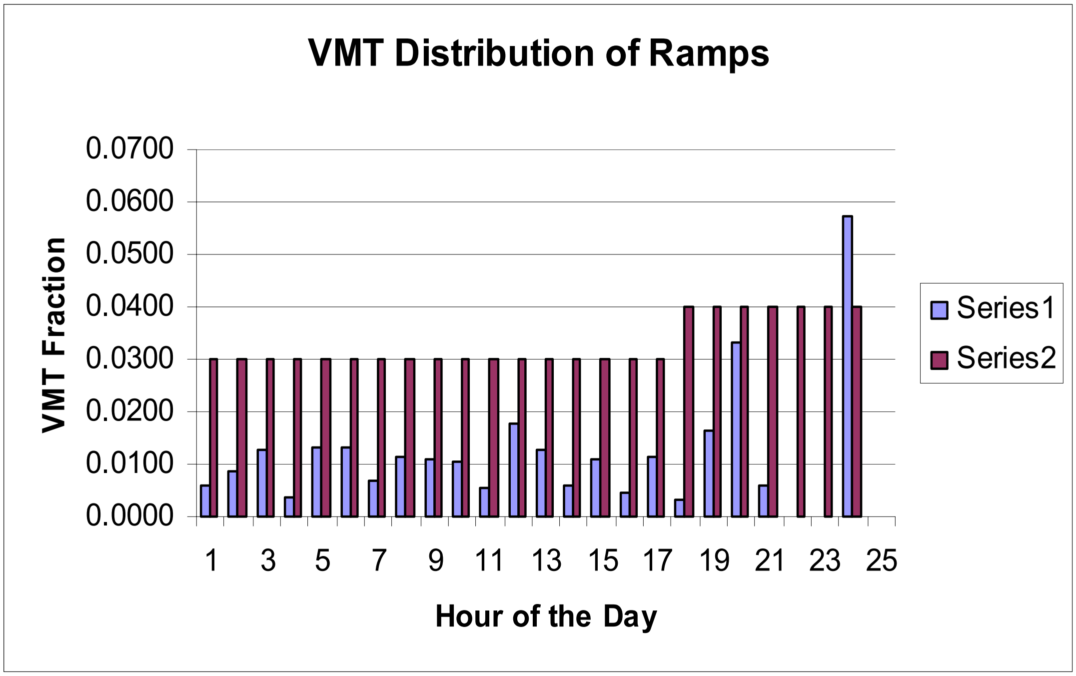

Figure 4.21: Distribution of VMT by Ramps for MOBILE6

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. Chi-square test was applied on the results of each facility class separately. To make sure that the individual cells in the expected range (default values) have values greater than 5, the VMT in the individual cells were used instead of using the VMT fractions. The total VMT in the individual facility classes of the default input data were assumed to be equal to those of the GPS input data for the purpose of obtaining the VMT by hour of the day values of the default data. The VMT fractions in each cell in the individual facility classes of the default input data were multiplied by the total VMT in those facility classes, to obtain the corresponding VMT values in each cell.

A Chi-squared probability value of 0 was obtained, with 23 degrees of freedom for the VMT by facility class distribution results. Since Chi-Squared probabilities for the

VMT distribution fractions were less than 0.05, the null hypothesis was rejected. Hence, the GPS and default values are different at 5% level of significance.

A sample size estimation process was applied to the VMT by facility class using the same procedure discussed in the earlier section. Sample size estimation technique was conducted in this section based on the variance in the travel in the individual hours of the day. The procedure was applied to all the functional class results separately and the results are shown in Tables 4.5-4.8. The estimates of mean and standard deviation in individual hours of the day were obtained using the VMT of number of vehicles traveling in those hours of the day. It can be seen from the tables that the number of observations in the individual hours of the day in most of the cases were very small, as the available sample size is small. However, the sample size estimation procedure demonstrates the use of current survey results in estimating a sample size for future GPS surveys aimed at VMT estimation.

As can be seen from the tables, the maximum number of observations required in each facility class is 1056 for freeways, 1012 for arterials, 2108 for local streets, and 918 for ramps. However, these are not the required sample size as these represent the number of observations required in each hour of the day. For obtaining the required sample size values corresponding to these observations the following procedure was followed. Among all the facility classes a maximum of 2108 observations were needed for the local streets in hour of the day 13. Actual number of observations present in that category was 127, observed from a survey of 395 vehicle days. Hence, for 2108 observations to exist in that particular hour of the day, a survey of 6635 vehicle days is needed. This value looks to be higher and not cost effective, but the increase in survey period can reduce the need for more instruments.

Table 4.5: Sample Size Estimation using Freeway VMT by Hour of the Day

Hour	Mean	Stdev	n	N
1	21891.17	65.86	2	0
2	1717.53	1130.65	2	166
3	3079.28	N/A	1	N/A
4	510.31	N/A	1	N/A
5	5536.52	4241.99	3	226
6	11073.92	10303.93	4	333
7	6453.1	7181.35	3	476
8	7514.32	4648.35	3	147
9	1602.54	1933.28	5	559
10	6495.94	6393.46	3	372
11	1422.44	1875.7	6	668
12	5277.78	4398.33	7	267
13	2054.15	3405.98	3	1056
14	11340.2	N/A	1	N/A
15	5945.2	N/A	1	N/A
16	9458.25	7782.77	2	260
17	9020	N/A	1	N/A
21	1111.17	N/A	1	N/A
24	6005.88	32.35	4	0

*n is the available sample size
*N is the required sample size

Table 4.6: Sample Size Estimation using Arterial VMT by Hour of the Day

Hour	Mean	Stdev	n	N
1	6889.23	7172.08	17	416.35
2	5129.36	5068	83	375.02
3	5923.51	7210.44	132	569.22
4	3883.38	5713.15	85	831.46
5	2984.25	3282.64	110	464.82
6	3659.93	4893.15	119	686.66
7	4687.77	6618.51	154	765.77
8	3894.7	4726.21	180	565.7
9	3786.8	5455.61	163	797.36

Table 4.6 (Continued)

Hour	Mean	Stdev	n	N
10	4270.67	5857.64	131	722.71
11	4141.3	4567.85	166	467.37
12	5017.51	6697.26	189	684.43
13	4489.35	5090.83	142	494
14	3728.98	4959.06	108	679.41
15	3752.6	4454.54	108	541.32
16	3948.46	4829.82	90	574.8
17	5133.49	8332.06	43	1012.03
18	4563.42	6600.14	27	803.6
19	5149.24	5635.94	18	460.21
20	6717.41	6412.22	14	350.05
21	6119.7	6655.23	9	454.34
22	8512.23	7277.22	2	280.77
23	3680.35	1913.32	4	103.83
24	3987.51	3173.85	7	243.38

*n is the available sample size
*N is the required sample size

Table 4.7: Sample Size Estimation using Local Street VMT by Hour of the Day

Hour	Mean	Stdev	n	N
1	587.94	404.66	9	182
2	980.81	918.38	76	337
3	1069.94	1491.74	112	747
4	780.2	1235.04	81	963
5	830.88	972.49	88	526
6	817.88	1082.42	102	673
7	981.74	1996.06	123	1588
8	714.65	1213.63	163	1108
9	801.43	879.7	132	463
10	1005.56	1544.92	112	907
11	1183.82	2242.52	148	1379
12	984.96	1149.87	175	524
13	911.71	2135.9	127	2108
14	614.19	1202.54	102	1473
15	871.79	1267.19	90	812
16	789.64	1423.31	79	1248
17	667.07	770.26	38	512
18	602.23	411.97	21	180
19	1938.6	3545.24	13	1285

Table 4.7 (Continued)

Hour	Mean	Stdev	n	N
20	1109.57	1237.97	10	478
21	340.78	440.06	6	641
22	1028.85		1	
23	1256.48	1289.47	3	405
24	105.75	123.23	3	522

*n is the available sample size
*N is the required sample size

Table 4.8: Sample Size Estimation using Ramp VMT by Hour of the Day

Hour	Mean	Stdev	n	N
1	508.15	388.74	6	224.83
2	280.33	183.97	16	165.46
3	405.3	326.61	29	249.47
4	489.3	102.43	3	16.84
5	348.64	250.41	16	198.17
6	328.11	295.89	23	312.42
7	298.91	200.56	20	172.95
8	374.91	276.27	26	208.6
9	378.13	445.61	21	533.5
10	402.15	374.98	18	334
11	252.86	298.74	19	536.22
12	515.57	613.34	40	543.67
13	329.68	364.55	30	469.71
14	203.7	157.37	14	229.29
15	295.82	280.72	18	345.95
16	209.04	262.21	10	604.45
17	577.96	238.4	5	65.37
18	144.27	125.53	3	290.86
19	981.33	604.82	2	145.92
20	907.15	1402.8	4	918.64
21	353.35		1	
24	796.63	82.73	4	4.14

*n is the available sample size
*N is the required sample size

4.2.2. VMT by Hour of the Day

MOBILE 6 also requires 24 VMT fractions to be supplied by hour of the day for all facilities combined. The only difference between this input and that in the previous section is that the VMT is aggregated by facility class. The VMT was distributed into 24 hours of the day, and then fraction of travel in each hour of the day was obtained. The results are shown in Table 4.9. The results are interpreted graphically in Figure 4.22.

Table 4.9: VMT by Hour of the Day Input for MOBILE6

Hour of the Day	GPS Value	Default Value
1	0.0117	0.0569
2	0.0458	0.0740
3	0.0827	0.0655
4	0.0356	0.0555
5	0.0382	0.0540
6	0.0515	0.0582
7	0.0783	0.0608
8	0.0766	0.0571
9	0.0666	0.0598
10	0.0630	0.0636
11	0.0790	0.0777
12	0.1062	0.0730
13	0.0694	0.0501
14	0.0432	0.0389
15	0.0446	0.0308
16	0.0396	0.0264
17	0.0233	0.0194
18	0.0123	0.0144
19	0.0108	0.0108
20	0.0098	0.0086
21	0.0053	0.0081
22	0.0019	0.0080
23	0.0017	0.0098
24	0.0029	0.0186

It can be observed from figure 4.22 that the GPS and default distributions follow similar patterns. The graph shows that there are two major peaks and a minor peak in both GPS and default distributions. The only difference is that the peak periods are more pronounced in the GPS data and there is a slight difference in the time when the peaks are attained. The morning peak period in the GPS distribution is between 8-9 AM while it is between 7-8 AM in the default distribution. The evening peak period for the GPS distribution is between 5-6 PM, while it is between 4-5 PM for the default distribution.

In between the morning and evening peaks, a small peak can be observed at 12 PM in both the distributions. The reason behind the temporal variations can be attributed to the fact that, the default data was collected at comparatively bigger cities than Lexington. Another difference in between these distributions is that, the default distribution has so-called peak spreading, which normally occurs in bigger cities.

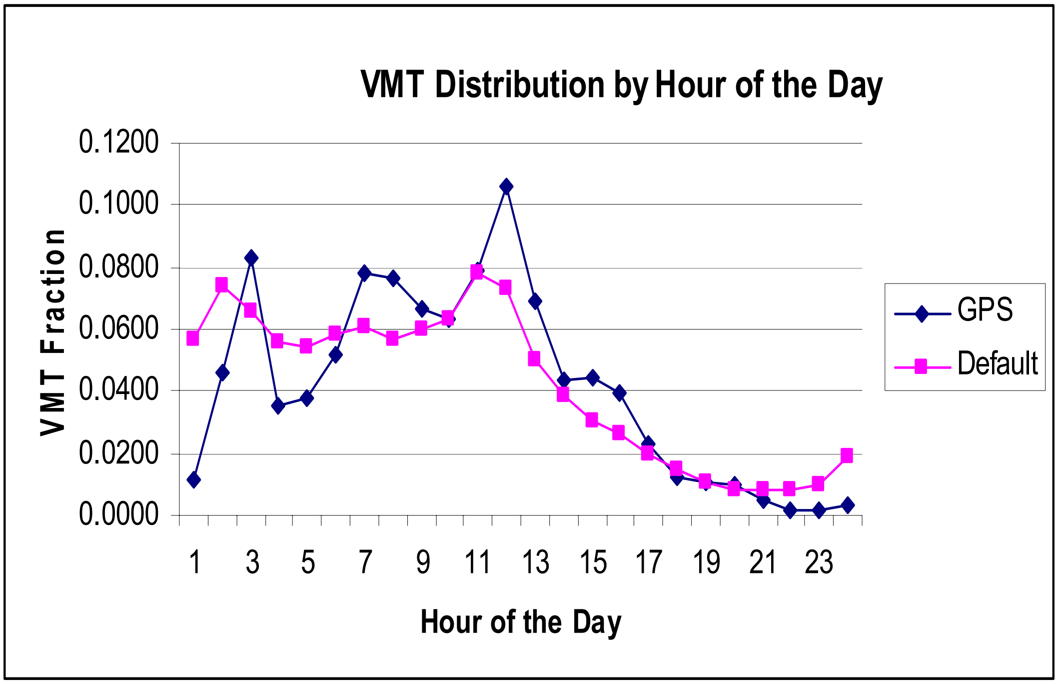

Figure 4.22: VMT Distribution by Hour of the Day for MOBILE6

Hypothesis testing was conducted using the obtained Chi-squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. The Chi-square test was applied on the results, treating the GPS values as observed results and the default values as expected results. To make sure that the individual cells of the default input data have values greater than 5, frequency of vehicles in the individual cells of the GPS and default input values were used rather than using the input fractions in the statistical test. To obtain the number of vehicles in the individual hours of the day of the default input data, it was assumed that the total number of vehicles traveling in a particular day was equal in both GPS and default data sets. The input fractions in the individual cells of the default data were multiplied by the total number of vehicles traveling in a day, to obtain the frequency of vehicles in the corresponding individual cells.

A chi-squared probability value of 0 was obtained, with 23 degrees of freedom for the VMT by hour of the day results. Since Chi-Squared probabilities for the VMT distribution fractions were less than 0.05, the null hypothesis was rejected. That means the GPS and default values are different at 5% level of significance. This result can be observed in also be observed in Figure 4.22 where, the GPS and the default VMT by hour of the day values were plotted.

4.2.3. VMT by Speed

This input command requires VMT distributions to be supplied for freeways and arterials separately for MOBILE6 as explained earlier. Data for VMT by facility type distribution was used for further analysis on this input option. First of all, the freeway VMT data was taken and the speed data was classified into 14 speed bins. Under each hour of the day, the VMT was classified into 14 speed bins using SQL queries in MS Access database. Speed VMT fractions were obtained for each hour of the day, such that all 14 fractions add up to one. This process was done by dividing each speed bin VMT by the total VMT of all 14 speed bins in a particular hour of the day. The same procedure was applied to the arterial VMT data. The results are shown in Tables 4.10and 4.12 for freeways and arterials respectively. The number of vehicles traveled in each hour of the day are also shown in the tables, to show the low level of travel on the freeways. The corresponding default values are shown in Tables 4.11 and 4.13. The graphical interpretations of the results are shown in Figures 4.23 and 4.24 for freeways and arterials respectively.

Table 4.10: VMT Distribution by Speed for Freeways (GPS Values)

	Speed Bin														
Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	No. of Vehicles
1									0.00	0.01	0.01	0.05	0.08	0.86	6.00
2					0.00	0.01	0.01	0.01	0.02	0.03	0.09	0.35	0.28	0.20	10.00
3							0.01	0.08	0.09	0.10	0.33	0.39			6.00
4	0.07	0.93													2.00
5							0.01	0.00	0.01	0.03	0.04	0.07	0.26	0.59	8.00
6										0.00	0.32	0.20	0.41	0.07	5.00
7											0.00	0.20	0.75	0.05	4.00
8								0.00	0.00	0.02	0.05	0.53	0.07	0.34	7.00
9	0.00	0.00	0.01	0.01				0.09	0.02	0.06	0.15	0.12		0.54	11.00
10	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.11	0.13	0.54	15.00
11		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.13	0.66	0.15	13.00
12						0.00	0.00	0.01	0.01	0.03	0.03	0.27	0.19	0.46	9.00
13			0.00	0.02					0.01	0.01	0.05	0.12	0.14	0.65	8.00
14							0.00	0.00	0.00	0.02	0.07	0.15	0.05	0.70	8.00
15											0.02	0.06	0.50	0.42	4.00
16								0.00	0.01	0.01	0.06	0.55	0.10	0.27	7.00
17											0.01	0.14	0.24	0.61	4.00
18															0.00
19															0.00
20															0.00
21											0.12	0.36	0.37	0.15	4.00
22															0.00
23															0.00
24								0.00	0.01	0.02	0.04	0.06	0.17	0.69	7.00

From Figure 4.23, it can be observed that the GPS and default values follow similar distributions although the GPS distributions are relatively erratic due to the small sample sizes. The graphs are drawn for 3 different time periods to display the variation for different times of the day although distributions are available for all 24 hours of the day. The morning peak period starts at 8 AM and ends at 9 AM, the evening peak period starts at 5 PM and ends at 6 PM, and the free flow period has been selected as starting at 4 AM and ending at 5 AM.

Table 4.11: VMT distributions by Speed for Freeways (Default Values)

	Speed Bin													
Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.008	0.027	0.021	0.022	0.022	0.038	0.034	0.054	0.061	0.07	0.251	0.115	0.255	0.021
2	0.026	0.007	0.008	0.016	0.028	0.033	0.034	0.036	0.036	0.044	0.245	0.173	0.302	0.013
3	0.026	0.003	0.006	0.006	0.013	0.028	0.034	0.035	0.041	0.037	0.218	0.107	0.44	0.013
4	0.015	0.01	0.002	0.002	0.004	0.017	0.023	0.037	0.042	0.045	0.225	0.119	0.442	0.018
5	0.008	0.009	0.005	0.003	0.004	0.016	0.023	0.036	0.038	0.042	0.235	0.117	0.445	0.018
6	0.007	0.003	0.004	0.01	0.012	0.024	0.029	0.033	0.04	0.039	0.229	0.101	0.454	0.014
7	0.01	0.002	0.006	0.009	0.015	0.028	0.034	0.033	0.035	0.035	0.229	0.096	0.455	0.013
8	0.008	0.008	0.005	0.004	0.005	0.018	0.026	0.038	0.038	0.042	0.226	0.112	0.451	0.018
9	0.011	0.007	0.005	0.002	0.004	0.021	0.028	0.036	0.038	0.052	0.215	0.115	0.448	0.018
10	0.016	0.008	0.003	0.004	0.008	0.027	0.032	0.036	0.032	0.039	0.212	0.064	0.5	0.018
11	0.016	0.041	0.023	0.02	0.028	0.032	0.05	0.049	0.045	0.056	0.222	0.109	0.296	0.015
12	0.019	0.011	0.005	0.011	0.018	0.026	0.049	0.038	0.031	0.053	0.224	0.124	0.374	0.017
13	0.018	0.006	0.001	0.002	0.003	0.016	0.019	0.032	0.036	0.052	0.213	0.067	0.518	0.017
14	0.014	0.004	0.003	0.001	0.001	0.009	0.018	0.026	0.026	0.055	0.206	0.098	0.521	0.018
15	0.009	0.003	0.003	0	0.001	0.007	0.017	0.022	0.026	0.048	0.217	0.105	0.523	0.02
16	0.005	0.002	0.002	0	0.001	0.005	0.016	0.018	0.025	0.04	0.228	0.112	0.525	0.023
17	0.003	0.001	0.001	0	0.001	0.003	0.015	0.015	0.025	0.035	0.235	0.116	0.526	0.025
18	0.001	0	0.001	0	0.001	0.002	0.014	0.013	0.024	0.033	0.239	0.119	0.527	0.026
19	0	0	0.001	0	0.001	0.001	0.014	0.012	0.024	0.03	0.242	0.121	0.527	0.026
20	0	0.001	0	0	0	0.001	0.012	0.01	0.02	0.024	0.245	0.129	0.527	0.032
21	0	0	0.001	0	0	0	0.01	0.009	0.018	0.021	0.246	0.132	0.527	0.035
22	0	0.001	0	0	0	0	0.011	0.008	0.017	0.02	0.245	0.134	0.527	0.036
23	0.002	0	0	0.001	0	0.001	0.012	0.01	0.021	0.022	0.245	0.127	0.527	0.031
24	0.003	0	0	0.001	1E-04	0.001	0.013	0.012	0.024	0.027	0.24	0.123	0.527	0.028

It can be clearly observed from Figure 4.23 that the default values represent more congested flow conditions (as represented by lower speeds) in the morning and evening peak periods than the GPS values. Considering the morning peak graph, it can be observed that the travel speeds of the GPS vehicles range from 30 mph to 60 mph (speed bins 7 and 12). Almost 70% of the total travel was made with speeds greater than 50 mph. The default distribution on the other hand, shows more congested conditions in that only 45% of the travel was made with speeds greater than 50 mph. The default travel speeds range from 0 mph to 65 mph (speed bins 1 and 13) in this particular peak hour. The speed distribution values can be a good measure of level of service and it can be concluded that the Lexington freeways have higher level of service than the national average.

Table 4.12: VMT Distribution by Speed for Arterials (GPS Values)

	Speed Bin														
Hr	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**No. Of Vehicles**
1	0.00	0.01	0.01	0.02	0.04	0.09	0.10	0.08	0.07	0.09	0.15	0.23	0.09	0.01	168
2	0.01	0.02	0.04	0.05	0.07	0.10	0.12	0.12	0.11	0.11	0.10	0.09	0.05	0.02	840
3	0.01	0.01	0.02	0.03	0.04	0.05	0.07	0.10	0.12	0.12	0.13	0.16	0.12	0.02	1341
4	0.01	0.02	0.03	0.04	0.06	0.08	0.10	0.15	0.14	0.15	0.10	0.09	0.03	0.01	747
5	0.02	0.03	0.04	0.06	0.08	0.09	0.13	0.15	0.13	0.08	0.05	0.05	0.06	0.04	933
6	0.01	0.03	0.04	0.05	0.06	0.09	0.13	0.15	0.11	0.10	0.09	0.09	0.04	0.02	1094
7	0.02	0.03	0.04	0.05	0.07	0.09	0.12	0.14	0.11	0.12	0.10	0.07	0.04	0.01	1499
8	0.01	0.02	0.03	0.04	0.06	0.09	0.12	0.13	0.12	0.11	0.11	0.10	0.06	0.01	1679
9	0.03	0.03	0.04	0.05	0.06	0.09	0.12	0.12	0.10	0.08	0.09	0.10	0.07	0.02	1508
10	0.01	0.03	0.03	0.05	0.07	0.09	0.12	0.12	0.10	0.10	0.09	0.11	0.08	0.01	1259
11	0.03	0.03	0.03	0.05	0.06	0.08	0.12	0.11	0.11	0.12	0.09	0.09	0.06	0.01	1589
12	0.01	0.02	0.04	0.04	0.05	0.07	0.11	0.12	0.11	0.12	0.11	0.09	0.07	0.02	1893
13	0.01	0.02	0.03	0.04	0.04	0.07	0.10	0.11	0.12	0.13	0.15	0.12	0.06	0.02	1380
14	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.15	0.11	0.11	0.10	0.11	0.03	0.00	942
15	0.02	0.01	0.02	0.04	0.04	0.07	0.09	0.13	0.12	0.12	0.14	0.13	0.06	0.00	995
16	0.01	0.02	0.02	0.04	0.06	0.11	0.15	0.15	0.15	0.10	0.09	0.07	0.02	0.01	831
17	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.03	0.05	0.08	0.06	0.03	0.01	0.00	390
18	0.00	0.01	0.02	0.03	0.04	0.07	0.13	0.16	0.11	0.16	0.12	0.11	0.04	0.02	226
19	0.00	0.03	0.03	0.07	0.04	0.06	0.14	0.15	0.11	0.09	0.12	0.10	0.04	0.01	166
20	0.00	0.01	0.03	0.03	0.05	0.10	0.09	0.12	0.11	0.11	0.08	0.16	0.09	0.01	138
21	0.00	0.00	0.01	0.01	0.02	0.04	0.09	0.10	0.17	0.18	0.21	0.08	0.05	0.02	89
22	0.00	0.01	0.06	0.04	0.04	0.05	0.07	0.08	0.36	0.17	0.04	0.06			22
23	0.01	0.04	0.06	0.06	0.11	0.09	0.14	0.17	0.19	0.11	0.02	0.01			44
24	0.01	0.01	0.01	0.04	0.04	0.05	0.07	0.12	0.15	0.19	0.14	0.16	0.03	0.01	70

Table 4.13: VMT Distribution by Speed for Arterials (Default Values)

	Speed Bin													
Hr	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	4E-04	0.005	0.006	0.005	0.016	0.085	0.321	0.138	0.28	0.06	0.063	0.01	0.01	1E-04
2	0.004	0.003	0.006	0.023	0.074	0.111	0.284	0.095	0.263	0.04	0.07	0.011	0.017	0
3	0.003	0.002	0.003	0.009	0.044	0.113	0.291	0.108	0.284	0.042	0.072	0.009	0.02	0
4	0.003	0.002	0.001	0.002	0.018	0.1	0.291	0.125	0.301	0.054	0.074	0.009	0.02	0
5	0.003	0.001	5E-04	0.002	0.018	0.101	0.29	0.125	0.302	0.054	0.075	0.009	0.02	0
6	0.003	0.002	0.002	0.005	0.034	0.109	0.289	0.113	0.293	0.046	0.074	0.009	0.021	0
7	0.004	0.002	0.003	0.008	0.043	0.113	0.286	0.108	0.289	0.043	0.072	0.009	0.021	0
8	0.004	0.003	0.002	0.002	0.022	0.103	0.283	0.124	0.302	0.052	0.074	0.009	0.02	0
9	0.004	0.002	0.002	0.003	0.025	0.105	0.284	0.122	0.299	0.049	0.075	0.009	0.021	0
10	0.005	0.003	0.003	0.009	0.045	0.115	0.282	0.102	0.284	0.042	0.078	0.01	0.023	0
11	0.005	0.017	0.009	0.022	0.065	0.122	0.281	0.096	0.256	0.041	0.065	0.01	0.013	0
12	0.006	0.007	0.008	0.022	0.068	0.117	0.277	0.092	0.264	0.039	0.071	0.011	0.019	0
13	0.004	0.002	0.002	0.004	0.026	0.101	0.285	0.121	0.3	0.05	0.076	0.01	0.021	0
14	0.004	0.002	0.002	0.002	0.012	0.073	0.292	0.122	0.317	0.064	0.079	0.01	0.021	1E-04
15	0.004	0.002	0.001	0.002	0.01	0.056	0.304	0.107	0.331	0.07	0.082	0.01	0.021	1E-04
16	0.004	0.002	9E-04	0.001	0.011	0.053	0.306	0.106	0.332	0.071	0.083	0.01	0.021	1E-04
17	0.003	9E-04	7E-04	0.002	0.01	0.053	0.307	0.106	0.333	0.071	0.083	0.01	0.021	0
18	0.003	0.001	0.002	0.002	0.01	0.053	0.306	0.106	0.333	0.07	0.083	0.01	0.021	1E-04
19	0	0	0	3E-04	0.009	0.05	0.33	0.105	0.331	0.07	0.073	0.01	0.021	2E-04
20	1E-04	0	0	0	0.008	0.05	0.33	0.106	0.329	0.07	0.076	0.01	0.021	4E-04
21	0	0	0	0	0.008	0.049	0.331	0.106	0.33	0.069	0.076	0.01	0.021	4E-04
22	0	0	0	0	0.008	0.049	0.329	0.106	0.332	0.069	0.076	0.01	0.021	5E-04
23	0	0	0	0	0.008	0.05	0.329	0.106	0.331	0.07	0.076	0.01	0.021	3E-04
24	0	0	0	0	0.009	0.05	0.327	0.105	0.332	0.07	0.075	0.01	0.021	2E-04

Considering the evening peak graph, a similar conclusion can be drawn. More than 90% of the travel by the GPS vehicles was made with speeds greater than 50 mph. The travel speeds range from 20mph to 65+ mph (speed bin 3 and 14) in the GPS class.

The default vehicle speeds range from 0mph to 65 mph and more than 70% of the travel was made with greater than 50mph speeds.

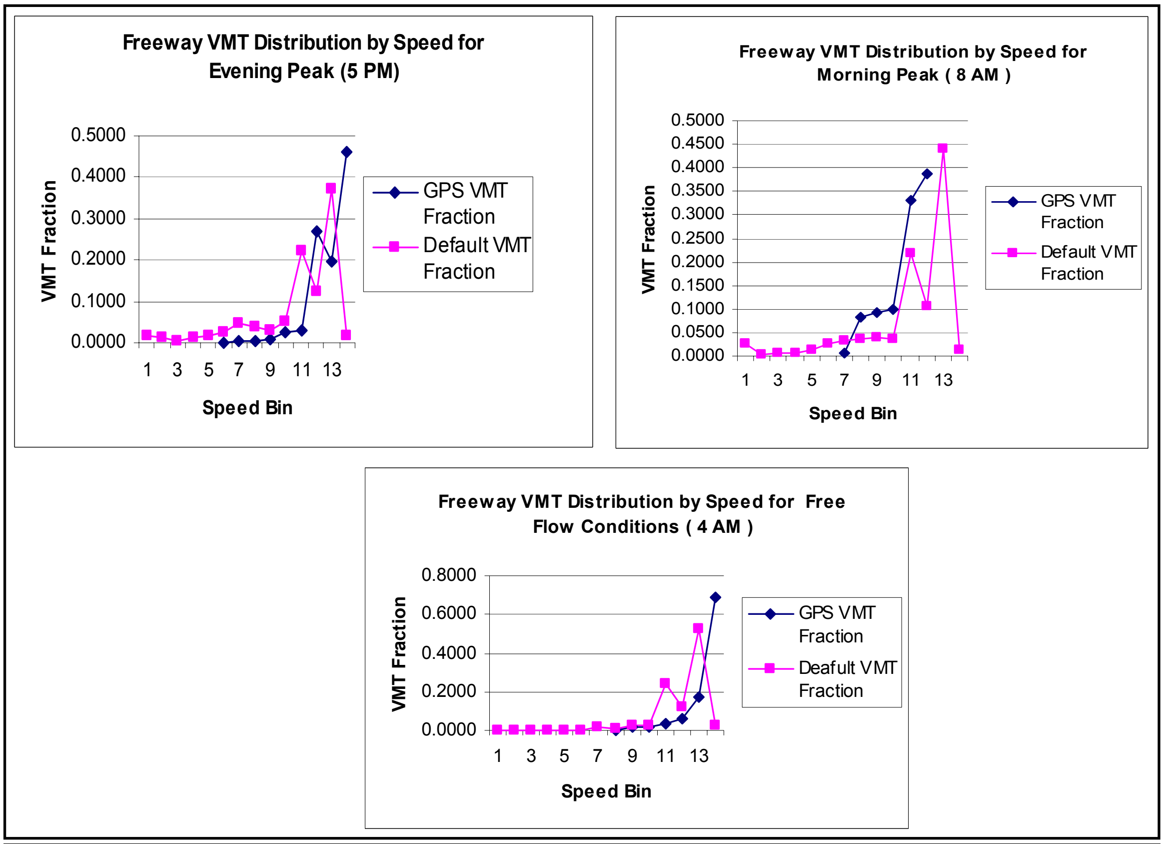

Figure 4.23: Graphical Interpretation of Speed Distribution Results for Freeways

Considering the free flow period graph, it can be observed that GPS travel was made with higher speeds than the default values. More than 95% of the GPS travel was made with greater than 50 mph. While more than 85% of the default travel was made with speeds greater than 50mph.

The reason for the more congested conditions in default observations than those of GPS could be that the cities of default data collection have more congested freeway travel than the Lexington. Another possible reason for this outcome could be that only about 4.7% of the road network consisted of freeways in Lexington meaning that most travel would have occurred on arterials.

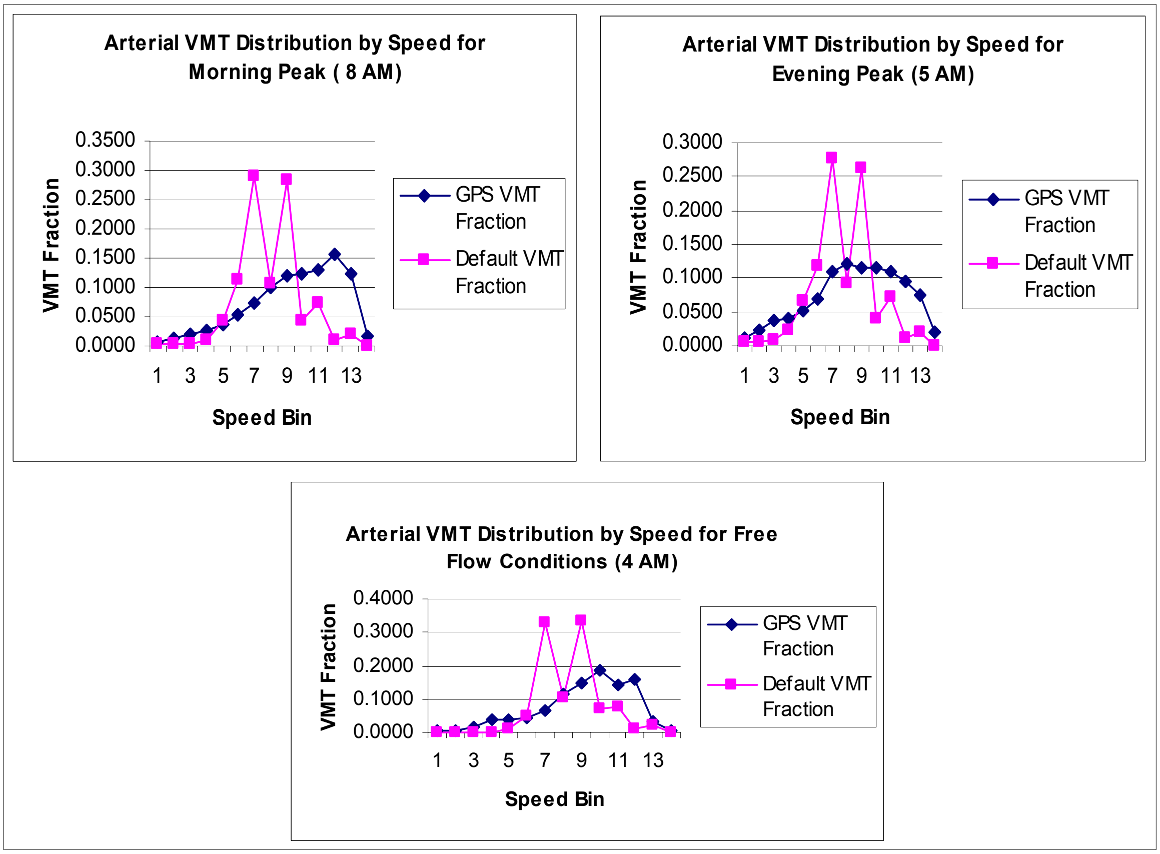

Figure 4.24: Graphical Interpretation of Speed Distribution Results for Arterials

Similar to the freeway speed distribution graphical analysis, the arterial results also can be viewed using Figure 4.24. Unlike the situation with the freeway travel, the GPS values in arterial travel show some sign of congestion although it is limited. Both in morning peak and evening peak of the GPS curves, it can be observed that most of travel was made with speeds ranging from 30 mph to 60 mph (speed bins 6 to 12). The default values display two peaks at the 7th and 9th speed bins. Overall, speeds in the default distribution appear to be lower than in the GPS distributions. The free flow conditions graph also shows similar travel conditions. It can be observed that a higher percentage of travel is observed with greater speeds in the GPS distributions than the default distributions. The reason could be that the Lexington road network has a comparatively higher number of arterial highways (with fewer traffic signals) than the cities in which the default data were collected. The congestion in the arterials may not be the reason for lower speeds in the default data, because the free flow graph has exactly similar distribution when compared with the other two peak period graphs.

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. The results were statistically compared using a Chi-Square test as applied in the previous sections. The statistical test was applied on the selected hours of the day values as the graphical comparison was also made on them. Hour of the day columns numbered 3, 12, and 24 in both freeway and arterial results were used for this purpose. Instead of comparing the fractions in the input data, the corresponding VMT values were used for applying the statistical test, to make sure that the individual cell values of the default input data were greater than 5. For this purpose, the total VMT in a particular hour of the day was assumed to be equal in both GPS and default input data. The VMT in the individual speed bins in each hour of the day of the default input data were obtained by multiplying the total VMT in those hours of the day by the corresponding VMT fractions.

The null values in the individual cells of the default input data were eliminated by merging the adjacent cells. Corresponding cells in the GPS data were also merged, to obtain equal matrix size for the GPS and default input data sets. In this process, hour of the day columns for the freeway results were resulted with 13 rows and those of the arterial results were resulted with 9 rows. The Chi-square test was applied on these columns individually and probability values of 0 were obtained for all hours of the day. Since Chi-Squared probabilities for the VMT distribution fractions were less than 0.05, the null hypothesis was rejected. Hence, the GPS and default values are different at 5% level of significance for both freeway and arterial classes.

4.2.4. Soak Distribution

To obtain soak time information that complies with EPA requirements, the GPS data had to be converted so that the trip start and trip end information was available for each vehicle trip. The GPS data was processed to differentiate between different trips made by each vehicle. This was achieved by applying certain criteria to the data. For example, if there is a break in the GPS readings for 2 to 3 minutes without a change in location, the end of one trip and the start of another are likely to have occurred. However the break in movement may also be due to a traffic jam or a particularly long traffic signal. Breaks in observations where movement has occurred may be due to a temporary loss in signal to the GPS or may indicate that the motorist failed to turn the instrument on for one or more trips. In the data used in this study this type of analysis was not required, as all the trips had been identified in the processed data file.

The Lexington data has a unique identification for each trip (trip ID). All trip records in the GPS data with same ‘trip ID’ information were grouped together in ascending order of time of the day. In these GPS data records, the first record represents the trip start and the last record represents the trip end. A total of 1947 trips were identified in the data in this manner. The soak durations were calculated by subtracting the trip end time of a trip from the trip start time of the successive trip of a given vehicle.

The soak duration was not found for the last trip made by each vehicle, as the trip start time of the next trip by that vehicle was unavailable. The GPS data file was made into three separate copies for the analysis of cold soaks, hot soaks and distribution of vehicle starts separately.

The analysis of soak distribution requires the soak time data classification into 70 soak bins. 70 columns were added to the GPS data, to accommodate data for the individual soak bins. Using the formulas in Table 2.3, soak durations for each of the 70 soak bins were identified. Using logical operators each soak bin was assigned with a binary value (true or false) based on soak duration of each trip. A 'true' value in a soak bin indicates that the soak time fitted into that particular soak bin. A data file filled up with 'true' or 'false' values for all the records was obtained as a result. The hour of the day information was then added as a separate column, using the time of day information from the GPS data.

As explained earlier, MOBILE6 requires soak-related input for weekdays and weekends separately. Hence the data file was divided into weekday and weekend data files and each file was analyzed separately, to obtain the number of vehicles that belong to a particular soak bin for each hour of the day. A computer program was written in Visual Basic to calculate the number of soaking vehicles that fall into each cell of the matrix based on the hour of the day information and the 'true' or 'false' information available for each GPS record. The 69^{th} and 70^{th} soak bins were filled up with null values, as there was no data available to calculate the stalls and restarts represented by those soak bins. The data in the matrix was then transformed into fractions to comply with the required MOBILE6 format. Fractions were obtained so that each cell value in the matrix represents a proportion of the number of soaking vehicles in that particular soak bin over the total number of soaking vehicles in all the soak bins, representing a particular time interval. The procedure was applied to both weekday and weekend data files and two separate matrices were obtained.

The cold soak analysis produced two 70 by 24 matrices, one for weekdays and one for weekends. The two matrices are shown in Appendixes A, C. Default values for these results are shown in Appendixes B, D. Graphical interpretation of the results has been included in the thesis although it was impossible to graphically present information from all the cells in the matrix. Instead, graphical presentation of a particular hour of the day (5 p.m.-6 p.m.) was selected as representative. This particular hour of the day was selected for interpretation of both cold soaks and hot soaks for the following reasons:

- It is an evening peak period when a lot of trips are expected to start
- There are more blank values in the result matrices for other hours of the day due to the small sample size available.

The proportion of cold soaks reported in the matrices range from 0 to 1, and these are typically small values since 70 of them must sum to 1. Thus, to graphically portray these values would generally not provide a clear depiction of the result. Hence, a cumulative distribution of the proportions was selected to portray the results. The cumulative soak distributions were developed separately for weekdays and weekends and are shown in Figure 4.24 and Figure 4.25. The default cumulative soak distributions are also included for comparison purposes.

It can be observed from Figure 4.24 that the highest concentrations of soaking vehicles in the GPS data are 6.4%, 7.2%, and 5.6% in the 48^{th}, 51^{st} and 60^{th} soak bins, respectively. The time interval-ranges for these soak bins are 110-150 minutes, 210-240 minutes, and 480-510 minutes, respectively. This suggests that the greatest number of cold soaks that are observed from vehicles starting their trip during the afternoon peak are those with soak times of approximately 2 hours, 4 hours, and 8 hours. The 8-hour soaks are probably from trips made to work in the morning. The 4-hour soaks are probably from those that made lunch trips from work. While it is more difficult to speculate as to why a relatively large number of cold soaks occur with approximately 2-hour duration, it is possible that these could result from shopping trips where we speculate that a shopping duration in the region of 1.5 to 2 hours is more likely than any other duration.

The cumulative graph of GPS soak times in Figure 4.24 is distributed similarly to those of the default data although the first few soak bins as well as those in the vicinity of the 60th soak bin are quite different. For example, between the 61st and 65th soak bins of the default distribution a total of approximately 12% of the soak times were observed, while the corresponding total values in the GPS data were approximately 20%. However, the fact that the default values are different from the Lexington values cannot be concluded by the graphical representation. Thus, this is left for statistical analysis that is done in the next section.

The cumulative distribution of soak times for the weekends is quite different to those for weekdays. The distribution for the weekend and for the evening peak is shown in Figure 4.25. The similarity between the GPS and default values are apparent although the GPS values display a more "stepped" function than the default values due to the numerous bins in which zero observations occur in the GPS data. The high incidence of empty cell in the weekend matrix was due to the fact that only one fourth of the trips out of all trips in the GPS data were weekend trips.

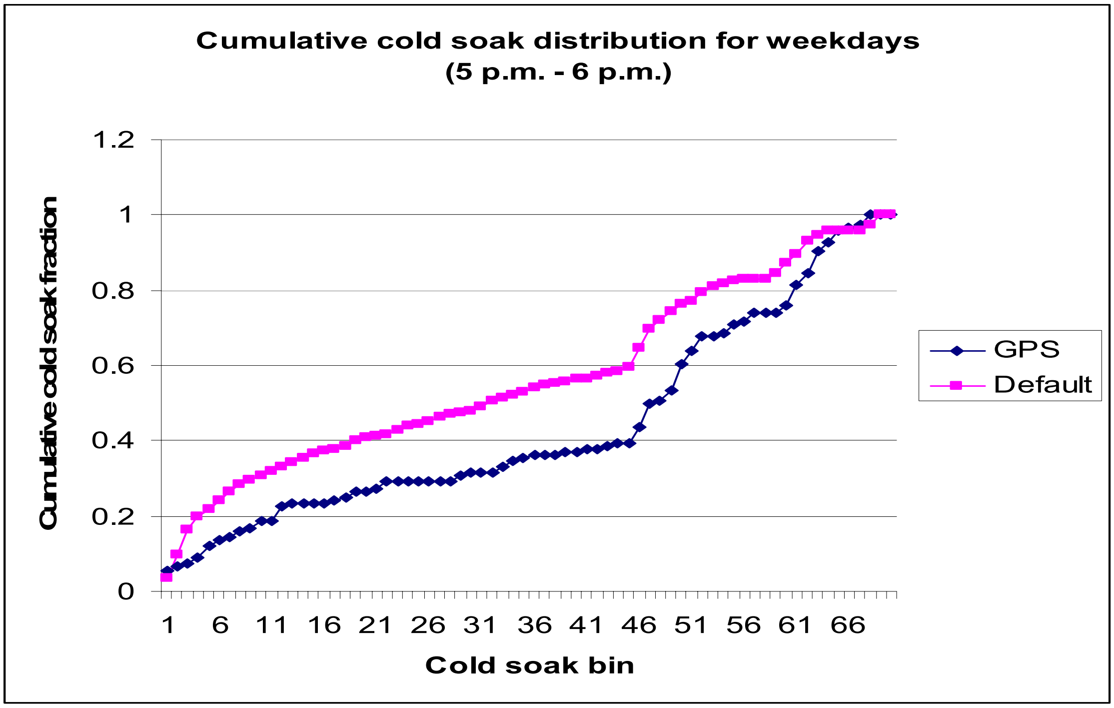

Figure 4.24: Cumulative Cold Soak Distribution for Weekdays

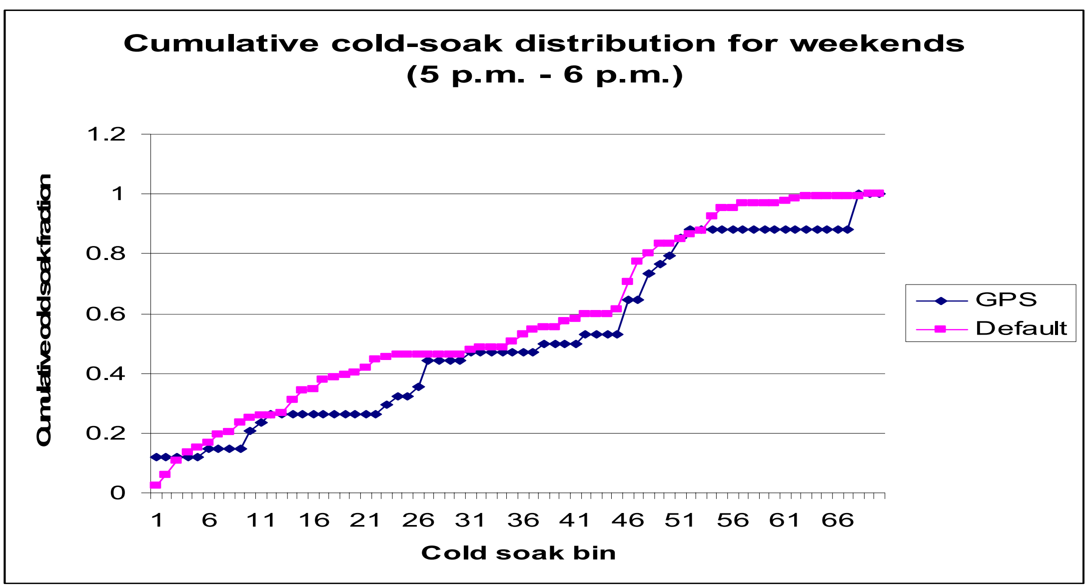

Figure 4.25: Cumulative Cold Soak Distribution for Weekends

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. The Chi-Square test was applied on the evening peak (5.00 p.m. to 6.00 p.m.) of the soak distribution matrices for weekdays and weekends separately. Instead of using the fractions in each cell, the corresponding number of vehicles experiencing cold soak were used in the statistical analysis. For this purpose the total number of soaking vehicles in each hour of the day were assumed to be equal in both the GPS and default input data sets. The number of vehicles in the individual cells of the default data in a particular cold soak bin were obtained by multiplying the corresponding default fractions with the total number of vehicles experiencing cold soak in that hour. To make sure that the individual cell values of the default data were greater than 5, adjacent cell values were merged. Corresponding cells in the GPS data were also merged to make sure that the GPS and default input matrices were of equal size. In this process a column of 14 rows was obtained for the weekday values and a column of 8 rows was obtained for the weekend values. The chi-square probabilities of 0.0009 and 0.005 were obtained with degrees of freedom of 13 and 7 for the weekday and weekend results respectively. Thus, the null hypothesis that the GPS and default distributions are similar for the afternoon peak was rejected.

4.2.5. Hot Soak

The analysis of the hot soak requires the soak time data classification into 60 soak bins of one minute each. 60 columns were added to the GPS data to prepare the soak bins. First, the 60 soak bins were prepared using EPA's hot soak definition. Then the soak durations were calculated and the soaks assigned to the appropriate soak bin in the same manner as was done with the cold soaks. The time interval information was also added as a separate column, using the time of day information from the GPS data. Separate matrices were established for weekdays and weekends and the table values were transformed into proportions as was done in the cold soak matrices.

The hot soak analysis produced two 60 by 14 matrices, one for weekdays and one for weekends. The two matrices are shown in Appendixes E, G. Default values for weekday hot soak distribution are shown in Appendix F. Figure 4.26 illustrates the cumulative distribution of hot soaks for the evening peak period of the weekdays. The distributions are reasonably similar to the default distribution. However, the GPS curve is not a smooth curve like the default distribution. The soak bins numbered 1 to 10 were filled with a reasonable number of observations to produce a uniform distribution in that range. The last soak bin (60) contained almost 63% of all observations. The soak bins between 11 and 59 were sparsely distributed with comparatively few values. The reason is that many trips ending in the evening peak are likely to have longer hot soak times unless they perform an intermediate task on the way home from work such as a short shopping trip or to pick up or drop off a passenger. The value for the default distribution for the 60^{th} soak bin is also comparatively higher (45%) than the other soak bins.

Figure 4.27 illustrates a comparison of distributions of hot soaks between weekdays and weekends for the evening peak period. The distributions follow a similar pattern, although the weekend distribution follows an uneven pattern due to the relatively small sample size of weekend values. The EPA did not develop weekend values for hot soaks because of the small sample size problem. The EPA suggests the use of weekday values instead of weekend values if the sample sizes for weekends are inadequate.

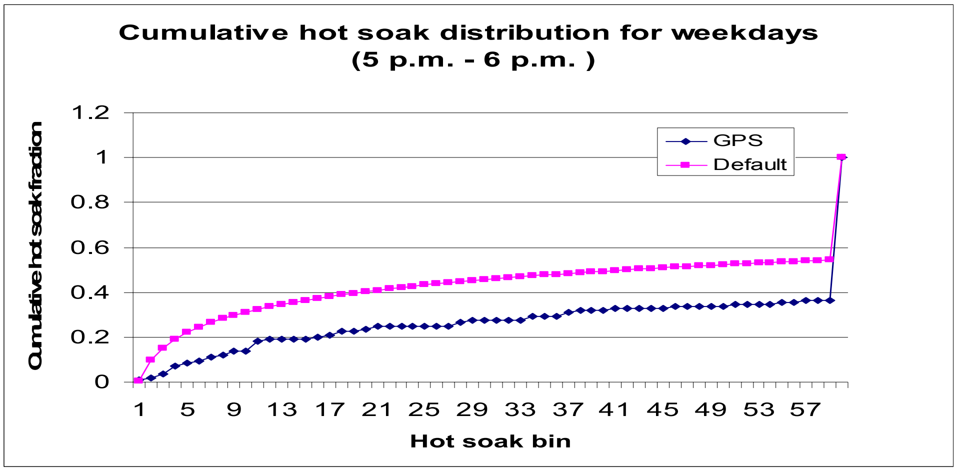

Figure 4.26: Cumulative Hot Soak Distribution for Weekdays

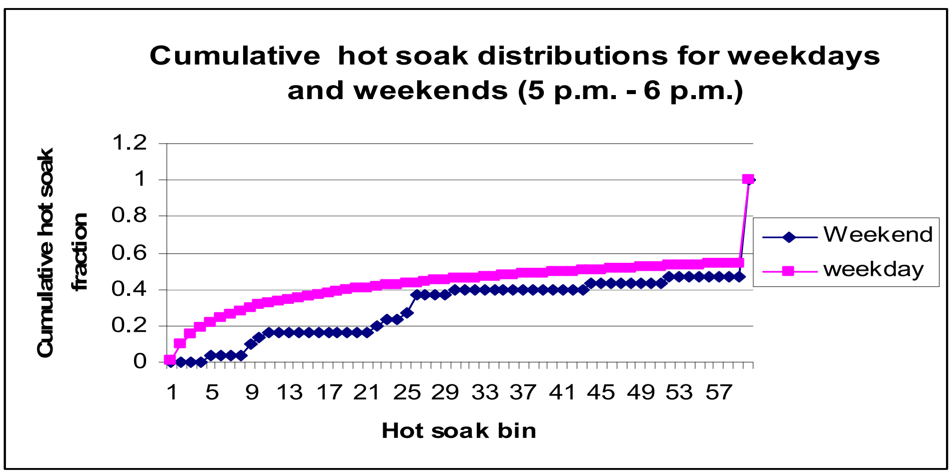

Figure 4.27: Cumulative Hot Soak Distributions for Weekdays and Weekends

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. The Chi-Square test was applied on the evening peak (5.00 p.m. to 6.00 p.m.) of the hot soak distribution matrices for weekdays and weekends separately. Instead of using the fractions in each cell, the corresponding number of vehicles experiencing hot soak were used in the statistical analysis. For this purpose the total number of hot-soaking vehicles in each hour of the day were assumed to be equal in both the GPS and default input data sets. The number of vehicles in the individual cells of the default data in a particular hot soak bin were obtained by multiplying the corresponding default fractions with the total number of vehicles experiencing hot soak in that hour. To make sure that the individual cell values of the default data were greater than 5, adjacent cell values were merged. Corresponding cells in the GPS data were also merged to ensure that the GPS and default input matrices were of equal size. In this process a column of 11 rows was obtained for the weekday values and a column of 7 rows was obtained for the weekend values. The chi-square test probabilities of 0 and 0.00061 were obtained with degrees of freedom of 10 and 6 for the weekday and weekend results respectively. Thus, the null hypothesis that the GPS and default distributions are similar for the afternoon peak was rejected.

4.2.6. Distribution of Vehicle Starts during the Day

As explained earlier, the analysis on distribution of vehicle starts requires classification of number of vehicle starts into each hour of the day separately for weekdays and weekends. The hour of the day information was added to the GPS data and the data was separated into weekday and weekend data files. The GPS data includes trip start and trip end information. The number of trip starts were classified into each hour of the day, using a simple query written in 'MS Access' data base. The query creates an external file containing two columns namely, 'hour of the day' and 'number of trip starts'. A separate column was added to this file to obtain fractions of trip starts for each hour of the day, according to MOBILE6 requirements. Each fraction represents the proportion of number of trip starts in a particular hour of the day over the total number of trip starts in all the hours of the day. The cell values for all the hours of the day add up to one.

The vehicle start distribution analysis produced the fraction of vehicle starts corresponding to each hour of the day for weekdays and weekends separately. The distributions obtained by the GPS data were compared with the default data. Figures 4.28 and 4.29 represent the comparisons between the GPS and the default values for weekdays and weekends respectively. Table 4.30 lists the numeric values.

From Figure 4.28, three peaks can be observed namely, morning afternoon and evening peaks for both GPS and default data. The GPS values of number of trip starts are very similar to those of the default values in the peak times. However, there is a difference in the distributions in that the peak period occurs at a different time for the GPS data than the default data. The peak periods for the default values occur earlier than those of the GPS data and the peak periods are wider than those of the GPS data. The difference in the metropolitan area population could be a possible reason for this discrepancy. As mentioned earlier the default data was collected in two metropolitan areas namely, Baltimore and Spokane. Lexington is a smaller metropolitan area than either Baltimore or Spokane and, subsequently, its travel patterns could be different. As the population of the metropolitan area increase, peak periods tend to start earlier and last longer. People tend to start work earlier and try to avoid the peak hour travel as far as possible to avoid traffic jams.

Figure 4.29 shows the weekend trip start distribution for both the GPS and the default values. During the weekend the peak periods are shifted to the afternoon and evening as most of the trips are recreational trips. The GPS data shows clear peaks in the afternoon and evening times. The default data show a more uniform pattern for the above-mentioned reasons.

Hypothesis testing was conducted using the obtained Chi-Squared probabilities at 5% level of significance. The null hypothesis was that the default and GPS values were equal, while the alternative hypothesis was just the opposite. The Chi-Square test was applied on the obtained results of the vehicle start distribution during the day. Instead of using the fractions in each cell, the corresponding number of vehicle starts were used in the statistical analysis. For this purpose the total number of vehicle starts in the day were assumed to be equal in both the GPS and default input data sets. The number of vehicles in the individual cells of the default data in a particular hour of the day were obtained by multiplying the corresponding default fractions with the total number of vehicle starts of the entire day. The Chi-square probabilities of 0 were obtained with 23 degrees of freedom for both the weekday and weekend results. Thus, the null hypothesis that the GPS and default distributions are similar was rejected.

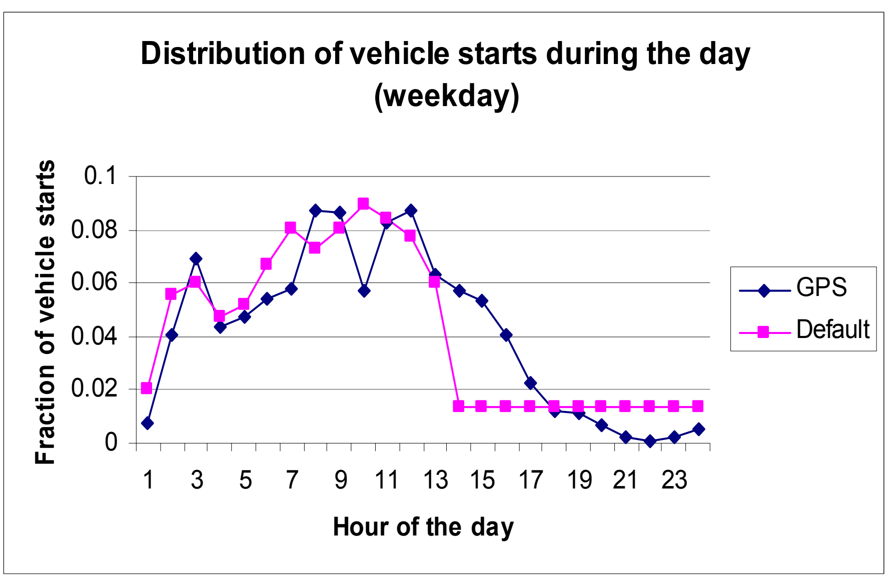

Figure 4.28: Distribution of Vehicle Starts during the Day (Weekdays)

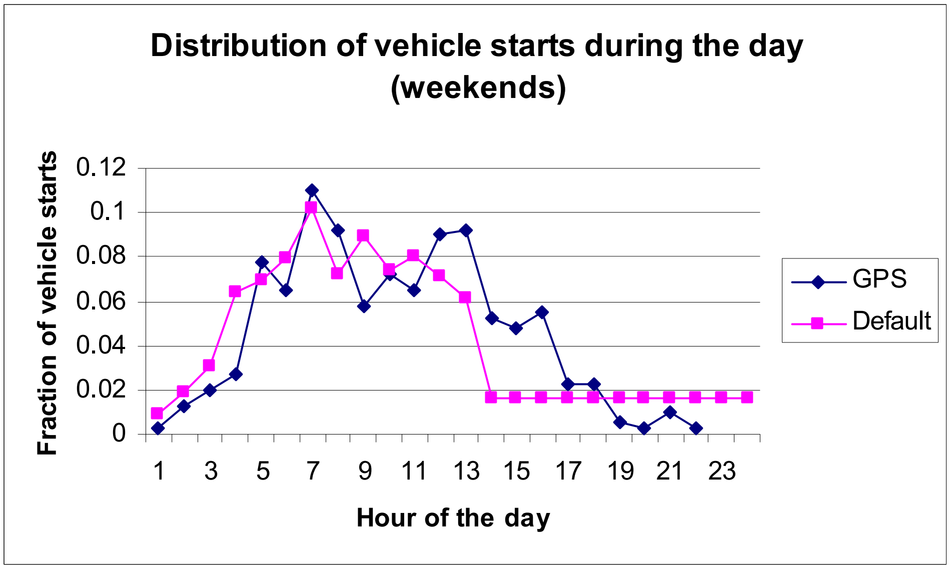

Figure 4.29: Distribution of Vehicle Starts during the Day (Weekend)

Table 4.14: Distribution of Vehicle starts during the Day

	Weekdays		Weekends	
Hour	GPS	Default	GPS	Default
1	0.007767	0.020408	0.002494	0.009142
2	0.040777	0.055416	0.012469	0.019299
3	0.069256	0.060283	0.01995	0.03098
4	0.043366	0.047253	0.027431	0.0645
5	0.047249	0.051648	0.077307	0.069071
6	0.054369	0.06719	0.064838	0.079736
7	0.058252	0.080691	0.109726	0.101574
8	0.087379	0.072998	0.092269	0.072626
9	0.086731	0.080377	0.057357	0.088878
10	0.056958	0.089796	0.072319	0.073641
11	0.082848	0.084144	0.064838	0.080244
12	0.087379	0.077237	0.089776	0.071102
13	0.06343	0.060126	0.092269	0.061453
14	0.056958	0.013858	0.052369	0.01616
15	0.053722	0.013858	0.047382	0.01616
16	0.040777	0.013858	0.054863	0.01616
17	0.022654	0.013858	0.022444	0.01616
18	0.012298	0.013858	0.022444	0.01616
19	0.011003	0.013858	0.004988	0.01616
20	0.00712	0.013858	0.002494	0.01616
21	0.001942	0.013858	0.009975	0.01616
22	0.000647	0.013858	0.002494	0.01616
23	0.001942	0.013858	0	0.01616
24	0.005178	0.013858	0	0.01616

5. Summary & Conclusions

The research study reported in this thesis was a proof-of-concept study of the use of GPS to supply vehicle activity data to MOBILE6. The study also addressed the supply of vehicle registration distributions to MOBILE6 using non-GPS sources. The study identified important travel related inputs for MOBILE6 and provided possible data sources in deriving them. The study developed methodologies for eight different input requirements under vehicle fleet and vehicle activity types of MOBILE6 input data using GPS and Registration data sources. The results were graphically and statistically compared with the EPA's national default values.

A methodology for obtaining vehicle registration distributions was developed and the procedure was applied to the Louisiana vehicle registration data in deriving vehicle registration inputs to MOBILE6. The results were statistically and graphically compared with the default values. The statistical results proved that the Louisiana values are different from the default values. However, the graphical results identified the nature of the difference between the vehicle fleet in Louisiana and the default data. In general, older vehicles were observed in Louisiana than in the default data. The difference is particularly significant in school buses.

The annual mileage accumulation rates were obtained using the Lexington, KY GPS data. Differences were found between the GPS and default distributions. In the default values, as the age of the vehicle increased, mileage accumulation rate decreased while in the GPS values the mileage accumulation rates randomly increased and decreased with age. This outcome was attributed to the type of vehicle fleet available in the area and the small sample size in the GPS data.

A new methodology was developed for classifying VMT by functional classification, using GPS data. TransCAD GIS software was used for this purpose. Using the overlay procedure within TransCAD, the street network attributes were attached to the GPS data and the functional classification analysis was performed. The analysis produced very similar results to those obtained by the Battelle team on the same data thereby validating the accuracy of the overlay procedure. However, the results differed from the national default values. A very small proportion of freeway travel was found, and a higher proportion of arterial travel than the national default values. This observation was attributed to the network conditions in Lexington. The analysis reinforces the EPA‘s statement that local values should be used wherever possible instead of applying default values.

VMT by hour of the day input was developed by aggregating the VMT by functional classification results. Although, the statistical results indicated that the GPS values were different from the default values, the graphical results showed similar distributions for them. The only difference observed was that the peak periods differed temporally. The city congestion levels, at which the data were collected, could be the reason for this observation.

The VMT distribution by speed input was obtained for freeways and arterials as required by the MOBILE6. It was observed that on both freeways and arterials the GPS speeds were higher than the default vehicle travel. The freeway travel in Lexington does not have VMT values in the lower speed bins indicating a high level of service on those facilities. These outcomes were attributed to the congestion levels and the road network conditions in the area at which the data were collected.

Three different soak related inputs, namely cold soak, hot soak and the distribution of vehicle starts during the day were derived from the Lexington GPS data and the results were compared with the default values. Cumulative distributions of soak data for the evening peak period were drawn separately for weekdays and weekends for both GPS and default values. Comparisons were made both graphically and statistically. The graphical comparisons of soak distributions show that the GPS values follow more or less similar distributions to those of the default values, although certain cell values were different. The distribution of vehicle starts from the GPS data and the default data are also similar although differences in peak periods were found. These differences could be attributed to the difference in metropolitan area size (Lexington versus Baltimore and Spokane) since more pronounced peaks were observed in the Lexington data than in the data from the larger metropolitan areas where "peak spreading" is more likely.

In using the Lexington data, for supplying inputs to MOBILE6, the primary problem that prevented more analysis was the small sample size. Hence using the results obtained in this study, a sample size estimation procedure was developed. This procedure was successfully applied to two input requirements namely, annual mileage accumulation rates and the VMT by functional class. Minimum sample sizes of 1305 and 6635 vehicle days were found necessary to achieve estimates within 10% of their true value with 95% confidence for annual mileage accumulation rates and VMT by functional class respectively. The procedure was not applied on the VMT by hour of the day as is it requires more aggregated data than VMT by functional class and therefore would be specified with smaller sample sizes. VMT by speed resulted in a large number of null values in their cells, which prevented further sample size analysis on them. To establish sufficient observations in each cell of the detailed input matrices required by MOBILE6 would require a considerably larger sample size. Since the Lexington data resulted in many empty cells in the matrices developed from its data, an estimate of the sample size that would be required to provide a reliable estimate of the input data could not be made. Analysis of larger databases of GPS data may provide the means of estimating the sample size that would be required to obtain reliable soak-related input data for MOBILE6. The summary of the results is shown in Table 5.1.

The conclusion of this study is that the use of GPS data for supplying input data to air quality models such as MOBILE6 appears a feasible and viable alternative to other methods of obtaining data input for such models. The study can be helpful in GPS based research on supplying travel related inputs to air quality models like MOBILE6. Although the accuracy of the results obtained in this study is affected by the small sample size, the procedure adopted in processing the data demonstrates the usage of GPS in obtaining vehicle activity inputs to MOBILE6. The sample size estimating procedure demonstrated in this study can be helpful for future GPS surveys aimed at supplying vehicle activity inputs to air quality models like MOBILE6. The differences in local vehicle fleet & activity characteristics emphasize the need for using the local data in MOBILE6.

There is a lot of scope for the future research in the use of GPS for obtaining travel related data to air quality models. EPA is planning to introduce microscopic air quality models in the future. GPS being an accurate method of collecting the automated microscopic data, it can be a powerful data source of the microscopic air quality models.

Table 5.1: Summary of the Results

Input Requirement	Result of Graphical Comparison	Null Hypothesis	Result of Statistical Comparison (95% confidence level)	Conclusion
Distribution of vehicle registrations	Vehicles in Louisiana are older than those of the national average	Vehicle registration distributions of Louisiana and the default are the same	Null hypothesis is rejected	Vehicle registration distributions of Louisiana and the default are different
Annual mileage accumulation rates	Age of the vehicles did not affect the mileage rates in Louisiana, unlike the national average	Mileage accumulation rates of the GPS and the default are the same	Null hypothesis is rejected	Mileage accumulation rates of the GPS and the default are different
VMT by facility class	Lower freeway travel and higher arterial travel were found in Lexington than those of the default values	VMT by facility class results of the GPS and those of the default are the same	Null hypothesis is rejected	VMT by facility class results of the GPS and those of the default are different
VMT by hour	Peak periods in Lexington varied temporally to those of the national average	VMT by hour distributions of the GPS and those of the default are the same	Null hypothesis is rejected	VMT by hour distributions of the GPS and those of the default are different
VMT by speed	High level of service was found in Lexington than national average	VMT by speed distributions of the GPS and those of the default are the same	Null hypothesis is rejected	VMT by speed distributions of the GPS and those of the default are different
Cold soak distribution	Similar distributions were observed in Lexington and the default	Cold soak distributions of the GPS and those of the default are the same	Null hypothesis is rejected	Cold soak distributions of the GPS and those of the default are different
Hot soak distribution	Similar distributions were observed in Lexington and the default	Hot soak distributions of the GPS and those of the default are the same	Null hypothesis is rejected	Hot soak distributions of the GPS and those of the default are different
Distribution of vehicle starts during the day	Peak spreading was not found in Lexington unlike in the national average	Vehicle start distributions of the GPS and those of the default are the same	Null hypothesis is rejected	Vehicle start distributions of the GPS and those of the default are different

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Appendix A: Soak Distribution Results for Weekdays using the GPS Data

Table A.1: Soak Distribution Results for Weekdays using the GPS Data

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0.14	0.15	0.11	0.07	0.14	0.07	0.07	0.07	0.08	0.1	0.06	0.06	0.09	0.09	0.07	0.03	0.1	0.33	0.09	0	0	0	0.29
2	0	0.02	0.01	0.04	0.06	0.03	0.02	0.05	0.02	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.03	0	0.11	0	0	0	0	0
3	0	0	0.01	0.04	0.03	0.03	0.01	0.03	0.02	0.01	0.02	0.01	0	0.01	0.03	0	0	0.05	0	0	0	0	0	0
4	0	0	0.03	0.02	0.03	0.03	0	0	0.05	0.01	0.03	0.02	0.01	0.04	0.01	0.02	0.06	0	0	0	0	0	0	0
5	0	0	0.02	0	0.01	0	0.02	0.05	0.01	0.03	0.08	0.03	0.02	0.03	0.05	0	0	0	0	0	0	0	0	0
6	0	0	0.01	0	0.01	0.01	0.01	0.03	0.02	0	0.03	0.02	0	0	0	0	0.03	0	0	0	0.33	0	0	0
7	0	0.02	0	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0	0.01	0	0	0.01	0.02	0.03	0	0	0	0	0	0	0
8	0	0	0	0.02	0.01	0.01	0.01	0	0.01	0	0.03	0.02	0.02	0	0.04	0	0	0.05	0	0	0	0	0	0
9	0	0	0	0.02	0.03	0.01	0.01	0.02	0.04	0.03	0.03	0.01	0.02	0	0	0	0.03	0	0	0	0	0	0	0
10	0	0	0	0	0	0.03	0.01	0.03	0.02	0.02	0.02	0.02	0.04	0.01	0.01	0.02	0.03	0	0	0	0	0	0	0
11	0	0	0	0.02	0	0	0.02	0.01	0	0	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0.04	0.01	0.01	0.02	0.01	0	0.01	0.02	0.04	0.01	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0.01	0.04	0	0.02	0	0.01	0.01	0.01	0.05	0	0	0	0	0	0	0	0	0	0
14	0	0	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0	0.02	0.01	0	0	0	0	0	0	0	0	0	0
15	0	0	0.01	0	0.01	0	0.04	0	0.01	0.01	0.02	0	0	0	0	0.02	0	0	0	0	0	0	0	0
16	0	0	0	0.02	0.03	0.01	0	0	0	0.01	0.01	0	0.01	0	0.01	0.02	0.03	0	0	0	0	0	0	0
17	0	0	0	0.02	0	0.01	0	0	0.02	0.02	0.01	0.01	0.01	0.03	0.03	0	0	0	0	0	0	0	0	0
18	0	0	0	0.02	0	0.03	0	0	0.01	0.02	0.02	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0
19	0	0	0.01	0	0	0	0.01	0.03	0	0	0.01	0.02	0	0	0	0	0.03	0	0	0	0	0	0	0
20	0	0	0	0	0	0.01	0	0	0	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0.02	0.01	0.02	0.01	0.03	0.01	0.01	0	0.01	0	0	0	0	0	0	0	0	0
22	0	0	0	0.04	0	0	0.01	0	0	0	0	0.02	0	0.01	0.01	0.02	0	0	0	0	0	0	0	0
23	0	0	0	0.02	0.01	0	0.01	0.01	0.02	0.02	0	0	0.01	0.03	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0.04	0	0	0.01	0.01	0.01	0.02	0	0	0.01	0.01	0	0	0	0.05	0	0	0	0	0	0

Table A.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0	0.01	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0
27	0	0	0	0.02	0.01	0	0	0.01	0	0.02	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.05	0	0	0	0	0	0
29	0	0	0	0.02	0	0	0	0	0.01	0.01	0.02	0.02	0	0	0.01	0	0	0	0	0	0	0	0	0
30	0	0	0	0.04	0	0	0	0.02	0.02	0.01	0.01	0.01	0.01	0	0.01	0.02	0	0	0	0	0	0	0	0
31	0	0	0.01	0.02	0.01	0.03	0.01	0.03	0.03	0	0.01	0	0.03	0.01	0.01	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0.04	0	0.01	0.01	0.01	0.02	0	0.01	0.01	0.01	0	0	0.05	0	0	0	0	0	0
33	0	0	0	0.02	0	0.01	0.04	0.03	0.02	0.01	0.02	0.02	0	0.01	0	0	0.03	0	0	0	0	0	0	0
34	0	0	0.01	0	0	0	0.01	0	0.01	0	0.02	0.02	0	0.01	0.01	0.02	0.06	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0.04	0.01	0.02	0	0	0.01	0.01	0.01	0	0.04	0	0	0	0	0	0	0	0
36	0	0	0	0	0.01	0	0.02	0	0	0.02	0	0.01	0.02	0.01	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0.01	0	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0	0	0.01	0.04	0.01	0.02	0	0	0	0	0	0	0	0
39	0	0	0	0.02	0	0.01	0	0.01	0.02	0.01	0.01	0.01	0	0.01	0.01	0.02	0	0	0	0	0	0	0	0
40	0	0	0.01	0	0.01	0	0	0.01	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0.01	0	0.01	0.01	0.01	0	0	0	0.02	0	0	0	0	0	1	0	0
42	0	0	0.01	0.02	0.01	0	0	0.01	0	0	0	0	0.01	0.03	0.03	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0.01	0	0	0	0.01	0.01	0.01	0.01	0	0	0	0	0.06	0	0	0	0	0
44	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0	0.01	0.04	0.01	0.01	0.02	0.03	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0.01	0	0.02	0.01	0	0.01	0.01	0	0	0.06	0	0	0	0	0	0	0
46	0	0	0	0.04	0.09	0.07	0.06	0.11	0.11	0.06	0.04	0.04	0.04	0.13	0.1	0.05	0.06	0.1	0	0	0.33	0	0	0
47	0.09	0.02	0.01	0.02	0.06	0.07	0.02	0.03	0.03	0.03	0.03	0.06	0.03	0.09	0.08	0.09	0	0.05	0.17	0.09	0	0	0	0
48	0	0	0	0.02	0.01	0.04	0.02	0.03	0.01	0.01	0.05	0.01	0	0.03	0.08	0.05	0.09	0.2	0	0	0	0	0	0

Table A.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
49	0	0	0	0	0	0.07	0.05	0.01	0	0.01	0.03	0.02	0.04	0.04	0.06	0.02	0.06	0.05	0.11	0.09	0	0	0	0
50	0	0	0	0	0	0.04	0.01	0.03	0.02	0.03	0.06	0.07	0.08	0.03	0.03	0.02	0.06	0.05	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0.03	0.02	0	0.02	0.03	0.05	0.04	0.04	0.09	0.03	0.05	0.06	0	0	0	0	0
52	0	0	0	0	0	0.01	0.04	0.05	0.02	0.02	0	0.04	0.02	0	0.03	0.04	0.03	0.05	0.06	0.18	0	0	0	0
53	0	0	0	0	0	0	0.04	0.03	0.02	0.02	0	0	0.02	0.01	0.03	0.09	0.06	0.05	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0.01	0.04	0.01	0.02	0.01	0	0	0	0.05	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0.01	0	0.03	0.03	0	0.01	0.02	0.01	0	0.04	0.04	0	0	0	0.09	0	0	0	0
56	0	0.02	0.01	0	0	0	0	0	0.01	0	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0.01	0	0	0	0	0	0.02	0	0.02	0.02	0.03	0.01	0.01	0.04	0	0	0	0	0.33	0	0	0
58	0	0.02	0.03	0	0	0	0	0	0.02	0.03	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0.03	0	0	0	0	0	0	0
60	0	0.02	0	0.02	0	0	0	0	0	0.01	0.03	0.02	0	0	0.03	0	0	0	0	0	0	0	0	0
61	0.09	0.02	0.01	0	0.04	0	0	0	0.01	0.01	0.02	0.06	0	0	0	0.04	0	0	0	0.09	0	0	0	0
62	0.18	0	0.01	0	0	0	0	0	0	0	0.01	0.03	0.01	0.01	0	0	0	0	0.06	0	0	0	0	0.43
63	0	0.07	0.02	0	0.01	0	0	0	0	0.02	0	0.06	0.05	0	0	0.02	0.03	0	0	0	0	0	0.33	0
64	0	0.05	0.02	0	0.01	0	0	0.01	0	0	0	0.02	0	0	0	0	0	0	0	0.09	0	0	0	0
65	0	0.13	0.01	0	0.01	0	0	0	0	0	0	0.03	0.01	0.01	0	0	0	0	0	0.09	0	0	0	0.29
66	0	0.04	0.04	0.02	0	0	0	0	0	0	0	0.01	0.01	0	0.03	0	0	0	0	0	0	0	0	0
67	0	0.02	0.03	0.05	0.01	0	0	0.01	0	0	0	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0.33	0
68	0.64	0.43	0.47	0.26	0.24	0.19	0.2	0.1	0.06	0.1	0.03	0.02	0.08	0.01	0.01	0.05	0	0.05	0.06	0.18	0	0	0.33	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B: Soak Distribution Default Inputs for Weekdays

Table B.1: Soak Distribution Default Inputs for Weekdays

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0.04	0.03	0.04	0.05	0.06	0.02	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2	0.03	0.06	0.04	0.05	0.06	0.05	0.06	0.05	0.05	0.06	0.05	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
3	0.02	0.03	0.03	0.05	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.07	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
4	0.02	0.03	0.02	0.03	0.04	0.05	0.05	0.04	0.02	0.03	0.03	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
5	0.01	0.01	0.02	0.02	0.02	0.03	0.02	0.03	0.05	0.04	0.04	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
6	0.01	0.01	0.03	0.02	0.03	0.04	0.04	0.03	0.03	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
7	0	0.01	0.02	0.01	0.01	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
8	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
9	0.01	0	0	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0	0	0	0	0	0	0	0	0	0	0	0
10	0.01	0.01	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11	0.01	0	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
12	0	0.01	0.01	0.03	0.01	0.03	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
13	0	0.01	0.02	0.01	0	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
14	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
15	0	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
16	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
17	0.01	0	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
18	0	0.01	0.01	0.02	0.01	0	0.01	0.01	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
19	0	0	0.01	0.01	0.01	0.01	0.02	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0	0.01	0.01	0.01	0.02	0.01	0.01	0	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
21	0	0.01	0	0	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0.01	0.01	0.01	0	0.01	0.02	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
23	0	0	0	0	0.02	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
24	0	0	0.01	0.02	0.01	0	0.01	0.02	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table B.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0.01	0	0	0	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0.01	0	0	0	0.01	0	0.01	0	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0.01	0	0.01	0.01	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0.01	0	0	0	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
31	0	0	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
32	0.01	0.01	0.01	0	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
33	0	0	0	0	0.01	0.01	0.01	0.01	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
34	0	0	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
35	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
36	0	0	0	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
39	0	0.01	0.01	0.02	0.01	0.01	0	0	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0	0	0.01	0	0.02	0.01	0	0.01	0	0	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0.01	0	0.01	0.01	0.01	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
42	0	0	0	0	0.01	0	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
43	0	0	0	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
44	0	0	0	0.01	0	0	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
45	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
46	0	0	0.01	0.06	0.07	0.05	0.05	0.06	0.07	0.06	0.07	0.05	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
47	0	0	0	0.04	0.04	0.05	0.02	0.02	0.05	0.04	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
48	0	0	0	0.02	0.02	0.03	0.02	0.03	0.04	0.02	0.03	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table B.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
49	0.01	0	0	0	0	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0	0	0	0	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
51	0	0	0	0	0.01	0.03	0.03	0.02	0.01	0.01	0.03	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
52	0	0	0	0	0	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
53	0	0	0	0	0	0	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
54	0	0	0	0	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
55	0	0	0	0	0	0	0.01	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
56	0	0	0	0	0	0.01	0	0.01	0.01	0.02	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
57	0.01	0.01	0	0	0	0	0	0.01	0.01	0.02	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
58	0.01	0.01	0	0	0	0	0	0	0.01	0.01	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
59	0.03	0.01	0	0	0	0	0	0	0	0.02	0.02	0.01	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
60	0.05	0.01	0	0	0	0	0	0	0	0.01	0.02	0.03	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
61	0.03	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.04	0.05	0.03	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
62	0.02	0.03	0.02	0.01	0.01	0	0	0	0	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
63	0.04	0.02	0.02	0.01	0	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0	0	0	0	0	0	0
64	0.02	0.06	0.01	0.01	0.01	0	0	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
65	0.05	0.04	0.02	0.01	0.01	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
66	0.05	0.04	0.02	0.02	0.01	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
67	0.04	0.03	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0.46	0.43	0.35	0.24	0.15	0.09	0.06	0.07	0.04	0.02	0.02	0.01	0.02	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
69	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C: Soak Distribution Results for Weekends using the GPS Data

Table C.1: Soak Distribution Results for Weekends using the GPS Data

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0.17	0	0.15	0	0.09	0.06	0.14	0.08	0.04	0.12	0.09	0.11	0.06	0.1	0	0.11	0	0	0	0	0	0
2	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0.06	0.05	0.06	0	0.11	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0.02	0	0.05	0	0	0	0.03	0	0.06	0	0	0.11	0	0	0	0	0	0
4	0	0	0	0	0	0	0.05	0	0	0	0.04	0	0.03	0	0	0	0.11	0	0	0	0	0	0	0
5	0	0	0	0	0	0.04	0	0.03	0.05	0	0.04	0	0	0.05	0.11	0	0	0	0	0	0	0	0	0
6	0	0	0.17	0	0	0.04	0.02	0	0	0.04	0.04	0.03	0.03	0	0	0.05	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.09	0	0	0.05	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0.06	0	0.08	0	0	0.03	0	0	0	0.11	0	0	0	0	0	0	0
9	0	0	0	0	0.04	0.04	0	0.03	0.05	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0.04	0	0.02	0	0	0	0.08	0.06	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0.05	0.06	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0.04	0.03	0.03	0	0	0.1	0.11	0	0	0	0	0	0	0
13	0	0	0	0	0	0.04	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0.02	0	0	0	0.04	0	0	0	0	0	0.11	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0.04	0	0	0	0.04	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0.02	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0.09	0.04	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0.04	0.03	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0.02	0.03	0	0.04	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0

Table C.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0.05	0	0.04	0.09	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0.02	0	0.05	0.04	0	0.03	0.03	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0.11	0	0	0	0	0	0	0
33	0	0	0	0	0.04	0	0.02	0.03	0	0	0	0	0.03	0.05	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0.17	0	0	0.04	0	0.03	0	0	0	0	0	0.05	0	0.05	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0.03	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0.05	0	0	0.03	0	0.05	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0.02	0	0.05	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0.06	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.04	0	0	0	0	0.04	0	0	0	0	0.05	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0.04	0.02	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0.02	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0.04	0.04	0.09	0.09	0.14	0.08	0.08	0.12	0.12	0	0.06	0.05	0.11	0.11	0	0	0	0	0	0
47	0	0	0	0	0.04	0.04	0.09	0	0.05	0	0.04	0	0.03	0.11	0	0.05	0	0.11	0.5	0	0	0	0	0
48	0	0	0	0	0	0	0.05	0.03	0	0	0	0.09	0	0	0.11	0.05	0	0	0	0	0.25	0	0	0

Table C.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
49	0	0	0	0	0	0	0.02	0	0	0.08	0.04	0.03	0	0	0.06	0.05	0	0.11	0	0	0	0	0	0
50	0	0	0	0	0	0	0.02	0.03	0.05	0.04	0.08	0.03	0.09	0	0	0.05	0	0.11	0	0	0	0	0	0
51	0	0	0	0	0	0	0.05	0	0	0.04	0	0.06	0	0.16	0	0	0.11	0.11	0	0	0.5	0	0	0
52	0	0	0	0	0	0	0	0.03	0.05	0.12	0.04	0.03	0.06	0	0	0.05	0	0.11	0	0	0	0	0	0
53	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0.05	0.06	0.05	0	0	0	1	0	0	0	0
54	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0.11	0	0.05	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0.05	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.05	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0.11	0	0	0	0	0	0	0
62	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
63	0	0.25	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	1	0.75	0.5	0.64	0.48	0.43	0.19	0.33	0.09	0.16	0.15	0.12	0.06	0.05	0.11	0.05	0	0	0.5	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix D: Soak Distribution Default Inputs for Weekends

Table D.1: Soak Distribution Default Inputs for Weekends

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0.11	0.03	0.03	0.02	0.05	0.03	0.06	0.04	0.06	0.06	0.04	0.02	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2	0.06	0.08	0.02	0.06	0.05	0.02	0.06	0.06	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
3	0.17	0.05	0.03	0.06	0.05	0.05	0.04	0.04	0.03	0.06	0.04	0.05	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
4	0.06	0	0.07	0.01	0.04	0.03	0.04	0.04	0.05	0.03	0.04	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
5	0	0.03	0.03	0.06	0.02	0.04	0.04	0.01	0.02	0.03	0.04	0.02	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
6	0.06	0	0.02	0	0.04	0.01	0.03	0.03	0.01	0.02	0.03	0.02	0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
7	0	0.05	0.02	0.01	0.01	0.02	0.05	0.02	0.03	0.01	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
8	0	0	0.02	0.02	0.03	0.02	0.04	0.01	0.03	0.04	0.03	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0.03	0.01	0.02	0.03	0.02	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0	0	0	0.01	0	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11	0	0	0	0.01	0	0.01	0.04	0.03	0	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
12	0	0	0	0.02	0.01	0.03	0.02	0.01	0.01	0	0.01	0	0.03	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0.01	0.01	0.01	0	0.03	0.01	0.01	0.02	0.01	0	0	0	0	0	0	0	0	0	0	0	0
14	0.06	0	0	0.01	0.02	0.01	0.02	0	0	0	0.01	0.05	0.01	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0.01	0	0.02	0.01	0.02	0	0	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0.02	0	0	0.01	0.01	0.01	0.02	0	0.01	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
17	0	0	0.02	0.02	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.03	0.02	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
19	0	0	0.02	0.01	0	0.01	0.01	0.01	0.03	0	0.03	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0.01	0.01	0	0.01	0.01	0	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
22	0	0	0	0.02	0	0.01	0.01	0.01	0	0	0.01	0.03	0.02	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0.02	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0.01	0	0	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table D.1 (Continued)

	Hour of the Day																						
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0.03	0	0	0.01	0.02	0	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0.01	0	0.01	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0.01	0	0.01	0.01	0.01	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0	0	0	0	0.01	0.03	0.01	0.01	0	0	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0.01	0.02	0.04	0	0	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
32	0	0	0.02	0	0.04	0	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0.01	0.03	0.01	0	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0.02	0.03	0.01	0.01	0	0	0.01	0.04	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
36	0	0	0.02	0	0	0.01	0	0.01	0.02	0.02	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0.02	0.01	0	0.01	0	0.02	0.03	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0.01	0	0	0.02	0.01	0.01	0.01	0.03	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0.02	0	0	0.02	0	0.01	0.01	0.03	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0	0	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0.02	0.01	0	0.01	0.02	0.01	0	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
42	0	0	0	0	0.01	0.01	0.02	0.01	0	0.01	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0.01	0	0.01	0	0.02	0.01	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0.02	0.01	0	0	0.01	0	0.01	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0.01	0.01	0.01	0.01	0.01	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0.03	0.03	0.04	0.09	0.04	0.06	0.08	0.04	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
47	0	0	0	0.02	0.01	0.02	0.04	0.05	0.05	0.05	0.04	0.07	0.12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
48	0	0	0	0.01	0.01	0.03	0.03	0.01	0.04	0.04	0.03	0.03	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table D.1 (Continued)

	Hour of the Day																							
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
49	0	0	0	0	0.02	0	0.03	0.03	0.02	0.03	0.06	0.03	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
50	0	0	0	0	0	0.01	0.01	0.02	0	0.01	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0	0	0	0.02	0	0.01	0.01	0.01	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
52	0	0	0	0	0.01	0	0	0.01	0	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
53	0	0.03	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
54	0	0.03	0	0	0	0.01	0.01	0.01	0.01	0	0.01	0.05	0.01	0	0	0	0	0	0	0	0	0	0	0
55	0.06	0	0	0	0	0	0	0.01	0	0	0	0.03	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
56	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
57	0	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
58	0.06	0.03	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0.03	0	0.01	0	0	0	0	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.06	0.03	0	0.01	0.01	0	0.01	0	0.01	0.01	0.01	0	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
61	0.06	0.05	0.02	0.02	0.01	0	0	0	0	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0.05	0.02	0.01	0.01	0.01	0	0.01	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
63	0	0.03	0.02	0.01	0.01	0.01	0	0	0	0	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
64	0	0	0.02	0.03	0.01	0.01	0.01	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
65	0	0.05	0.03	0	0	0.01	0	0	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0.03	0.03	0.01	0.01	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0.22	0.42	0.34	0.28	0.26	0.2	0.14	0.13	0.1	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0.05	0	0.04	0	0.03	0.02	0.01	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix E: Hot Soak GPS Results for weekdays

Table E.1: Hot Soak Results for Weekdays using the GPS Data

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2	0.03	0.06	0.06	0.04	0.03	0.07	0.09	0.01	0.08	0.06	0.00	0.09	0.04	0.05
3	0.02	0.04	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.05	0.05	0.03
4	0.01	0.03	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.04	0.04	0.02
5	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.03	0.03	0.02
6	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01
7	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01
8	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
9	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
10	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
11	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
12	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
14	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
15	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
16	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
17	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
18	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
19	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
20	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
21	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
22	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
23	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
24	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
25	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
26	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
27	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
28	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
29	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table E.1 (Continued)

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.74	0.59	0.58	0.46	0.38	0.34	0.32	0.37	0.37	0.37	0.62	0.46	0.52	0.70

Appendix F: Hot Soak Default Values for weekdays

Table F.1: Hot Soak Distribution Default Inputs for Weekdays

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2	0.03	0.06	0.06	0.04	0.03	0.07	0.09	0.01	0.08	0.06	0.00	0.09	0.04	0.05
3	0.02	0.04	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.05	0.05	0.03
4	0.01	0.03	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.04	0.04	0.02
5	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.03	0.03	0.02
6	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01
7	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01
8	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
9	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
10	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
11	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
12	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
14	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
15	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
16	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
17	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
18	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
19	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
20	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
21	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
22	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
23	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
24	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
25	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
26	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
27	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
28	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
29	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table F.1 (Continued)

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.74	0.59	0.58	0.46	0.38	0.34	0.32	0.37	0.37	0.37	0.62	0.46	0.52	0.70

Appendix G: Hot Soak GPS Results for weekdays

Table G.1: Hot Soak Results for Weekends using the GPS Data

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.06	0.04
2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.05	0.00	0.00	0.00	0.03	0.03
3	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.04	0.00	0.03	0.01
4	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.05	0.00	0.04	0.00	0.00	0.03
5	0.00	0.00	0.20	0.00	0.00	0.04	0.03	0.00	0.00	0.04	0.04	0.03	0.03	0.03
6	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.05	0.00	0.04	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.09	0.00	0.00	0.03	0.01
8	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.01
9	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.00	0.00	0.00	0.08	0.07	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.03	0.03
12	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.04	0.00	0.00	0.01
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
18	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.04	0.08	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.09	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.04	0.00	0.03	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.04	0.10	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
30	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.05	0.04	0.00	0.03	0.03	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
34	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01
35	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
41	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01

Table G.1 (Continued)

	Hour of the Day													
Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.03	0.00	0.01
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01
56	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
58	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	1.00	1.00	0.60	0.91	0.78	0.52	0.59	0.55	0.53	0.61	0.44	0.53	0.48	0.62

Vita

Srinivas Varanasi was born in a small town near Visakhapatnam, India, in 1979. He received his Bachelor of Engineering for Civil Engineering from Andhra University, India, in 2001. He joined the graduate program in Civil Engineering at Louisiana State University in August 2001. He expects to receive the degree of Master of Science in Civil Engineering in December 2003.