FINAL REPORT

Vehicle Activity and Personal Travel Inputs to Emission Models

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George Mason University
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Vehicle Activity and Personal Travel Inputs to Emission Models

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List of Acronyms

EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
SIP	State Implementation Plan
EMFAC	Emission Factor Model
CAA	Clean Air Act
NAAQS	National Ambient Air Quality Standards
LRP	Long Range Plans
TIP	Transportation Improvement Programs
I/M	Inspection and Maintenance
RFG	Reformulated Gasoline
RVP	Reid Vapor Pressure
NGV	Natural Gas Vehicle
LDGV	Light Duty Gasoline Vehicle
LDGT	Light Duty Gasoline Truck
MSA	Metropolitan Statistical Area
VMT	Vehicle Miles of Travel
NPTS	Nationwide Personal Transportation Survey
ATS	American Travel Survey
VOC	Volatile Organic Compound
CO	Carbon Monoxide
NOx	Nitrogen Oxide

Research Background

The research presented in this report was performed at George Mason University with a small grant from the Federal Highway Administration (FHWA) Office of Planning, Environment and Real Estate Services. The George Mason University research team produced the following three products for this research project:

1. A report titled "Vehicle Activity and Personal Travel Inputs to Emission Models." (this document) In this report a methodology for deriving vehicle activity parameters from the travel survey databases is discussed.
2. TRIMM, which is a Microsoft Windows based software application that mines data from the reduced versions of 1990 and 1995 NPTS data and 2000 NHTS data
3. A manual for using TRIMM as well as providing proper guidance to the users.

More information about obtaining these documents may be found at:

http://mason.gmu.edu/~mvenigal/TRIMM

Acknowledgments

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Executive Summary

The primary use of the MOBILE model is for developing on-road mobile source emission inventories for use in air quality planning. The emission rates generated by MOBILE require a multitude of input variables. Version 6 of MOBILE (MOBILE6) includes default values for most of these input variables. Users who desire a precise estimate of local emissions can substitute information that more specifically reflects local conditions. Travel surveys in general and Nationwide Personal Transportation Survey (NPTS) data in particular have been determined as promising sources for deriving these locality specific variables [*5*]. This research deals with the reduction, analysis and derivation of personal travel variables from the NPTS databases for use as inputs to MOBILE6.

State of the practice in emission factor modeling relies too much on default parameters imbedded in the model. Therefore there is a need for deriving these inputs for the various geographic regions for providing realistic values. Moreover, the national input data differ among specific localities and regions of the country. Hence, the resulting MOBILE6 default emissions will not necessarily represent the mobile source emissions for a specific locality. The input options in MOBILE6 create significant new information burden on states, preparing submissions for SIP and transportation conformity purposes. Hence developing accurate travel related input data for air quality models like MOBILE6

has always been a major challenge for the transportation planners involved in air quality modeling.

The office of Planning, Environment and Realty (HEP) of Federal Highways Administration (FHWA) has teamed up with the Civil, Environmental and Infrastructure Engineering Department of George Mason University in addressing the issues related to certain hard to obtain vehicle activity and travel activity inputs to MOBILE6. FHWA sponsored this research study under the Transportation and Environmental Research Program (TERP). The office of Dean, School of Information Technology and Engineering (IT&E) at George Mason University shared 28% of the expenditures.

Research Objectives

The primary goal of this research is to derive location specific travel variable inputs to MOBILE6 and conduct a sensitivity analysis of MOBILE6 in relation to the derived travel variable inputs. Specific objectives are to:

- Study and analyze the applicability of NPTS data for use in emission modeling.
- Derive the location specific travel variable inputs required for MOBILE6 from these data.
- Compare the MOBILE6 default inputs to the parameters derived from the NPTS data
- Conduct a sensitivity analysis of MOBILE6 by replacing the default variables with the values derived from the NPTS data.

- Compare and contrast the emission factors derived with the default emission factors.

Input Requirements of Emission Factor Models

On-road mobile source emission factor models require a multitude of input requirements such us the travel activity data, vehicle data etc., and can report the emission factors for various pollutants such as carbon monoxide, volatile organic compounds, particulate matter etc.

The primary use of the MOBILE model is for developing on-road mobile source emission inventories for use in air quality planning. The EMission FACtor (EMFAC) model is used in California to calculate the emission rates from all on road motor vehicles. The emission rates generated by MOBILE6 require a multitude of input variables. MOBILE6 includes default values for most of these input variables.

The input requirements for MOBILE6 can be broadly classified into 5 categories: external conditions; vehicle fleet characteristics; state programs; fuel program and vehicle activity parameters. As a case study, this research focuses on vehicle activity related inputs to MOBILE6 as well as the sensitivity of the model to these inputs. Included among the vehicle activity data needs for MOBILE 6 are the following:

- Distribution of vehicle miles traveled by vehicle class
- Vehicle Miles of Travel (VMT) distribution by hour
- Starts per day distribution by vehicle class and vehicle age
- Engine starts per day and their distribution by hour of the day.
- Average trip length distribution
- Engine start soak time distribution by hour (cold soak distribution)

- Hot soak duration

Keeping these input requirements and other considerations in view, earlier research studies have determined that the NPTS data offers considerable promise in deriving the locality specific input variables to MOBILE6. The 1990 and 1995 NPTS data and 2000 NHTS data were analyzed for achieving the study objectives.

The combination of each unique household identification number and vehicle identification number in NPTS/NHTS data is flagged as a new trip chain. These trip chains were used to compute the cold soak and hot soak times that require the end times of the previous trip and the trip start times of the next trip respectively by the household vehicle. Several challenges faced in processing the NPTS data are explained in detail in the main body of the report.

NPTS Derived Inputs vs. MOBILE 6 Default Inputs

The NPTS/NHTS data were analyzed to derive the following vehicle and travel activity inputs for MOBILE6.

- Start Distribution
- Cold Soak Activity
- Hot Soak Activity
- VMT by hour of the day
- Vehicle Type Classification
- Vehicle Age Classification

In order to visualize the trends in variation of start distribution by hour of day, starts as a percentage of daily vehicle starts for all of United States (Nationwide), Washington D.C and MOBILE6 default are plotted in the following figure for a weekday. The percent starts from NPTS data for Nationwide and Washington D.C. is estimated to be higher than the MOBILE6 default during the morning peak hour.

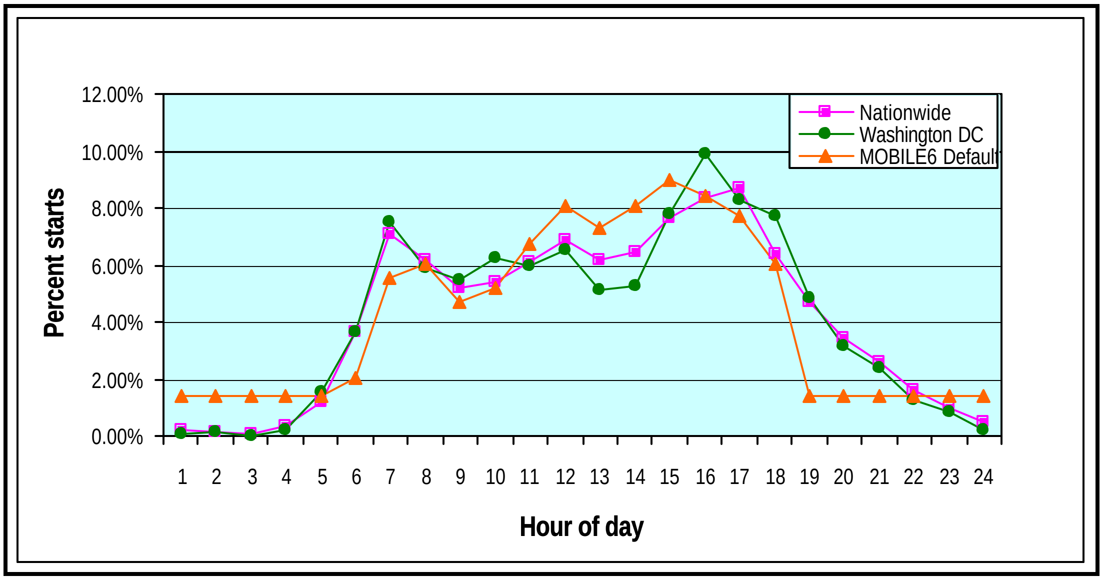


Figure E.1
Weekday Starts Distribution by Hour of Day

A plot of the MOBILE6 default, Nationwide and Washington D.C. MSA from NPTS data is shown in Figure E.2. It can be observed that the VMT fractions derived from NPTS are slightly lower than the default fractions during the morning hours and high during the afternoon and evening hours.

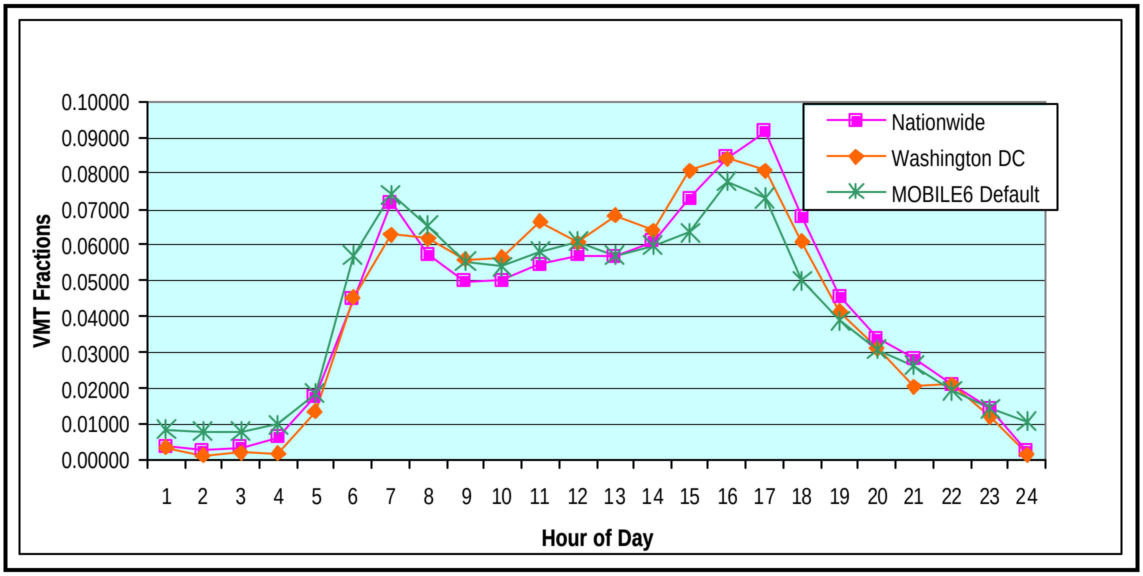


Figure E.2
VMT Distribution by Hour of Day

Tables E.1 shows the weekday trip length distribution input from 1995 NPTS data for all of the United States. The first row in each table shows the MOBILE6 default values. The default values are the same for weekday and weekend trip length distributions and for each of the 14 hourly groups. It is observed that the percent VMT in an 11 to 20 minute trip length is much higher than the default values.

Table E.1
Nationwide Weekday Trip Length Distribution from 1995 NPTS

	Trip Length (minutes)						
Hourly Group		Less than 10 min	11 to 20 min	21 to 30 min	31 to 40 min	41 to 50 min	51 or more min
	Default	**6.74%**	**18.51%**	**16.78%**	**13.11%**	**8.33%**	**36.53%**
	6-7AM	6.71%	17.06%	18.60%	12.53%	12.25%	32.85%
	7-8AM	11.02%	23.29%	20.90%	10.82%	9.84%	24.13%
	8-9AM	15.71%	24.54%	17.40%	8.70%	7.32%	26.33%
	9-10AM	18.08%	24.92%	15.35%	6.54%	6.80%	28.31%
	10-11AM	19.48%	24.12%	14.29%	6.36%	5.10%	30.65%
	11-12N	22.54%	26.35%	16.77%	6.34%	5.69%	22.31%
	12-1PM	24.12%	25.64%	13.50%	5.99%	5.72%	25.03%
	1-2PM	20.56%	25.56%	16.22%	7.18%	6.42%	24.06%
	2-3PM	17.73%	25.61%	17.82%	7.49%	7.35%	24.00%
	3-4PM	15.90%	25.40%	17.54%	8.50%	8.52%	24.14%
	4-5PM	13.46%	22.17%	18.46%	9.62%	8.65%	27.64%
	5-6PM	13.67%	23.71%	19.00%	9.63%	10.09%	23.90%
	6-7PM	17.44%	27.13%	18.47%	8.60%	8.60%	19.76%
	7-8PM+	15.35%	25.12%	18.01%	8.47%	8.66%	24.39%
	MOBILE 6 Default values are the same for all the 14 hourly groups for each of the trip lengths						

Starts per day are derived from NPTS data as a fraction of the *total vehicle trips* by each of the three vehicle classes for individual vehicle age groups to the *total number of vehicles* in each vehicle class and vehicle age. Table E.2 shows the starts distribution for a weekday from 1995 NPTS data. There is a lot of variation in the default values and the NPTS derived values for the starts per day variable. The starts per day are underestimated by nearly 50%. MOBILE6 uses 7.28 starts per day for LDGV and 8.06 starts per day for LDGT1 and LDGT2 for a weekday. The same default value is used for vehicles of all ages within a vehicle class.

Table E. 2
Starts per day distribution for a weekday (1995 NPTS)

Vehicle Starts Per Day			
Vehicle Age	LDGV	LDGT1	LDGT2
MOBILE6 Default	**7.28**	**8.06**	**8.06**
1	3.50	4.25	6.00
2	4.25	4.03	5.03
3	4.37	4.13	4.50
4	4.41	3.92	4.63
5	4.45	3.93	4.90
6	4.46	4.19	4.60
7	4.38	4.05	4.52
8	4.34	3.76	4.76
9	4.24	3.76	4.45
10	4.20	4.00	4.10
11	4.19	3.80	4.29
12	4.21	3.90	4.21
13	4.12	3.71	4.14
14	4.05	3.61	3.97
15	4.13	3.71	3.96
16	3.92	3.55	3.97
17	3.85	3.74	4.52
18	4.04	3.85	4.86
19	3.81	3.26	4.02
20	3.75	3.69	4.06
21	3.92	3.69	3.75
22	3.66	3.46	3.50
23	4.65	3.53	2.80
24	3.33	4.44	3.60
>=25yrs	3.69	3.60	3.52

Sensitivity Analysis of MOBILE6

MOBILE6 reports emission rates in grams or milligrams of pollutant per vehicle mile traveled (g/mi or mg/mi). Emission rates from MOBILE6 can be combined with estimates of travel activity (total vehicle miles traveled, or VMT), which also change over time, to develop highway vehicle emission inventories expressed in terms of tons per hour, day, month, season, or year. Based on the MOBILE6 guidance, the default variables were replaced by various travel inputs derived from NPTS data. Various combinations of these variables were given to MOBILE6 and the sensitivity of MOBILE6 to these travel activity inputs was observed. During the sensitivity analysis, input parameters other than those being tested, were based on EPA national default.

Table E.3 shows a comparison among the default emission factors, emission factors obtained by changing VMT, starts distribution, cold soak and hot soak distribution (set 1) and the emission factors obtained by changing all the travel variables (set 2) derived from NPTS data. It can be seen that the start emissions are affected mostly. The CO start emissions are increased by nearly 25% for LDGT2 (set 1). The NOx start emissions are affected mostly (42% decrease for LDGV) by changing all the derived travel activity inputs. This decrease in the emissions is mainly due to the starts per day variable (nearly 50% less than the default). Table E.4 shows the emission factors obtained by changing only the starts per day variable. It is observed that the start emissions are effected mostly and the running emissions are not effected which is obvious since the “starts per day” input is varied. The percent changes are indicated in the table and the negative sign indicates a decrease in the emission factors.

Figure E.3 shows the change in emission factors by varying the cold soak, hot soak, VMT and starts distribution inputs. The start emissions and composite emissions are affected mostly and there is a very minor change in the running emissions.

Table E.3
A summary of the emission factors (g/mi) obtained by replacing the MOBILE6 defaults with NPTS derived inputs

Pollutant Type	LDGV			LDGT1			LDGT2		
	MOBILE6 Default	Set 1	Set 2	MOBILE6 Default	Set 1	Set 2	MOBILE6 Default	Set 1	Set 2
Composite VOC	0.928	1.005	0.820	0.937	1.029	0.782	1.192	1.304	1.036
Composite CO	10.47	11.52	9.91	12.03	13.48	10.57	15.98	17.83	14.62
Composite NOX	0.734	0.775	0.694	0.682	0.721	0.618	1.054	1.108	0.988
VOC Start	0.204	0.274	0.152	0.266	0.351	0.164	0.319	0.423	0.215
VOC Running	0.204	0.206	0.206	0.242	0.244	0.244	0.362	0.365	0.365
VOC Total	0.408	0.480	0.358	0.508	0.596	0.408	0.681	0.788	0.580
CO Start	2.75	3.69	2.08	4.14	5.52	2.62	5.21	6.97	3.76
CO running	7.71	7.83	7.83	7.89	7.95	7.95	10.77	10.87	10.87
CO total	10.47	11.52	9.91	12.03	13.48	10.57	15.98	17.83	14.62
NOX Start	0.148	0.186	0.104	0.156	0.194	0.091	0.207	0.259	0.138
NOX Running	0.586	0.589	0.589	0.526	0.527	0.527	0.847	0.85	0.850
NOX Total	0.734	0.775	0.694	0.682	0.721	0.618	1.054	1.108	0.988
HOT Soak Loss	0.144	0.144	0.080	0.110	0.110	0.051	0.123	0.123	0.063
Running Loss	0.214	0.220	0.220	0.161	0.165	0.165	0.196	0.201	0.201
Set 1 : Emission factors obtained by replacing VMT ,starts distribution, cold and soak and hot soak distributions									
Set 2 : Emission factors obtained by replacing all the derived travel activity inputs									

Table E.4
Comparison of Emission Factors for LDGV by Replacing the Starts per Day Input

Emissions	Default	NPTS	% Change
Composite VOC	0.928	0.774	-20%
Composite CO	10.47	9.26	-13%
Composite NOX	0.734	0.669	-10%
VOC Start	0.204	0.113	-81%
VOC Running	0.204	0.204	-0%
VOC Total	0.408	0.317	-29%
CO Start	2.75	1.55	-77%
CO running	7.71	7.71	-0%
CO total	10.47	9.26	-13%
NOX Start	0.148	0.083	-78%
NOX Running	0.586	0.586	-0%
NOX Total	0.734	0.669	-10%
HOT Soak Loss	0.144	0.080	-80%
Running Loss	0.214	0.214	-0%

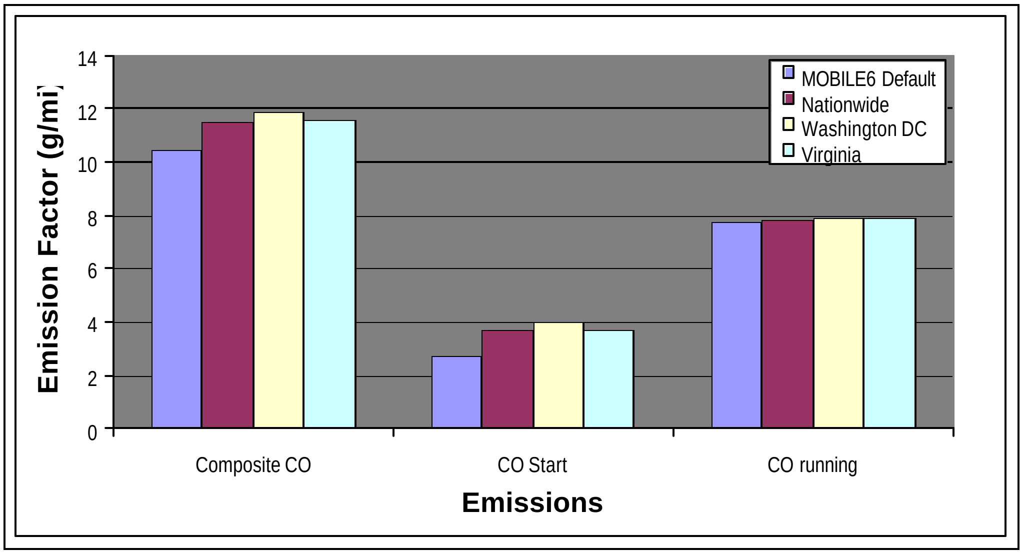


Figure E.3
Variation of CO Emission Factors by changing Cold Soak, Hot Soak, Start Distribution and VMT Inputs

Conclusions

NPTS data has been studied and analyzed thoroughly to derive the travel variables that are required as inputs to MOBILE6. A thorough examination of the relationship between MOBILE6 input parameters and the relative importance of these parameters in deriving the emission factors have been studied. Each parameter evaluated was varied and the resulting MOBILE6 emissions were compared to emissions determined with default inputs. The following conclusions were drawn based on the observations.

1. Several of the travel related variables could be derived using typical travel survey data. NPTS data offers great promise in this respect.

2. Travel variable inputs vary significantly from MOBILE6 defaults, which are most popularly used for getting the locality specific emission factors.
3. MOBILE6 has been found to be sensitive to these inputs, which makes it a worthwhile effort to derive the input variables from NPTS or other survey data.
4. Care must be taken to use the inputs derived from travel survey data, as there are several data gaps that can be adjusted for by following the suggested recommendations.

Recommendations

1. Local survey data when available in large sample size is preferred to NPTS data to derive the locality specific variables.
2. Analysis must be based on the latest NPTS data (if NPTS must be used)
3. Certain degree of data analysis background is needed to mine survey databases for use in deriving MOBILE6 inputs and hence NPTS data has been found to be ideal for deriving an automated data-mining tool to shield regular MOBILE6 users from the complexities of the analysis of the travel variables. Also, the tool will ensure certain degree of uniformity in practice across the nation.

Development of Travel Related Inputs Model for MOBILE6 (TRIMM)

Taking above recommendations in to consideration, a database mining tool called *Travel* Related Inputs Model for MOBILE6 (TRIMM) was developed. The details of TRIMM and a brief user manual is presented in Appendix B of this report.

1. Introduction

1.1 Background

Vehicle emissions include substances such as carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOC's) that degrade air quality, thereby threatening public health and the environment. It has been estimated that approximately one third of the total US anthropogenic emissions of carbon dioxide come from the transportation sector [*1*]. About one quarter of the total emissions are from light duty vehicles and heavy-duty vehicles [*2*]. The Environmental Protection Agency (EPA) tracks trends associated with these pollutants, and provides national emissions estimate by pollutant and source. The Federal Highway Administration (FHWA) uses this data to supply the performance indicators required to measure the reduction of on-road mobile source emissions.

Air quality modeling is used for determining and visualizing the significance and impact of these emissions to the atmosphere. Air quality modeling is especially useful for policy-makers whose decisions are often based on emission measurements. The pollutants of interest for air quality studies are primary pollutants that are directly emitted into the atmosphere like carbon monoxide (CO), sulfur dioxide (SO_2) and secondary pollutants like surface level ozone (O_3). Ozone is formed by the reaction of volatile organic compounds (VOC's) and nitrogen oxides (NO_x) in the presence of sunlight. In urban areas motor vehicles are the primary sources of volatile organic compounds, carbon monoxide and nitrogen oxides.

In 2000, on-road transportation sources accounted for 42 percent of carbon monoxide (CO) emissions, 32 percent of nitrogen oxides (NO_x) emissions, 25 percent of volatile organic compounds (VOC) emissions, and one percent of particulate matter (PM-10) emissions [3]. Control of these pollutants is critical for reducing their impacts on public health and the environment. Air quality studies require accurate information on the emissions of these pollutants with high spatial and temporal resolution so that the causes of air pollution can be better understood and effective plans can be developed for future air quality improvement.

The EPA develops and supports regulatory emission models such as the MOBILE model, which can be used in the development of State Implementation Plans (SIPs) and the transportation conformity process [*4*]. Regional emission inventory studies employ these regulatory models to obtain emission factors (e.g. grams of CO for one mile traveled). These emission factors are combined with transportation variables (e.g. vehicle miles of travel) to derive the total emissions under different conditions. This combination determines the contribution of emissions from mobile sources in a city, county or state. Vehicle data, travel activity, fleet mix and various other parameters are required as inputs to these models.

1.2 Problem Statement

The primary use of the MOBILE model is for developing on-road mobile source emission inventories for use in air quality planning. The emission rates generated by MOBILE require a multitude of input variables. Version 6 of MOBILE (MOBILE6) includes default values for most of these input variables. Users who desire a precise estimate of local emissions can substitute information that more specifically reflects local conditions. Travel surveys in general and Nationwide Personal Transportation Survey (NPTS) data in particular have been determined as promising sources for deriving these locality specific variables [*5*]. This research deals with the reduction, analysis and derivation of personal travel variables from the NPTS databases for use as inputs to MOBILE6.

1.3 Research Need

State of the practice in emission factor modeling relies too much on default parameters imbedded in the model. Therefore there is a need for deriving these inputs for the various geographic regions for providing realistic values. Moreover, the national input data differ among specific localities and regions of the country. Hence, the resulting MOBILE6 default emissions will not necessarily represent the mobile source emissions for a specific locality. The input options in MOBILE6 create significant new information burden on states, preparing submissions for SIP and transportation conformity purposes. Hence developing accurate travel related input data for air quality models like MOBILE6 has always been a major challenge for the transportation planners involved in air quality modeling.

Though some EPA technical documents [*6, 7, 8, 9*] address MOBILE6 input needs, they mainly address the input formats and the manner in which these variables are used internally in the model. Though they indicate what type of data are appropriate for use within MOBILE6, they do not go far enough to address the methods to derive these data for many input parameters.

Travel activity input parameters may be derived at local, regional and national level from the available transportation data sources, most notably travel survey data. The research addresses the methods to derive various travel activity inputs to MOBILE6 from travel survey data and conduct the sensitivity analysis of MOBILE6 by replacing the default values with locality specific values.

Nair, et al. [10, 11] used the local household travel survey data and developed empirical relationships for deriving soak period inputs and trip duration inputs for the Dulles-Fort Worth area. However these empirical models are not flexible and the data processing required special analytical skills. Venigalla et al. [4, 5] used the 1990 and 1995 Nationwide Personal Transportation Survey Data (NPTS) to derive start modes for MOBILE5x and soak period inputs to MOBILE6. However, there are a host of other vehicle activity inputs that can be derived from travel surveys, which are not addressed in the available literature. This research presents methods for deriving a number of such travel activity inputs from NPTS data.

1.4 Research Objectives

The primary objective of this research is to derive location specific travel variable inputs to MOBILE6 and conduct a sensitivity analysis of MOBILE6 in relation to the derived travel variable inputs. Specific objectives are to:

Study and analyze the applicability of NPTS data for use in emission modeling.

- Derive the location specific travel variable inputs required for MOBILE6 from these data.
- Compare the MOBILE6 default inputs to the parameters derived from the NPTS data
- Conduct a sensitivity analysis of MOBILE6 by replacing the default variables with the values derived from the NPTS data.
- Compare and contrast the emission factors derived with the default emission factors.

1.5 Research Sponsorship

The office of Planning, Environment and Realty (HEP) of Federal Highways Administration (FHWA) has teamed up with the Civil, Environmental and Infrastructure Engineering Department of George Mason University in addressing the issues related to certain hard to obtain vehicle activity and travel activity inputs to MOBILE6. FHWA sponsored this research study under the Transportation and Environmental Research Program (TERP). The office of Dean, School of Information Technology and Engineering (IT&E) at George Mason University shared 28% of the expenditures.

2. State of the Practice

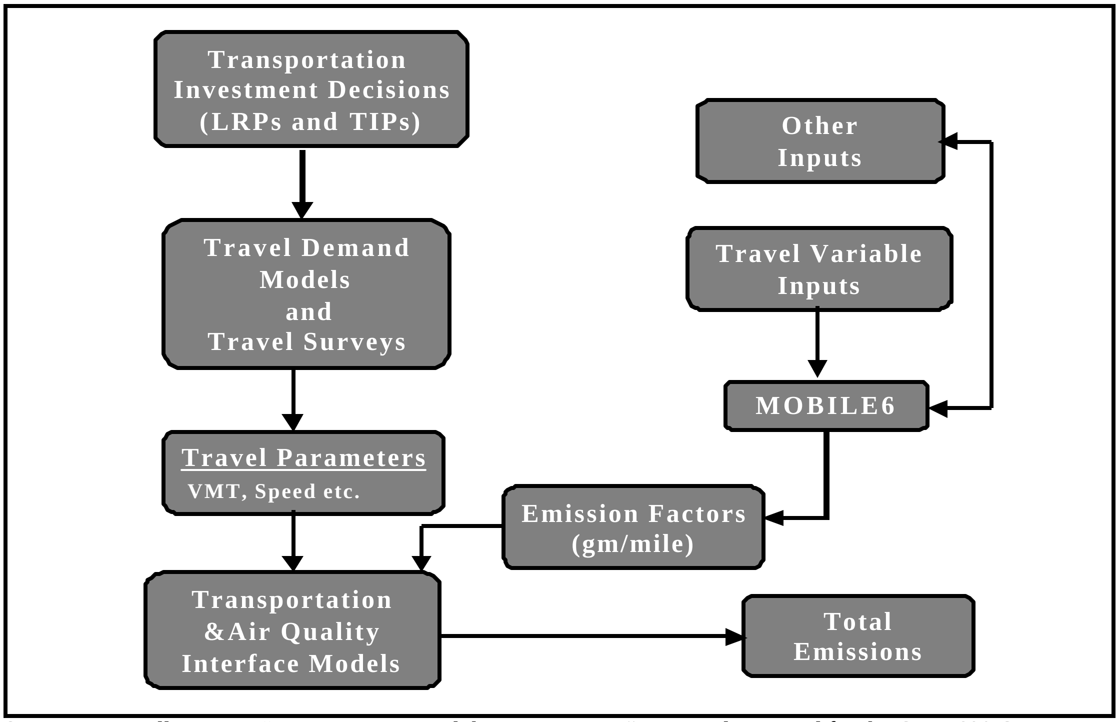
The Clean Air Act of 1970 (CAA) mandates that mobile source emission inventories be prepared as an integral part of State Implementation Plans (SIP). An SIP is a plan that contains procedures to monitor, control, maintain and enforce compliance with the National Ambient Air Quality Standards (NAAQS). Under the CAA, NAAQS serve as national target for the maximum concentration of a specific pollutant in the ambient air. To comply with the regulation of CAA, the Federal Highway Administration (FHWA) and Environmental Protection Agency (EPA) have established air quality requirements that impact transportation planning processes and traffic operations.

Air quality in all geographical regions of the country is classified as either in attainment or non-attainment. The EPA deems an area to be in attainment when the air quality is monitored and the resultant concentrations are found to be consistently below the NAAQS. The pollutants for which NAAQS have been established are known as criteria pollutants. EPA designates six pollutants as criteria pollutants. These include carbon monoxide, oxides of nitrogen, ground level ozone, fine particulate matter, sulfur dioxide, and airborne lead. Areas that have ambient criteria pollutant concentrations above the NAAQS are considered to be in non-attainment for those pollutants. Some areas are designated as "maintenance" areas. These are regions that were initially designated as non-attainment and have since attained compliance with the NAAQS [*8*].

Both transportation long range plans (LRPs) and transportation improvement programs (TIPs) must be analyzed in areas that do not or previously did not meet the air quality standards. This is to ensure that those plans and programs do not:

- Cause new air quality violations
- Worsen existing violations or
- Delay attainment of national air quality standards.

Desirable assessment of mobile source emissions is an essential of an effective air quality improvement program. An emission factor model plays a vital role in assessing the nature and magnitude of on-road motor vehicle emissions and their impact on ambient air quality. The MOBILE model is the primary tool used by most air quality planners at national, state and local levels to estimate on-road mobile source emissions and hence is a key to assessing associated environmental impacts. Figure 2.1 shows a schematic of modeling regional emissions [*12*]. It shows the procedure for analysis of the transportation investment decisions (LRP's and TIP's) using the MOBILE6 emission factor model before they are brought into effect.



Source: Venigalla, M.M., " Transportation and the Environment". Material Prepared for the CEIE 690 Course at George Mason University.

Figure 2.1
Regional Emissions: Modeling Schematic

2.1 A Brief History of MOBILE

The MOBILE model was first developed in 1978 and since has been revised seven times. Each revision included significant changes to input requirements, computational algorithms and/or outputs. Listed below is a brief history of the MOBILE model [*13*].

- MOBILE1 (1978) – Calculated HC, CO, and NOx for calendar years 1970 through 1999 for six vehicle types (Diesel cars and light trucks were not included).
- MOBILE2 (1981) – Updated with new data on emission-controlled vehicles at higher mileages.

- MOBILE3 (1984) – Updated with additional data. California emission rates were eliminated. Added tampering (rates and associated emissions impacts) and anti tampering program benefits.
- MOBILE4 (1989) – Significant changes to evaporation algorithms were made and running losses included for the first time. A higher deterioration rate for mileages above 50,000 was employed. Modeled fuel volatility (Reid Vapor Pressure, RVP) effects on exhaust emission rates.
- MOBILE4.1 (1991) – Impact of oxygenated gasoline was included. Evaporation-resting losses were added. Effects of Tier 1 and Cold CO standards were incorporated.
- MOBILE5 (1992) and MOBILE5a (1993) – Basic emission rates derived from IM240 data, impacts of new standards and Reformulated Gasoline (RFG) programs were incorporated. Included impact of oxygenated fuels on VOC emissions.
- MOBILE5b (1996) – Additional Inspection/Maintenance (I/M) options were incorporated.
- MOBILE6 (2001) – Latest in the MOBILE series. Calculates HC, CO and NOx emission factors for calendar years 1952 to 2051 for 28 vehicle types.

The emphasis of this research is on version 6 of the model - MOBILE6.

2.2 Overview of MOBILE6

MOBILE6 is a software tool that estimates current and future vehicle emissions under a host of different conditions. MOBILE6 is the approved US EPA motor vehicle emission factor model for estimating volatile organic compounds (VOC), nitrogen oxides (NOx) and carbon monoxide (CO) from different vehicles. State and local air quality and transportation agencies outside of California are required to use MOBILE6 in SIP development and transportation conformity determination [*14*]. The EMission FACtor (EMFAC) model is used in California to calculate the emission rates from all on road motor vehicles. MOBILE6 is based on substantial new test data and accounts for changes in vehicle technology and regulations. It incorporates many new features, including many new input and output options.

MOBILE6 can break down emissions by roadway type, time of day, vehicle category, and other categories that allow detailed modeling of local specific situations. MOBILE6 includes default values for a wide range of conditions that affect emissions. The EPA recommends that states use locality specific travel variables as inputs instead of the default values. Users may prefer to use the default values if the data for an input requirement are unavailable.

2.2.1 MOBILE6 Inputs

There are three types of MOBILE6 input files: command files, batch files, and external data files. All these three types of files must be in the form of ASCII DOS text files. Command input files are the method for users to specify what sorts of results are needed from MOBILE6. Many MOBILE6 commands require extensive user-supplied data that users must provide in separate files called "external" data files. All the below discusses input requirements are given in one of the following type of files.

The input requirements for MOBILE6 can be broadly classified into 5 categories [6].

- ✍ External Conditions
- ✍ Vehicle Fleet Characteristics
- ✍ State Programs
- ✍ Fuel Program
- ✍ Vehicle Activity

These inputs are explained in detail in the following sections.

2.2.1.1 External conditions

These are the conditions external to the highway vehicle fleet and transportation network, which influence the vehicle emissions. External condition commands allow users to specify the time frame, altitude, and weather conditions they wish to model. Options include:

- ✍ Calendar year
- ✍ Month of evaluation
- ✍ Altitude
- ✍ Temperature
- ✍ Humidity
- ✍ Other air-conditioning related input options

2.2.1.2 Vehicle fleet characteristics

MOBILE6 allows a new vehicle classification system, which reflects more accurately for emission standards than the previous versions. Fleet characteristic commands allow users to supply vehicle age, power source and activity level variables such as:

- Distribution of vehicle registrations
- Diesel fractions
- Annual mileage accumulation rates
- Natural Gas Vehicles (NGVs) fraction
- Alternate emission factors for Natural Gas Vehicles (NGVs)

2.2.1.3 State Programs

State program commands allow users to model the impact of state-specific emission control programs such as:

- Effects of fuel program on emissions
- Effects of stage II on refueling emissions
- Anti-tampering programs
- Inspection/Maintenance (I/M) programs

2.2.1.4 Fuel Program

Fuel commands allow users to model the impact of various gasoline fuel parameters including:

- Sulfur content of gasoline
- Sulfur content of diesel fuel
- Oxygenated fuels programs
- Fuel Reid Vapor Pressure (RVP)

- Effective season for RFG calculation

2.2.1.5 Vehicle Activity

The MOBILE6 model requires a wide variety of vehicle activity data as inputs. Included among the data needs are the following:

- Distribution of vehicle miles traveled by vehicle class
- Engine start soak time distribution by hour (cold soak distribution)
- Hot soak duration
- Engine starts per day and their distribution by hour of the day.
- Average trip length distribution
- Starts per day distribution by vehicle class and vehicle age
- Vehicle Miles of Travel (VMT) distribution by speed, hour and facility

Procedures for obtaining requirements, which are classified as external conditions, state and fuel programs mentioned above are pretty straightforward. Most of the research is on preparing inputs that are classified as vehicle activity requirements. A detailed description of each of the travel activity input is given in chapter 3.

2.2.2 Default Values for Travel Variables in MOBILE6

While preparing the default values for VMT, EPA used the data from travel demand models and traffic counts. Five different urban areas were selected, out of which results from three cities were obtained from travel demand models and those of the other two (Baltimore and Spokane) were obtained from traffic count data. Although all the aforementioned cities have different types of road networks and functional classes, EPA used these merged data to represent national default values. While preparing default values for mileage accumulation rates, EPA used data from travel behavior surveys. Specifically, for the Light Duty Gasoline Vehicle (LDGV) class, the 1992 Truck Inventory and Use Survey were used. For the Light Duty Gasoline Truck (LDGT) vehicle class the 1995 NPTS data was used.

2.2.3 Sensitivity Analysis of MOBILE6

In a sensitivity analysis conducted by the EPA [*14*], it was found that the amount of influence on all three pollutant emission rates (CO, NOx, VOC) from different inputs varied greatly in magnitude. These pollutant emission rates were found to be very sensitive to changes in travel behaviors such as vehicle miles travel by hour of the day, vehicle travel speeds and vehicle types. Among these parameters VMT by vehicle type exerted the most significant and sensitive affect on both NOx and CO emissions.

The term "sensitive" is used to describe the effect of various parameters on the emission factors. Understanding the behavior of the model under various conditions becomes more critical as the task of collecting local data is time and resources intensive. Through this sensitivity analysis users can understand the model's behavior and can prioritize costly data collecting efforts and ultimately initiate emission control strategies according to parameter sensitivity. During the sensitivity analysis input parameters other that those being tested were based on the EPA national default data. The least significant digit of the MOBILE6 emission factor output is the thousandth digit. When the emission factor is multiplied by vehicle miles traveled, which is typically in millions the thousandth digit of emission factor becomes very significant.

Miller et al. [*15*] studied and analyzed the heavy-duty vehicle characteristics and emissions in Tennessee and compared with the MOBILE6 national defaults. It was established that heavy-duty trucks contribute such a large proportion of the total mobile source emissions, especially NOx and hence it is important to characterize the heavy-duty vehicle fleet and heavy-duty vehicle VMT accurately.

3. Travel Activity Inputs to the MOBILE6 Model

As mentioned in Chapter 2, MOBILE6 model requires a wide variety of travel activity data as inputs. Through input files, users can input local data to best meet their needs. Included among the travel activity data needs are the following:

- ✍ Fraction of Vehicle Miles Traveled (VMT) by vehicle class
- ✍ VMT by hour, speed and facility
- ✍ Starts per day by vehicle age
- ✍ Distribution of vehicle starts during the day
- ✍ Soak distribution
- ✍ Hot soak activity
- ✍ Weekday and weekend trip length distribution

3.1.1 Fraction of Vehicle Miles Traveled (VMT) by Vehicle Class

The VMT fraction by vehicle class varies from area to area and can have a significant effect on overall emissions from highway mobile sources. The VMT fractions specify the breakdown of total highway VMT that are accumulated by each of 16 combined vehicle classes [*6*]. MOBILE6 requires that local VMT fractions by vehicle class be supplied separately for 16 vehicle class definitions. These vehicle classes are determined by the regulations under which the vehicles are certified for sale. The 16 vehicle classes are shown in Table 3.1 [*6*]. MOBILE6 calculates the default VMT fractions based on national average data characterizing vehicle age distributions and annual mileage accumulation rates by age for each vehicle class, and the total number of vehicles of each vehicle class nationally. MOBILE6 allows this default distribution to be replaced by local values.

Table 3.1
Vehicle classification for VMT Mix

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 (6,00-8,500 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. GVRW)
12	HDV8A	Class 8a Heavy-Duty Vehicles (33,001-60,000 lbs. GVRW)
13	HDV8B	Class 8b Heavy-Duty Vehicles (> 60,000 lbs. GVRW)
14	HDBS	School Buses
15	HDBT	Transit and Urban Buses
16	MC	Motorcycles (All)

The vehicle classes used for entry of the VMT fractions do not differentiate vehicles by the type of fuel used (i.e., diesel versus gasoline).

3.1.2 Vehicle Miles Traveled Fraction by Hour of the Day

Vehicle Miles Traveled (VMT) by hour of the day is a very important parameter requirement used to forecast mobile source emissions. Total national VMT has been increasing mainly due to the following factors.

- Increase in vehicle ownership
- Increase in number of vehicles
- Decrease in average vehicle occupancy

The VMT fraction by hour of the day, speed and facility vary with geographic region. The amount of vehicle miles traveled varies significantly during the day. MOBILE6 has a national average default distribution for the daily VMT. The distribution is simply the fraction of all daily VMT by all vehicle classes, which occurs in each hour of the day. According to the MOBILE6 guidance, the VMT fractions by hour of the day used in inventory modeling should be consistent, where possible, with assumptions used in other highway vehicle related planning.

3.1.3 Vehicle Engine Starts Per Day

The number of vehicle engine starts per day also varies with geographical area. This input variable allows users to specify the average number of engine starts (trips) per vehicle per day for specific vehicle classes and ages for weekend days and/or weekdays. MOBILE6 assigns each of the 28 individual vehicle classes (not to be confused with 16 vehicle classes used for VMT fractions by day) at each of 25 ages a separate default for number of engine starts per day. The defaults differ for weekdays and weekends. For example, light duty passenger vehicles use 7.28 starts per day for weekdays and 5.41 starts per day for weekend days. Light trucks use 8.06 starts per day for weekdays and 5.68 starts per day for weekend days. The same default value is used for vehicles of all ages within a vehicle class. But for most purposes, EPA does not expect states to develop local estimates. States may choose to use the default values for vehicle engine starts per day instead of developing local values.

3.1.4 Vehicle Engine Starts by Hour of the Day

Exhaust emissions that occur immediately after a cold engine start can account for a significant fraction of the emissions that occur during a vehicle trip. The fraction of the vehicle starts in each hour of the day is required as direct input to MOBILE6, which contains default values for the distribution of the engine starts by hour of the day for a weekday and a weekend day.

3.1.5 Vehicle Trip Length Distribution

Trip-length activity estimates are used to calculate running loss emissions. Running loss emissions are evaporative emissions, i.e., emissions that have escaped from a vehicle while the engine is operating. Fuel evaporation, especially from the fuel tank occurs during trips due to the heating of the fuel system. These emissions are affected by the length of time the vehicle has been in operation. Longer trips mean more evaporative running loss emissions due to increased fuel system temperatures. The rate of running emissions is assumed to continually increase as a function of trip length until it reaches a plateau at a trip length of about 50 to 60 minutes. The 24-hour day was divided into fourteen different hourly groups.

3.1.6 Soak Length Activity Factors for Start Emissions

Soak distributions are required as direct inputs to MOBILE6. A vehicle is considered soaking if the engine is not running. The length of time between two successive events that defines an engine turn off and ignition is known as the soak period. Soak distribution is further classified as cold soak distribution and the hot soak distribution based on the length of time for which the engine is turned off. Hot soak emissions are evaporative emissions, which may be produced by a warm, but no longer running vehicle.

There has been a significant change from MOBILE5 to MOBILE6 with respect to soak time distribution. MOBILE5 uses the concept of mode fractions, which requires the classification of vehicle miles traveled into three operating modes: cold-transient, hot-transient, and hot-stabilized. The transient mode of operation consists of all operations before 505 seconds after the start of the trip. Transient trips are further classified into cold transient and hot transient depending on whether the start mode was a cold start or a hot start. Hot starts are those that occur less than 1 hour after the end of the preceding trip. In MOBILE6 the *start* emissions are separated from the *running* emissions.

Cold soak input in MOBILE6 ranges from zero minutes to a maximum of 12 hours (720 min) and a hot soak ranges from 1 minute to a maximum of 1 hour (60 min). The MOBILE6 default values for soak duration distribution on weekends and weekdays were developed from instrumented vehicle studies conducted on 168 vehicles in the Baltimore and Spokane areas [*7*].

3.2 Data for Deriving Locality Specific Travel Variables

The Highway Performance Monitoring System (HPMS) provides vehicle use data from traffic counts performed in each state. These data can be obtained from FHWA and can be used in deriving VMT distributions. However, the EPA recommends that local count data should supplement HPMS data to obtain more representative values [6]. Areas with available travel demand models can directly use estimated link volumes to provide local input data. However, there are some limitations to this method. The output form travel demand models is not meant to provide detailed vehicle classifications. Keeping these input requirements and other considerations in view, Venigalla and Pickrell [5] have determined that the NPTS data offers considerable promise in deriving the locality specific input variables to MOBILE6. The NPTS data provides information on various travel parameters from which several travel activity related variables that are required as inputs to MOBILE6 can be derived.

A description of the NPTS data and its characteristics are discussed in the following sections.

3.3 Nationwide Personal Transportation Survey (NPTS) Data

The Nationwide Personal Transportation Survey (NPTS) is primarily sponsored by the U.S. Department of Transportation and is conducted periodically (every 5-7 years). Data are collected for many types of trips, various modes, trip lengths and trip purposes for all geographic areas from sample United States households. These data are expanded to provide annual, national estimates of trips and miles by travel mode, purpose, time of day, day of week, and a host of other characteristics that are used by transportation planners and others concerned with the mobility of the American public and the human, economic and environmental impacts of transportation. The NPTS serves as the nation's inventory of daily personal travel and is the only authoritative source of national data on the daily trips including,

- ✍ Purpose of the trip
- ✍ Means of transportation used
- ✍ Travel time
- ✍ Time of day the trip took place
- ✍ Driver characteristics (age, sex, worker status, education level, etc.)
- ✍ Vehicle attributes (make, model, model year, amount of miles driven in a year).
- ✍ Vehicle occupancy

3.3.1 Uses of Nationwide Personal Transportation Survey (NPTS) Data

The NPTS is a tool in the urban transportation planning process. It provides data on personal travel behavior, trends in travel over time, trip generation rates and data for various other planning and modeling applications.

The NPTS data can be used to

- ✍ Quantify travel behavior
- ✍ Analyze changes in travel trends over time
- ✍ Relate travel behavior to the demographics of the traveler
- ✍ Look at the relationship of demographics and travel over time
- ✍ Look at the relationship of travel and land use

The 2001 NHTS data updates information gathered as a part of the 1969, 1977, 1983, 1990, and 1995 Nationwide Personal Transportation Surveys (NPTS) and the 1977 and

1995 American Travel Survey (ATS). Along the lines recommended by Venigalla et al. [*4*] and Venigalla and Pickrell [*5*] a comprehensive analysis of the 1995 NPTS and 2000 NHTS was undertaken to derive several vehicle activity inputs to MOBILE6.

4. Analysis of the NPTS Data

A comprehensive analysis of the 1995 NPTS database was undertaken to derive certain travel related inputs to MOBILE6. The NPTS data include information on 409,025 trips made in one day (travel day) by over 42,000 households using over 75,000 vehicles across the United States. Similarly, the 2000 NHTS data includes information on 248,517 trips made by over 26,000 households using over 53,000 vehicles. The 2000 NHTS data, which was just released in January 2003, is not used in the sensitivity analysis of MOBILE6.

The NPTS database includes five different tables: the travel day trip file, household file, vehicle file, person trip file, person file and segmented trip file. Among all these files the *day trip* file and the *vehicle* file are the two most relevant files for this study. All the data from these two tables is not necessary to derive the inputs to MOBILE6. Some of the relevant and useful variables for deriving some of the inputs to MOBILE6 include

- Household identification number
- Vehicle identification number
- Start time of the trip
- Length of the trip
- Trip purpose variables
- Geographic classifications: state, census region, census division, metropolitan statistical area (MSA) and MSA size.
- Vehicle type and make year of the vehicle

- Day of the week trip took place (weekday/weekend)

These variables were extracted from the 1995 NPTS database to create a smaller database for the analysis. Though the National Personal Transportation Survey is skillfully executed and the data are well organized, the data needed some screening before it could be analyzed to derive the travel related inputs required for MOBILE6.

4.1 Data Screening

Highway trips were separated from transit trips and vehicle trips were isolated from person trips since trip chains can be reconstructed for trips made using only the household vehicles. It was observed that household vehicles made only 320,646 trips out of 409,025 trips in the travel day data. Non-household vehicles or transit were used for making the remainder of the trips. Trips for which the start time of the trip was not specified were also separated. All person trips that represent a duplicate vehicle trip were discarded since distinct vehicle trips are required for computing the soak times and to calculate the total number of vehicle starts per day. At the final stage of the screening when only the unique vehicle trips were retained in the final analysis database, the overall sample size was reduced to 239,642 trips.

4.2 Reconstructing Trip Chains

The three most important variables used for identifying each chain of the trips in the database are: the unique household identification number, the vehicle identification number (within the same household) and the start time of the trip. The combination of each unique household identification number and vehicle identification number is flagged as a new trip chain. Trip chains are required to compute the cold soak and hot soak times that require the end times of the previous trip and the trip start times of the next trip respectively by the household vehicle.

Accuracy issues arise with travel survey data when the survey instruments are not exclusively developed for air quality modeling purposes. Even when they are designed for air quality modeling purposes, the data are seldom accurate enough at the detailed level required in emissions modeling. Therefore the trip chains used for final analysis were subjected to a series of consistency checks.

Due to the nature of the survey methods used in collecting the NPTS data, the respondents reveal the start time and duration of trip from a trip-log or from their memory recollection. The soak period data analysis revealed several instances where the computed soak periods either appeared questionable or, even unreliable. For example, even though a meticulous data screening process was undertaken to prevent the occurrences of overlapping person trip chains, a small number of vehicle trips were found to have overlapping durations. Consequently, these trips in the chains showed negative soak periods. The trips and in some cases entire vehicle trip chains were discarded from the analysis data [5]. After the final screening process, the sampling characteristics of the retained unique vehicle trip data were assumed to be representative of the sampling characteristics of the 1995 NPTS database. There were 184,478 distinct trips made by the household vehicles after screening the data. These vehicle trips were used in deriving the travel activity inputs to MOBILE6. The schematic of data analysis for NPTS database is shown in Figure 4.1 [*16*].

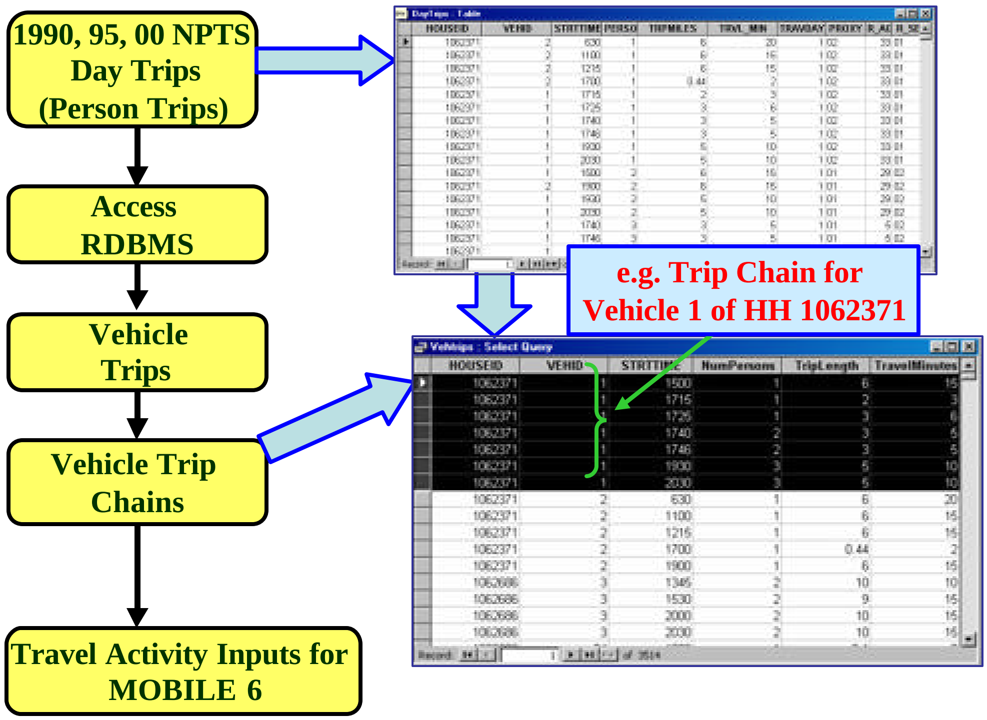


Figure 4.1
Schematic of Data Analysis of NPTS Database

4.3 Start Distribution

Start distribution input for MOBILE6 is the total number of engine starts in each hour of the day. In order to visualize the trends in variation of start distribution by hour of day, starts as a percentage of daily vehicle starts for all of United States (Nationwide), Washington D.C and MOBILE6 default were plotted in Figures 4.2 and 4.3 for weekday and weekend, respectively. It can be seen that the general trend is indicating higher percent starts during the morning peak hour and the evening peak hour with a relatively lower starts during the night hours on a weekday. A significant difference exists in the starts distribution for the weekday and for the weekend. This is intuitive as most motorists have different usage patterns for their vehicles on weekdays than on weekends. Figure 4.4 shows the variation of starts distribution from the 1995 NPTS and the 2000 NHTS data. The distribution does not vary considerably during the morning peak period and the evening peak period but there is a small variation during the afternoon period.

4.4 Trip Purpose Classification

All the trip purpose classifications given in NPTS data are reclassified under 3 major trip purpose groups; home based work (HBO) trips, home based other (HBO) trips and non-home based (NHB) trips.

Figure 4.5 shows the distribution of starts by trip purpose based on the 1995 NPTS data. The trend indicates higher percent of starts during the morning and evening peak periods for the home based work trips and higher percent of starts during the afternoon period for the home based other trips. The non-home based trips have variable starts distribution.

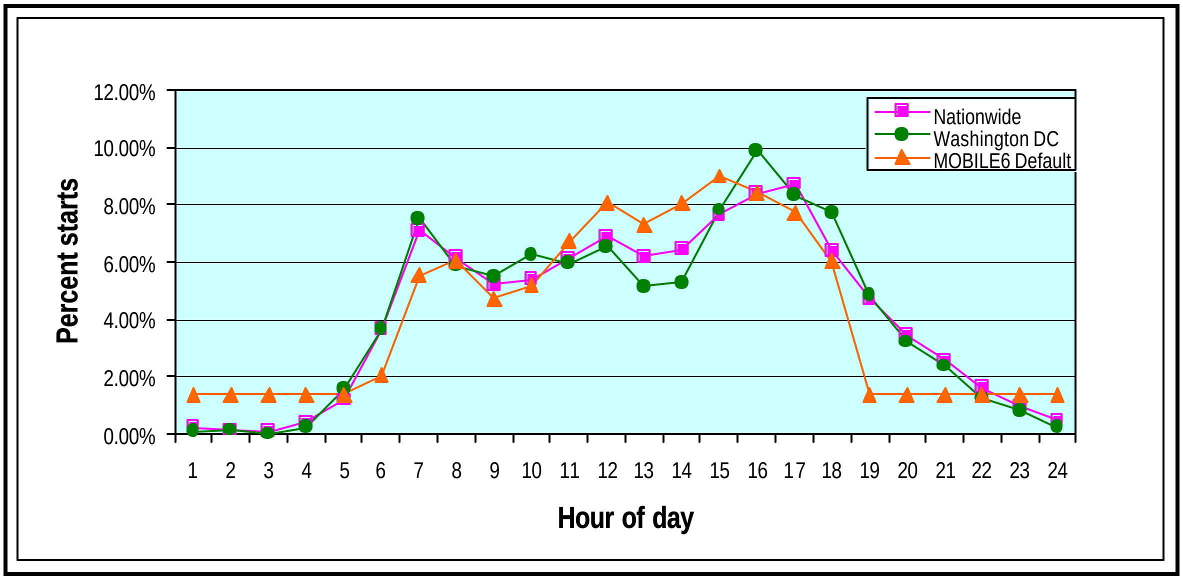


Figure 4.2
Weekday Starts Distribution by Hour of Day

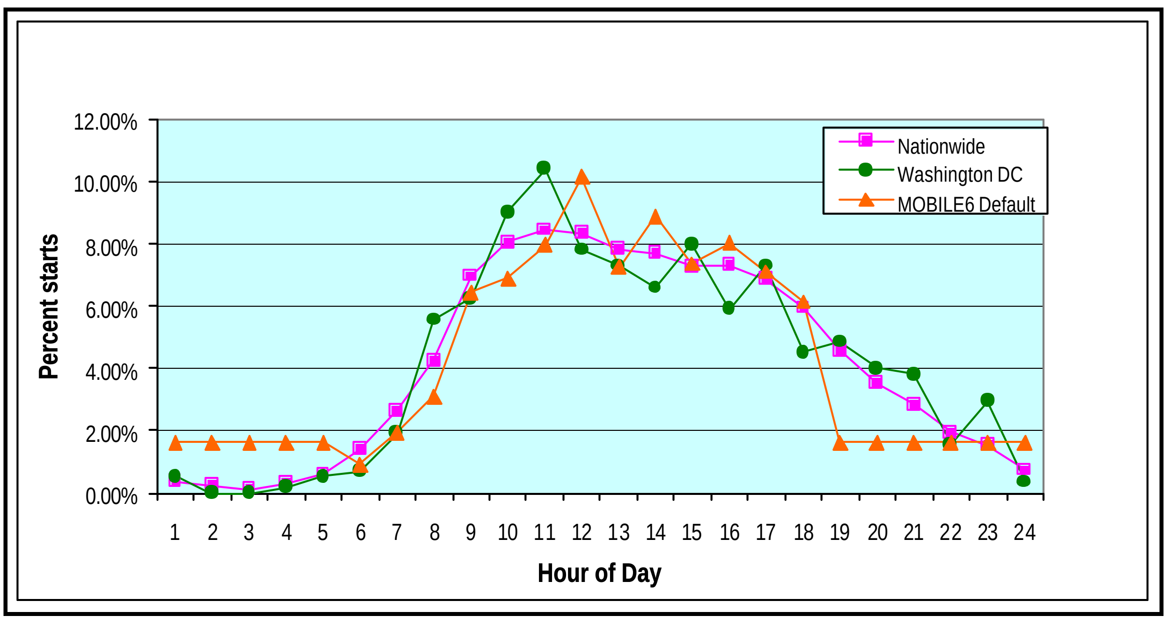


Figure 4.3
Weekend Starts Distribution by Hour of Day

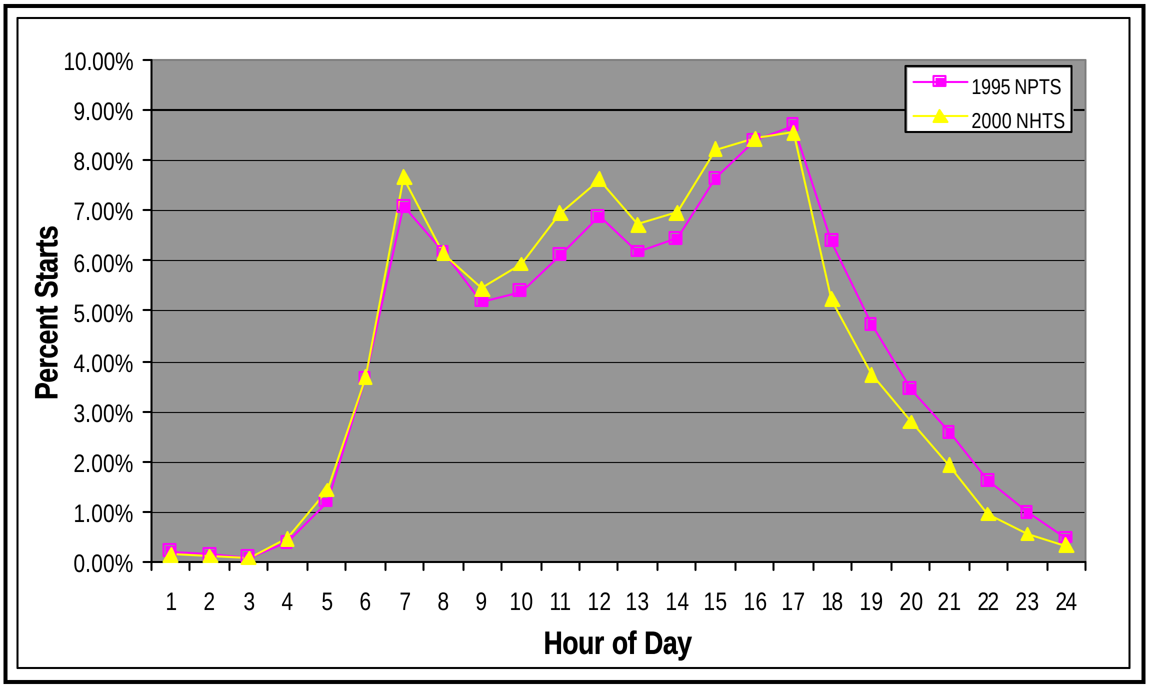


Figure 4.4
Weekday Start Distribution from 1995 NPTS and 2000 NHTS Data

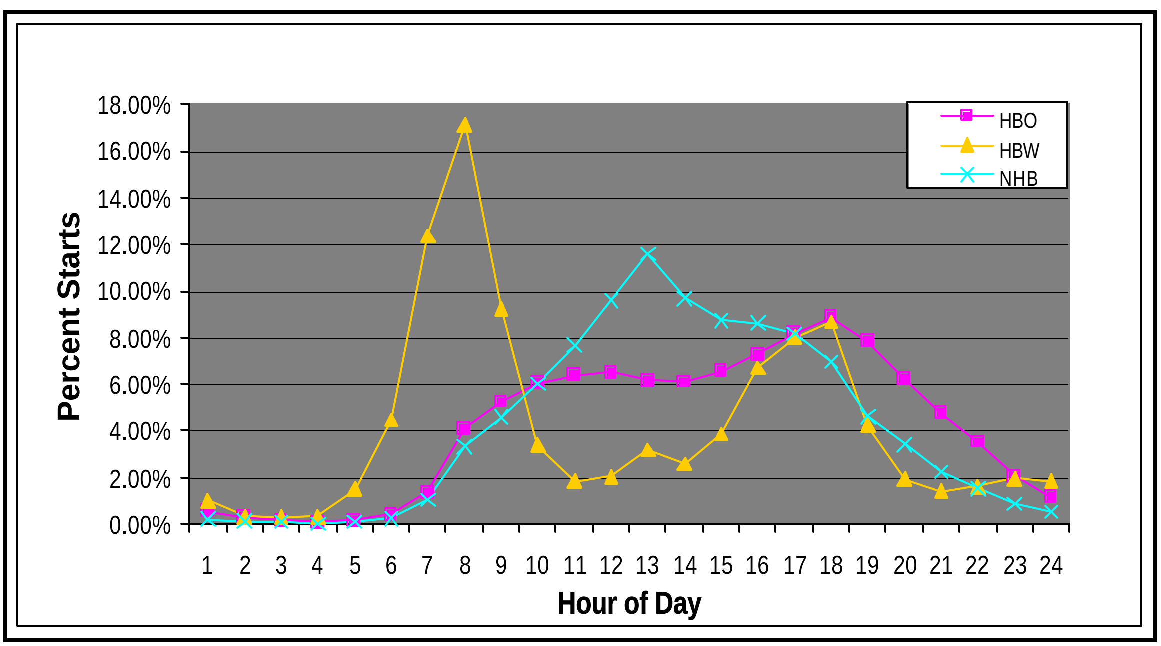


Figure 4.5
Starts Distribution by Trip Purpose (based on 1995 NPTS)

4.5 Computing Soak Durations

A soak is defined as the duration of time preceding a vehicle start in which the vehicle's engine is not operating. The temporal distribution of the soak time in an area is an important determinant of area-wide mobile source emissions. Distribution of soak duration over time is an important input for the emissions forecasting model since the start emission are dependent on the soak durations. MOBILE6 uses the cold soak time of a vehicle trip as one of the several factors to estimate the emissions associated with the engine start of the trip. The trip soak time is dependent on various factors such as the purpose of the preceding trip, the time of day of the trip start, and other socio-demographic characteristics of the zone of trip start. Hot soak is the period of time for which the engine remains hot after the engine is turned off and gasoline evaporation continues when the car is parked.

Figure 4.6 gives an idea of how the cold soak, hot soak and the starts distribution are derived from the NPTS data. Assume that there were 2 trip made by a household vehicle on a particular day. Trip1 starts at 7 AM and ends at 7:45 AM. Trip 2 starts at 9 AM and ends at 9:45 AM. So there are 2 trip starts 50% at 7 AM and 50% at 9 AM. The cold soak of trip 2 is the time elapsed when the trip 1 ended and the trip 2 started which is 75 min in this particular case. Hot soak of trip 1 is 60 minutes. (Since hot soak can range to a maximum of 60 minutes).

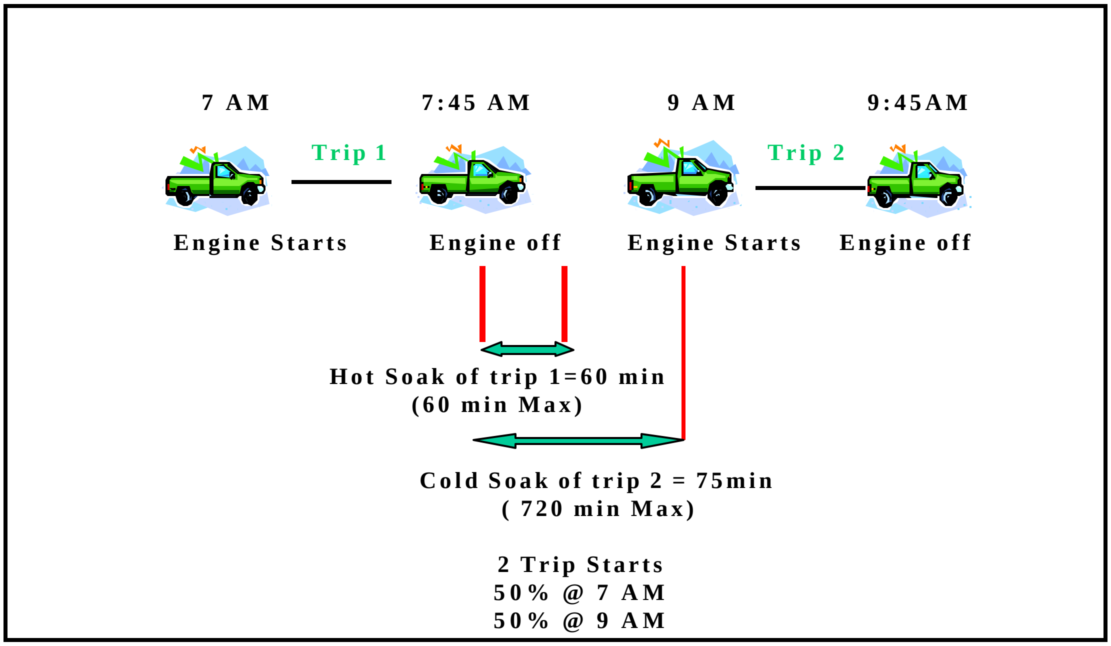


Figure 4.6
Diagrammatic Representation of cold soak and hot soak calculation from NPTS data

4.6 Deriving Cold Soak Activity

The cold soak period between two successive trips made by the vehicle was computed based on the begin-time of the current trip and the end-time of the previous trip. The end times of the trips were computed based on the start time of the trip and the length of the trip (in minutes). The NPTS travel-day data contained information only on a 24-hour travel-day, between 4:00 AM of current day and 3:59 AM of the next day. Determining the soak times of the first trip made in each trip chain is, therefore, difficult. In order to facilitate the computation of first-start soak time, previous day's travel activity is assumed to be identical to that of the travel day, both in terms of person and vehicle trip characteristics and the last trip end time on the previous day is assumed to be equal to last trip end time on the travel day.

Each of the soak times derived above was identified with the appropriate MOBILE6 soak interval category shown in Table 4.1. The frequencies of each of the 70 soak period intervals for each hour of weekday and weekend day were then obtained.

Table 4.1
MOBILE6 Soak Interval Classification of Soak Times

Soak Interval Number, N	Range of Soak Time
1	Greater than 0.01 and ? 1.0 minutes
2 to 30	Greater than (N-1) and ? N minutes
31 to 45	Greater than (2n-32) and ? (2N-30) minutes
46 to 67	Greater than (30N-1, 320) and ? (30N-1, 290) minutes
68	Greater than 720 minutes
69	Greater than zero, but less than 0.01
70	Zero minutes (stalls, not used)

Soak interval number 69 of the MOBILE6 model is designed to represent re-starts with soak duration as low as 1/100th of a minute. The NPTS survey methods adopted a travel time resolution of one minute, which means that the NPTS data cannot be used to derive soak period distribution data for interval number 69. [5] There were no trips with zero soak periods.

In order to visualize the trends in variation of soak time by hour of day, average soak times for the four census regions are plotted in Figure 4.7. It can be seen that the general trend is indicating higher soak times for morning periods, followed by a relatively flatter trend during the midday and evening hours. The overall trend doesn't change across the 4 census regions.

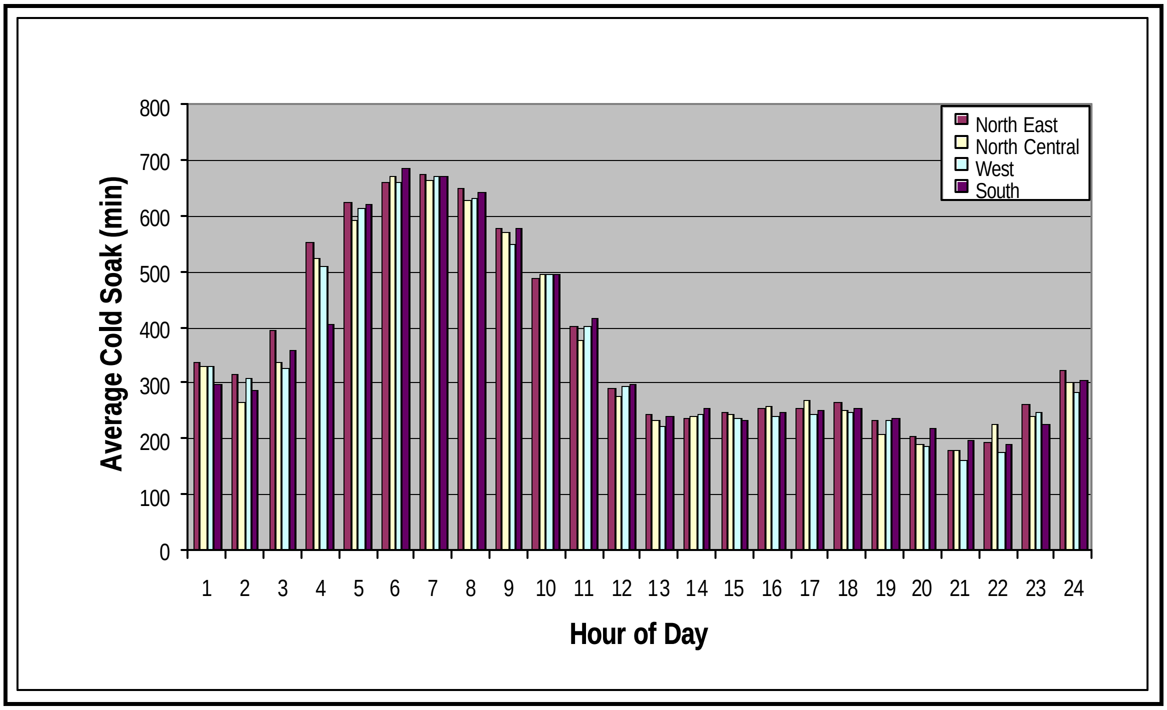


Figure 4.7
Average Cold Soak by Census Region

4.7 Deriving Hot Soak Activity

The hot soak period is computed based on the end time of the current trip and the start time of the next trip. Hot soak emissions are highest immediately after the engine is shut down and decrease over time, reaching a baseline level in about an hour. Hot soak emissions are truncated if the engine is turned on again before an hour has elapsed. For trips that did not start before an hour has elapsed, the soak period is greater than 60 minutes and hence the hot soak period for such trips is taken as 60 minutes. The hot soak time distributions represent the number of vehicles experiencing a hot soak of a given duration (1 to 60 minutes) at each hour of the day. MOBILE6 assumes that hot soak durations range from 1 minute at minimum to a maximum of 60 minutes.

4.8 Vehicle Miles Traveled (VMT) by hour of the day

NPTS data does not provide travel data information based on the speed of the vehicle and the roadway type. Hence only VMT fraction by hour of the day is derived as inputs from NPTS data. The total vehicle miles traveled in each hour of the day for a trip is computed based on the trip start time, total trip duration and the vehicle miles traveled in the trip. A vehicle trip is classified into a particular hourly group if any part of the trip duration was in a given hourly group. A given vehicle trip could potentially be classified into one, two, or even three different hourly groups depending on the duration of the trip, and how many group interval boundaries it crossed. This classification can be best illustrated with an example of two general cases.

- ✍ If a vehicle trip was from 8:15 AM to 8:45 AM with 25 miles of travel, it is classified as a trip in hourly group 8 with 25 miles of travel in that hourly group.
- ✍ If the trip was from 9:15 AM to 10:20 AM with 50 miles of travel, its contribution has to be split between two hourly groups (9 and 10 hour). Thus, the 50 miles of travel is split between hourly group 9 and 10 in the ratio of the travel time in each hour. Hence the VMT in 9 hour group is ((45 minutes) / (65 minutes)) * (50

miles) and the VMT in the 10 hour group is ((20 minutes) / (65 minutes)) * (50 miles).

Figure 4.8 illustrates the comparison of percent VMT at each hour of the day from the 1995 NPTS and 2000 NHTS. It shows a general trend of higher VMT during the morning peak times and the evening peak times. The 2000 NHTS data shows a higher VMT for the afternoon period than the 1995 NPTS data.

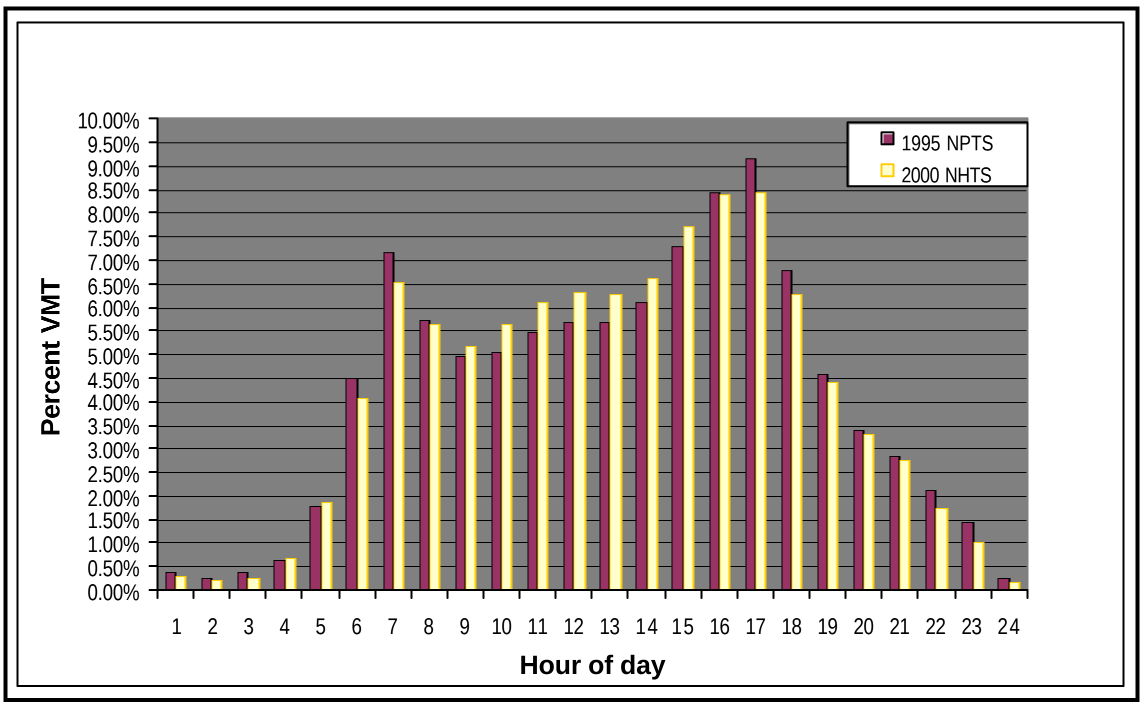


Figure 4.8
VMT by Hour of Day

4.9 Vehicle Type Classification

The NPTS data include data on trips made by different vehicle types. The vehicle classification given in NPTS data is not the same as the MOBILE6 vehicle classification. The different vehicle types in NPTS data are regrouped into 3 types of MOBILE6 vehicle classification: Light Duty Gasoline Vehicle (LDGV), Light Duty Gasoline Truck 1 (LDGT1) and Light Duty Gasoline Truck 2 (LDGT2). Since NPTS data contains only the personal travel data information, travel data inputs to MOBILE6 for heavy-duty trucks cannot be obtained. The MOBILE6 classification of NPTS data vehicle types can be seen in Table 4.2.

Table 4.2
Mobile 6 classification of NPTS Vehicle Type

NPTS Vehicle Type	***MOBILE6 Classification***
Automobile	Light Duty Gasoline Vehicle (LDGV)
Van	Light Duty Gasoline Truck 2 (LDGT2)
Sport Utility Vehicle	Light Duty Gasoline Truck 2 (LDGT2)
Pickup Truck	Light Duty Gasoline Truck 1 (LDGT1)
Other Truck	Light Duty Gasoline Truck 2 (LDGT2)

4.10 Vehicle Age Classification

In MOBILE6, vehicle age is accounted in a 25-year range. Vehicles with vehicle age from 1 year to 24 years are classified as vehicle age groups 1 to 24 and all other vehicles with vehicle age greater than 24 years are grouped as vehicles with age greater than 25 years. The range may be expressed as 0 to 24 years (age = base year minus model year); alternatively its values may be considered to range from 1 to 25 years (age = base year minus model year +1). The 1995 NPTS and 2000 NHTS data have a variable in the vehicle file that specifies the model year of the vehicle and the vehicle age is calculated with respect to the base year 1996 and 2003, respectively.

5. MOBILE6 Default Vs. NPTS Derived Variables

MOBILE6 includes default values for a wide range of parameters that affect emissions. These defaults are calculated to represent “national average” input data values. Substituting default values with information related to local conditions will result in more precise estimates of local emissions. The following two issues that are of specific interest to air quality modelers:

- How do travel survey based vehicle activity *inputs* themselves differ from the MOBILE6 defaults.
- How do emission rates based on these inputs compare to emission rates derived from MOBILE6 default values.

A comprehensive evaluation of the inputs with respect to defaults as well as a sensitivity analysis of the MOBILE 6 model to the NPTS derived inputs was undertaken.

5.1 MOBILE6 Input Files

The MOBILE6 input parameters derived from NPTS data are listed below

- Engine starts per day by vehicle class and distribution by hour
- Average trip length distribution
- Hot soak duration
- Cold soak distribution
- Distribution of vehicle miles traveled by vehicle class

These parameters are organized as separate ASCII files for input to MOBILE6.

5.1.1 Distribution of Vehicle Miles Traveled (VMT) by Vehicle Class

The VMT fraction input permits the user to assign VMT to specific vehicle types. VMT mix supplied must consist of a set of sixteen fractional values, representing the fraction of total highway VMT accumulated by each of the 16 combined vehicle types (Table 3.1). Fraction of Vehicle Miles Traveled is obtained for only 3 vehicle classes from analyzing the NPTS data i.e. Light Duty Gasoline Vehicle (LDGT1), Light Duty Gasoline Truck 1 (LDGT1) and Light Duty Gasoline Truck 2 (LDGT2) since NPTS data deals only with personal travel. All values must be between 0 and 1, and the 16 values must add up to 1.0.

The VMT mix fractions obtained from NPTS data are adjusted in the ratio of the default VMT mix fractions for the 3 vehicle classes so that the sum of the VMT mix fractions add up to the sum of the default VMT mix fractions for the 3 vehicle classes. For example the national default VMT mix fractions for LDGV, LDGT1 and LDGT2 vehicle are 0.354, 0.089 and 0.297 respectively which add up to 0.74. But the national fractions of VMT mix derived from NPTS data are 0.666, 0.156 and 0.178 which add up to 1.0. Hence these fractions are adjusted in the ratio of the default fractions so that they add up to 0.74. The VMT fractions after adjustment are thus 0.493, 0.115 and 0.132 respectively. Figure 5.1 shows a comparison of the VMT mix for each of the above 3 vehicle classes. It can be seen that the VMT mix for various geographic regions (Nationwide, Washington DC and Virginia) is more than the MOBILE6 default VMT mix for LDGV. For LDGT2, these values are lesser that the MOBILE6 defaults.

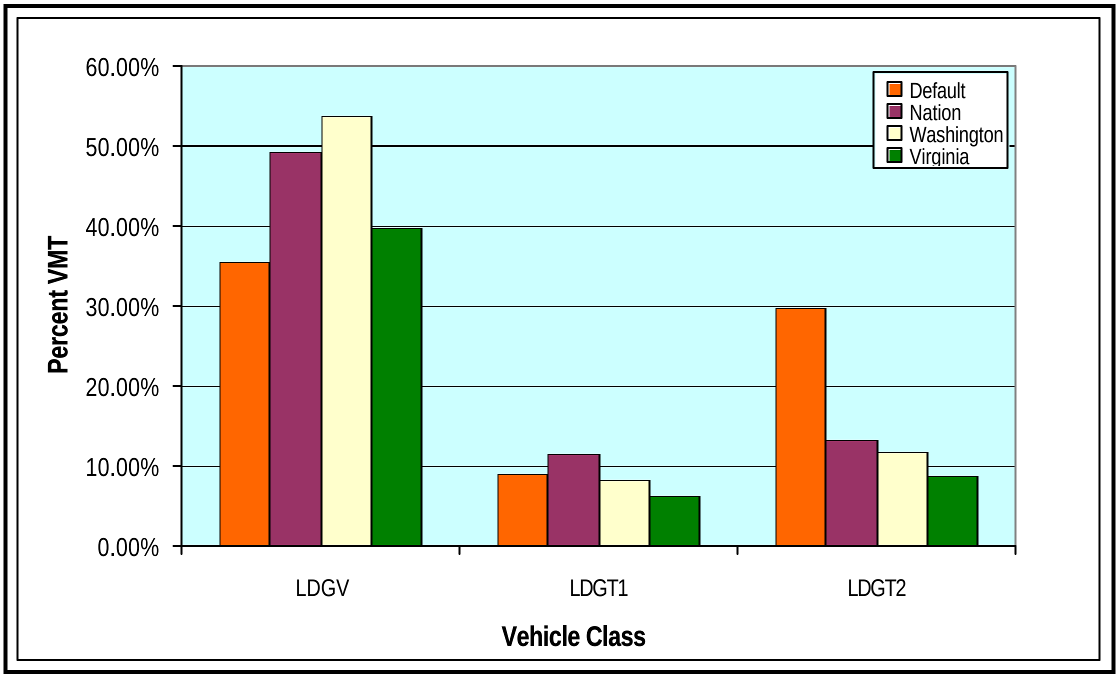


Figure 5.1
VMT Mix (Based on 1995 NPTS)

5.1.2 Distribution of VMT by Hour of Day

VMT by hour input file allows the user to assign the fraction of total VMT occurring at each hour of the day. The VMT distribution for each hour should add up to 1.0. Distribution of Vehicle Miles of Travel by roadway type and speed can also be given as inputs to MOBILE6 but NPTS data does not provide information on roadway type and speed classifications of the trips and hence these inputs cannot be derived. A comparison of the default values provided by MOBILE6 and the locality specific values obtained from NPTS data for Washington Metropolitan Statistical Area (MSA) are shown in Table 5.1. It can be observed that the VMT fractions derived from NPTS are low than the default fractions during the morning hours and high during the afternoon and evening hours. Figure 5.2 shows a comparison of the VMT by hour fractions for Nationwide, Washington MSA, Commonwealth of Virginia from 1995 NPTS and MOBILE6 defaults. It can be observed that the evening peak hour VMT is more from NPTS data.

Table 5.1
Default Vs. 1995 NPTS data values for the VMT by Hour of Day Variable

Hour of Day	Default	Washington DC	Difference
1	0.86%	0.37%	0.49%
2	0.81%	0.14%	0.67%
3	0.80%	0.21%	0.59%
4	0.98%	0.19%	0.79%
5	1.86%	1.36%	0.50%
6	5.69%	4.54%	1.15%
7	7.40%	6.29%	1.11%
8	6.55%	6.19%	0.36%
9	5.55%	5.61%	-0.06%
10	5.40%	5.66%	-0.26%
11	5.82%	6.65%	-0.83%
12	6.08%	6.07%	0.01%
13	5.71%	6.83%	-1.12%
14	5.98%	6.40%	-0.42%
15	6.36%	8.08%	-1.72%
16	7.77%	8.41%	-0.64%
17	7.30%	8.08%	-0.78%
18	5.01%	6.10%	-1.09%
19	3.89%	4.15%	-0.26%
20	3.08%	3.13%	-0.05%
21	2.64%	2.06%	0.58%
22	1.94%	2.12%	-0.18%
23	1.44%	1.22%	0.22%
24	1.08%	0.15%	0.93%

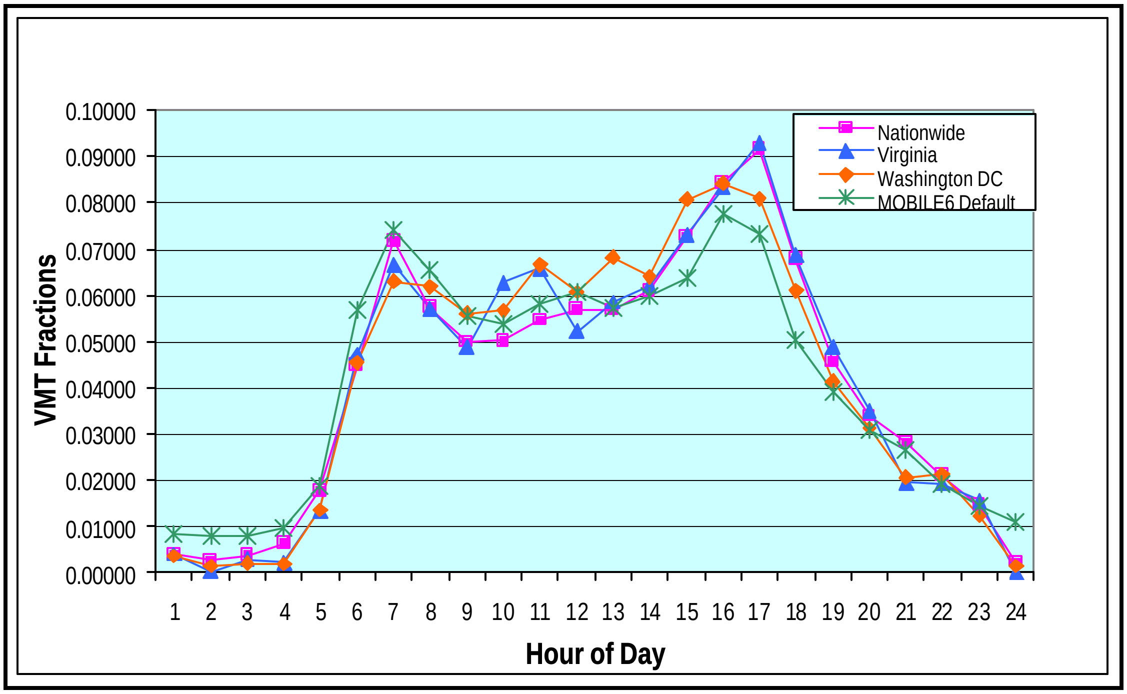


Figure 5.2
VMT Distribution by Hour of Day

5.1.3 Engine Start Soak Time Distribution by Hour of Day

The MOBILE6 model contains a soak length distribution for each of the 24 hourly groups separately for weekdays and weekends. Each of these distributions contains 70 values representing a range of soak durations varying from 0 to over 720 minutes. From the soak time data, the model computes percentage of vehicles that have been soaking for a given amount of time prior to an engine start for each hour of the day. This, in turn, affects start emissions, which depend on the length of soak time. The same soak time distributions are applied to all vehicle classes and all vehicle ages. Values for each of the 70 soak durations for each of the 24 hours of the day for week and weekend days (3,360 values) are derived from NPTS data and given as a cold soak time input to MOBILE6.

5.1.4 Hot Soak Length Distribution by Hourly Group

By convention hot soak duration is defined to range from a minimum of 1 second to a maximum of 1 hour. The one-hour limit was chosen for consistency with the Federal Test Procedure definition of a hot soak. But MOBILE6 adopted a hot soak resolution of 1 minute and the hot soak period range from 1 to 60 for 14 hourly intervals.

The 24-hour day was divided into 14 different hourly groups. 13 of the 14 hourly groups have duration of one hour. These start at 6:00AM and run through 7:59:59 PM. The fourteenth hour contains the remaining nighttime hours as one interval. Consolidating these hours into one group was done because there was less data available for these time periods and the emissions contributed during the night periods have a relatively smaller impact on daily ozone or CO formation than those contributed during the morning periods or day. The hot soak length distribution for weekday and weekend are given as two separate input files to MOBILE6.

5.1.5 Average Trip-Length Distribution

The weekday and weekend trip length distribution are the percent vehicle miles traveled in each of the 6 trip length groups. MOBILE6 contains default values for weekday and weekend trip length distributions. The model uses the same values for the weekday and weekend distributions. Tables 5.2 and 5.3 show the weekday and weekend trip length distribution input from 1995 NPTS data for all of the United States. The first row in each table shows the MOBILE6 default values. The default values are the same for weekday and weekend trip length distributions and for each of the 14 hourly groups. It is observed that the percent VMT in an 11 to 20 minute trip length is much higher than the default values for both the weekday and weekend trips. Figures 5.3 and 5.4 show the percent VMT in each hourly group for a 11 to 20 minute trip length for weekday and weekend respectively. The deviation of the NPTS derived values from the defaults can be clearly observed.

Table 5.2

Nationwide Weekday Trip Length Distribution from 1995 NPTS

		Trip Length (minutes)					
Hourly Group		Less than 10 min	11 to 20 min	21 to 30 min	31 to 40 min	41 to 50 min	51 or more min
	Default	**6.74%**	**18.51%**	**16.78%**	**13.11%**	**8.33%**	**36.53%**
	6-7AM	6.71%	17.06%	18.60%	12.53%	12.25%	32.85%
	7-8AM	11.02%	23.29%	20.90%	10.82%	9.84%	24.13%
	8-9AM	15.71%	24.54%	17.40%	8.70%	7.32%	26.33%
	9-10AM	18.08%	24.92%	15.35%	6.54%	6.80%	28.31%
	10-11AM	19.48%	24.12%	14.29%	6.36%	5.10%	30.65%
	11-12N	22.54%	26.35%	16.77%	6.34%	5.69%	22.31%
	12-1PM	24.12%	25.64%	13.50%	5.99%	5.72%	25.03%
	1-2PM	20.56%	25.56%	16.22%	7.18%	6.42%	24.06%
	2-3PM	17.73%	25.61%	17.82%	7.49%	7.35%	24.00%
	3-4PM	15.90%	25.40%	17.54%	8.50%	8.52%	24.14%
	4-5PM	13.46%	22.17%	18.46%	9.62%	8.65%	27.64%
	5-6PM	13.67%	23.71%	19.00%	9.63%	10.09%	23.90%
	6-7PM	17.44%	27.13%	18.47%	8.60%	8.60%	19.76%
	7-8PM+	15.35%	25.12%	18.01%	8.47%	8.66%	24.39%
	Default values are the same for all the 14 hourly groups for each of the trip lengths						

Table 5.3
Nationwide Weekend Trip Length Distribution from 1995 NPTS

Hourly Group		Trip Length (minutes)					
		less than 10 min	11 to 20 min	21 to 30 min	31 to 40 min	41 to 50 min	51 or more min
	Default	**6.74%**	**18.51%**	**16.78%**	**13.11%**	**8.33%**	**36.53%**
	6-7AM	7.16%	17.74%	15.17%	8.46%	4.47%	47.00%
	7-8AM	10.81%	17.97%	12.26%	7.42%	5.25%	46.29%
	8-9AM	14.29%	18.57%	11.18%	4.25%	4.72%	46.99%
	9-10AM	21.36%	24.74%	13.91%	5.32%	5.98%	28.69%
	10-11AM	18.73%	21.33%	10.70%	4.56%	5.95%	38.73%
	11-12N	20.24%	22.50%	13.48%	4.85%	6.32%	32.61%
	12-1PM	20.12%	26.82%	14.73%	6.21%	5.85%	26.27%
	1-2PM	17.16%	26.10%	13.44%	7.58%	7.60%	28.12%
	2-3PM	15.62%	24.01%	16.36%	8.10%	5.18%	30.73%
	3-4PM	15.12%	25.12%	16.23%	5.65%	6.44%	31.44%
	4-5PM	13.86%	20.74%	14.80%	6.93%	7.37%	36.30%
	5-6PM	14.28%	20.94%	16.38%	8.29%	10.53%	29.58%
	6-7PM	16.24%	22.91%	15.67%	6.54%	6.71%	31.93%
	7-8PM+	14.37%	23.10%	16.46%	7.44%	7.61%	31.02%
	Default values are the same for all the 14 hourly groups for each of the trip lengths						

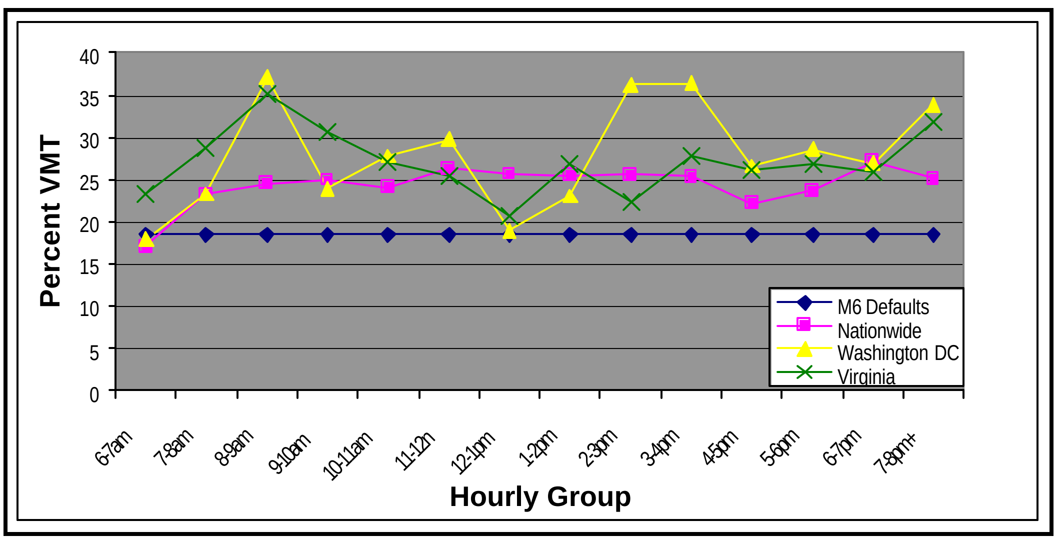


Figure 5.3
Percent VMT for each Hourly Group with a Trip Length of 11 to 20 Minutes for a Weekday Trip

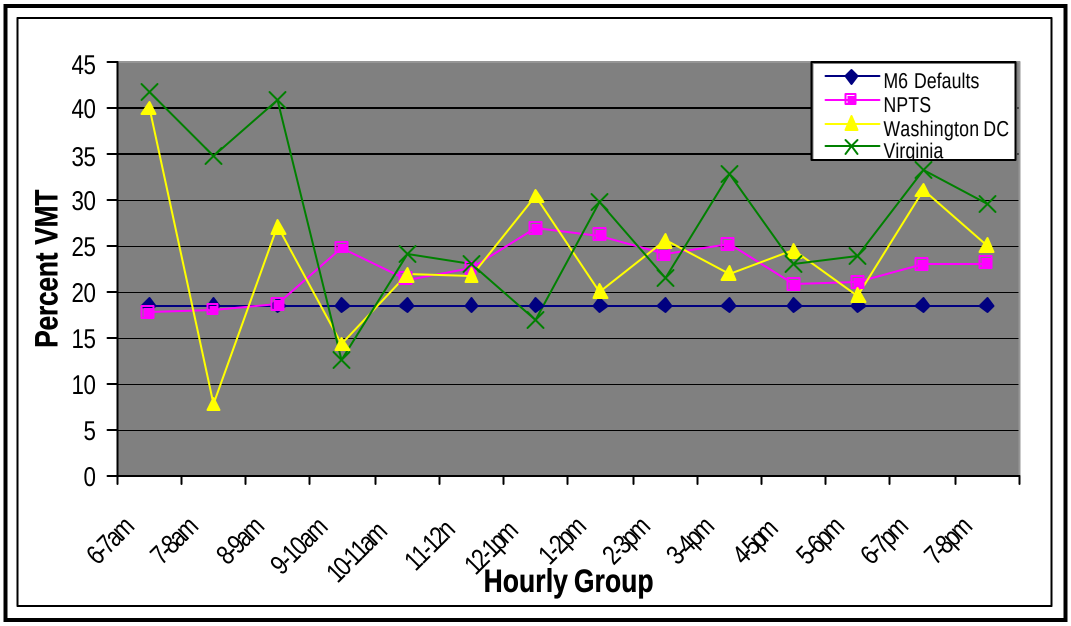


Figure 5.4
Percent VMT for each Hourly Group with a Trip Length of 11 to 20 Minutes for a Weekend Trip

5.1.6 Starts per Day

In MOBILE6 each of the 28 individual vehicle classes at each of 25 age groups is assigned a separate default for number of engine starts per day. The number of starts per day affects engine exhaust start emission estimates for light duty gasoline and diesel passenger cars and trucks and motorcycles. It will also affect the evaporative hot soak losses on all gasoline fueled vehicles, including heavy-duty vehicles and buses, which occur at trip ends. Starts per day are derived from NPTS data as a fraction of the *total vehicle trips* by each of the three vehicle classes for individual vehicle age groups to the *total number of vehicles* of each vehicle class and vehicle age. Table 5.4 shows the total vehicle trips for a weekday for whole of United States. Table 5.5 shows the total number of vehicles used in making these trips. Table 5.6 shows the total number of starts per day per vehicle which is obtained by dividing the total vehicle trips present in Table 5.4 with the corresponding total number of vehicles used that are shown in Table 5.5.

Table 5.4
Weekday Total Vehicle Starts

Total Vehicle Starts			
Vehicle Age	LDGV	LDGT1	LDGT2
1	14	17	12
2	1130	294	634
3	7148	1368	2936
4	8308	1813	2956
5	8535	1410	2761
6	7843	1340	2144
7	7553	1256	1798
8	7632	1201	1803
9	8870	1591	1738
10	7772	1603	1548
11	7755	1389	1421
12	6870	1338	1006
13	4894	1024	804
14	3696	740	603
15	2162	434	293
16	1290	337	131
17	1044	284	95
18	892	208	68
19	953	352	193
20	754	277	142
21	529	229	45
22	293	135	56
23	200	67	28
24	80	80	36
>=25yrs	767	414	109

Table 5.5
Total Vehicles used in making the Trips shown in Table 5.4

Total Vehicles			
Vehicle Age	LDGV	LDGT1	LDGT2
1	4	4	2
2	266	73	126
3	1636	331	653
4	1885	462	639
5	1916	359	563
6	1757	320	466
7	1726	310	398
8	1760	319	379
9	2092	423	391
10	1851	401	378
11	1851	366	331
12	1630	343	239
13	1188	276	194
14	912	205	152
15	523	117	74
16	329	95	33
17	271	76	21
18	221	54	14
19	250	108	48
20	201	75	35
21	135	62	12
22	80	39	16
23	43	19	10
24	24	18	10
>=25yrs	208	115	31

Table 5.6
Weekday Vehicle Trip Starts Per Day

Vehicle Starts Per Day			
Vehicle Age	LDGV	LDGT1	LDGT2
1	3.50	4.25	6.00
2	4.25	4.03	5.03
3	4.37	4.13	4.50
4	4.41	3.92	4.63
5	4.45	3.93	4.90
6	4.46	4.19	4.60
7	4.38	4.05	4.52
8	4.34	3.76	4.76
9	4.24	3.76	4.45
10	4.20	4.00	4.10
11	4.19	3.80	4.29
12	4.21	3.90	4.21
13	4.12	3.71	4.14
14	4.05	3.61	3.97
15	4.13	3.71	3.96
16	3.92	3.55	3.97
17	3.85	3.74	4.52
18	4.04	3.85	4.86
19	3.81	3.26	4.02
20	3.75	3.69	4.06
21	3.92	3.69	3.75
22	3.66	3.46	3.50
23	4.65	3.53	2.80
24	3.33	4.44	3.60
>=25yrs	3.69	3.60	3.52

There is a great variation between default values and the NPTS derived values for the starts per day variable. The starts per day are underestimated by nearly 50%. MOBILE6 uses 7.28 starts per day for weekdays for LDGV and 8.06 starts per day for weekdays both for LDGT1 and LDGT2. The same default value is used for vehicles of all ages within a vehicle class. Hence this input could account for a lot of deviation of the emission factors from the default values.

6. Data Gaps

The analysis of the NPTS data revealed several limitations of NPTS data for deriving some of the MOBILE6 travel input variables such as the cold soak period and the starts per day variables. These limitations arise from inadequate or missing data. These data gaps and the recommendations to overcome these data gaps are discussed in this chapter.

6.1 Cold Soak Period

Cold soak period input to MOBILE6 requires the fraction of vehicles having a cold soak of interval ranging in between 1 and 70 for all the 24 hour periods of the day for weekday and weekend travel. Hence providing data for cold soak period input requires that soak times be derived in as many as 3,360 cells.

Many data gaps were found while deriving the cold soak inputs for the Washington Metropolitan Statistical Area (MSA) and the commonwealth of Virginia. There are fewer than 3,360 vehicle trips in the screened NPTS data sample for the Washington area and the state of Virginia. Figures 6.1, 6.2 and 6.3 show the total number of vehicle starts for each MOBILE6 cold soak interval and for each hour of the day for whole of United States, Washington DC MSA and the Commonwealth of Virginia. The numbers in each of the blocks represent the total number of starts for a particular hour of day. The shaded blocks in the figure show that there is no data available for a particular hour of day and soak interval combination. By observing the shaded regions in Figure 6.2

it is understood that there is inadequate data from NPTS for deriving the cold soak distribution.

The hour of the day variable influences soak times significantly. If certain time periods were grouped, it would help reduce the efforts needed to provide soak distribution inputs. Grouping the time periods would also enhance the utility of the travel survey data for deriving the soak times be requiring fewer cells for which soak period distribution shave to be developed. Venigalla et al. have consolidated the soak period data into fourteen time periods, which include the following groups of hours of day. [*4*]

- Night Period: 11 PM through 4 AM
- Early Morning Period: 5AM and 6AM
- Afternoon Period: 1 PM through 3 PM
- Evening Period: 7 PM though 10 PM
- Ten separate soak times for each hour during: 7 AM through 12 Noon; and 4 PM through 7 PM

This grouping of the time periods was done based on a Tukey's pair-wise comparison test at a 5% significance level that was conducted to identify pairs of hours of day for which there is no statistically significant difference in soak times. It can be seen that the 14 time period classification reduces the total number of cells for which soak periods are to be derived from 3,360 to 1960 for both weekday and weekend. This grouping enhances the utility of the soak distribution derived from travel data sample by enhancing the travel data sample size in many cells. The consolidated time periods and the enhanced cell sizes for the nationwide sample, Washington Metropolitan Statistical Area (MSA) and the Commonwealth of Virginia can be seen in Figures 6.4, 6.5 and 6.6 respectively.

Soak Interval	Hour of Day 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	24	7	3		10	22	144	531	572	349	262	265	290	257	350	413	451	415	278	171	117	112	50	38
2	2	2		1	2	4	15	60	105	69	73	79	65	52	67	85	105	99	71	56	40	26	6	4
3	2	1	1		3	7	37	109	134	107	99	119	117	99	110	136	88	68	46	36	18	13	10	3
4	2	2	1		2	8	29	136	201	221	178	226	224	188	222	285	183	162	99	77	64	37	14	9
5	7	4	4	1	3	11	53	170	178	118	109	109	128	107	120	137	262	326	230	131	108	57	26	21
6	1					1	9	28	47	35	40	56	42	48	58	57	41	40	21	15	9	6	2	
7	4	4			1	2	25	72	122	112	137	158	164	155	186	181	188	184	118	78	67	43	19	11
8			1	1	2		4	22	28	43	41	38	34	33	41	49	48	47	41	29	23	6	5	8
9	3	4	2		1	8	41	118	122	75	76	91	92	67	105	90	246	336	221	170	96	73	41	10
10	9	3	2	1	2	1	10	48	157	222	222	264	240	212	225	300	176	119	85	61	32	21	4	3
11	1	1			3	1	5	31	49	100	85	112	117	98	88	117	49	22	15	10	2	2		
12	1	1					1	6	35	43	58	66	79	58	52	73	79	103	50	37	31	17	6	1
13	1				1	3	7	28	23	12	24	28	35	26	26	29	61	65	55	31	25	9	6	7
14	2	1						2	27	24	25	37	37	31	32	46	54	43	39	23	21	8	5	3
15	10	3	1		1	3	26	66	143	180	231	286	284	235	263	287	324	321	243	154	109	85	50	19
16	1					1	3	18	15	22	24	25	33	30	28	38	28	28	15	17	17	4	1	1
17	2		2	1			3	6	14	25	28	35	39	33	35	40	62	46	51	38	26	14	8	3
18	2	1	1			1	3	7	28	45	51	59	54	53	63	69	38	38	22	17	7	8	2	3
19	1	1					3	12	56	124	179	221	218	185	202	212	138	68	55	33	19	20	7	1
20	3					4	12	43	51	39	48	54	58	38	47	57	157	208	152	134	114	34	21	7
21						2		4	11	9	16	19	22	22	21	28	24	9	9	11	3	2	3	
22	1	1			1			13	23	66	85	91	111	75	103	105	74	85	70	71	37	28	10	2
23		1		1			1	2	7	14	32	23	24	27	29	25	26	33	19	10	12	3	3	1
24	2					3	9	26	38	30	26	24	49	25	36	42	132	195	187	141	79	44	19	10
25	6			1				8	57	109	171	212	230	197	161	224	119	61	56	25	20	11	7	2
26							1	12	30	38	63	60	99	89	50	86	41	12	8	8	5	1	3	2
27								4	5	28	34	36	63	39	36	41	56	48	50	33	18	9	6	1
28		1					3	15	14	11	11	15	21	17	18	18	26	27	42	32	16	7	3	3
29		1						4	5	12	18	21	23	34	28	23	41	27	17	19	13	4	2	
30	1	2	1	1		1	9	41	77	115	134	145	201	162	130	174	185	190	154	128	62	31	18	7
31								5	12	22	30	27	56	45	47	48	35	39	33	32	20	15	3	4
32	2						3	16	44	80	123	144	221	186	145	143	137	64	45	28	25	5	6	2
33		2	1			2	5	24	43	48	44	49	55	58	43	52	78	138	142	97	61	35	10	8
34	2		1				4	8	18	42	55	70	95	90	72	67	69	59	67	56	30	15	7	
35	6	3	1		2	1	9	33	68	104	125	151	225	182	169	156	191	183	196	122	83	50	26	11
36							2	5	25	38	60	58	88	84	63	46	46	35	25	26	20	8	1	
37							1	6	28	15	20	18	34	23	16	28	50	45	22	30	25	10	6	2
38	7	2	1	1	1	4	8	19	62	81	136	137	186	203	142	157	167	160	188	137	71	31	16	13
39	2						2	4	17	35	36	46	63	55	47	44	43	40	40	29	15	12	7	2
40	2	1	2			2	8	19	63	85	131	157	193	199	175	148	161	157	176	124	103	64	24	14
41	2					2	4	8	24	39	50	45	78	103	54	57	57	65	48	52	36	19	4	2
42			1			1	3	17	41	25	31	33	41	39	31	25	36	146	142	130	91	45	20	4
43	10	1	1				2	4	24	87	119	162	161	262	181	155	126	44	31	26	17	11	2	2
44					1	1	1	6	17	19	26	28	35	39	27	30	40	50	45	49	40	17	5	2
45		1				1	6	17	29	70	109	118	119	133	115	101	109	131	148	118	82	40	15	11
46	20	12	6	4	6	3	15	101	232	426	593	757	739	840	763	704	741	811	899	872	670	332	144	64
47	26	7	4	3	1		19	44	95	233	355	506	481	517	483	533	523	555	605	636	549	404	154	61
48	29	16	6	2	1	4	8	13	35	115	254	340	298	346	358	390	370	386	437	400	360	373	166	64
49	29	21	6	2	5	3	8	8	15	68	164	308	273	214	287	346	360	365	315	280	291	347	167	71
50	24	13	7	5	1	5	7	10	10	29	102	281	346	176	221	282	410	365	222	181	200	220	186	85
51	30	15	10	5	4	4	5	5	9	19	56	310	472	213	209	211	390	423	206	194	129	166	160	84
52	20	17	11	5	9	4	13	7	5	12	36	206	547	219	156	152	249	429	160	141	98	127	115	61
53	29	10	12	1	5	4	13	12	1	10	16	127	348	217	163	131	173	328	163	89	94	81	95	61
54	19	12	8	5	10	7	16	19	8	9	17	48	213	269	180	119	124	198	166	74	43	75	89	50
55	16	8	5	2	6	23	29	15	7	5	10	25	101	142	174	128	105	119	145	65	38	50	68	36
56	26	14	12	2	6	19	30	30	11	7	5	17	54	80	208	167	95	103	104	62	37	45	47	38
57	14	8	3	2	15	21	44	35	20	10	4	10	17	50	249	229	130	82	75	43	33	25	33	31
58	12	8	7	3	14	32	57	64	30	12	2	6	12	28	188	291	147	109	62	47	24	14	38	29
59	17	5	7	5	21	57	90	116	62	12	4	2	13	25	91	355	311	177	60	34	35	21	26	34
60	49	12	5	1	17	55	118	190	87	20	9	5	6	22	119	494	537	341	104	48	26	25	35	96
61	81	16	12	8	25	52	152	244	87	37	20	7	7	25	175	625	873	567	123	44	27	30	40	108
62	39	14	8	4	17	64	178	256	115	39	14	4	3	12	46	246	562	747	156	33	20	22	32	47
63	23	12	3	4	38	81	225	292	158	55	27	5	3	7	24	98	289	465	191	38	19	19	15	13
64	13	8	5	3	25	82	207	306	186	75	38	31	3	3	4	37	135	293	189	56	22	13	12	12
65	10	13	6	7	26	84	224	397	210	87	46	19	9	7	6	20	83	196	189	74	21	6	13	10
66	5	4	9	6	31	118	225	378	254	113	52	14	18	8	5	18	27	79	137	74	18	13	12	5
67	6	5	5	8	35	123	309	418	242	128	59	35	12	9	5	8	11	48	67	66	31	17	6	6
68	32	12	20	38	201	772	2755	5394	4111	2767	2204	1509	1087	1063	901	692	582	558	554	398	243	166	168	91

Blocks: Number of Starts in each hour of day   Shaded blocks: No data available

Figure 6.1
MOBILE6 Soak Interval Matrix for whole of United States from 1995 NPTS

Soak Interval	Hour of Day 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1							1	9	5	6	2	4	3	2	1	6	7	6	2	2		2	1	
2						1		2		1		1	1	2					1		1	1		
3							1	1		1	2	2		1	1	1		1	1					
4								3		2	2	4	1		2	2	4	1	2	1				
5								1	2	3	1	1	4		1		4	4	4		1			
6									2				1		1									
7								1	1		6	1	2	1	1	2	3	1	1		1			
8												1							1					
9								1				1	1		1		3	2	2		2			
10								1	3	2	1	2	5	3	4	5	1					1		
11										1		1		1		1	1							
12											1				1	1	2	2	1			1		
13																		1	2	1				
14																				1	1			
15								1			3	3	3	1	2	3	3	3	5	3	2			
16											1		1		1									
17													1		1		2	2						
18										2	3	2	1					1						
19									1		1	2	3	1	1		1	2	1					
20								1	1		1		1			1	3	4	3	2	2			
21													1			1	1							
22									1				2			1		1	2	2				
23											2						1		1					
24													1		1	1	1	2	3		2			1
25									1	2	5	2	1	4	1		2	1	1					
26											1				1				1					
27													1	1			2	1	1					
28											1							1						
29																		1						
30							1		2	1	1	1	2	1		4	2	1		1				
31													1				1	1	2		1			
32											2	1	3	3	1	2	3	3						
33							1		1			1	2			1		3	1	1		1		
34											1	2		1		1	1							
35							1	1	1	1	2	2	2	1	2	4	1		2	1				
36															1			1		1				
37																		1						
38									2	1			1	3	2	1	3	1		3		1		
39												1					1	1	1			1		
40											2	1	2	1	2	2	1	2		2	1			
41										2			1				1					1		
42									1	1			1					3	2		1	1		
43									1	1		2	2		2		2		1	2				
44								1											1		1			
45									1		3	1				2	1	1	1	3	1			
46								2	2	3	8	6	7	9	12	8	7	5	4	7	4	3	1	
47										2	2	3	3	5	3	4	2	3	3	3	3	2	1	
48											2	1	6	3	1	4	3	2	5	6	4	6	1	
49	1		1							1		2	1	3	2	1	6	5	3	2	3	2	1	
50										1	1	1	3	1	4	3	2	1	1	3	3	4	1	
51											2	3	3	1	2	1	4		3			2	1	
52		1								1		1	5	3	2	1	1	5	2	1	1			
53						1						2	2	2		1	2	3	1	2		1		1
54													1	1		3	2	2	3	1				1
55						1								1	2	4	1	1	1		1		3	1
56															2	1	5		1	1				
57								1							3	4		1					2	
58					1		1							1	2	2				2			1	1
59									1							5	6	3			1			
60								1	1						1	6	3	4		2			1	
61			1			2	2	1					1		1	2	7	5	2	2				2
62							1	3		1						2	10	7	5					
63							2	3	1	1	1							3	4		1			
64	1					4	1	4	2	2								1	5					1
65						3	3	3		1								2	3	2	1			
66						2	2	3	3								1	1	2				1	
67					1		3	3	3	1		1		1					1	3		1		1
68	1				1	7	29	54	40	33	24	21	5	11	3	11	13	3	9	2	4	1	2	2

Blocks: Number of Starts in each hour of day   Shaded blocks: No data available

Figure 6.2
MOBILE6 Soak Interval Matrix for Washington DC MSA from 1995 NPTS

Hour of Day

Soak Interval	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1		1					1	7	6	6		7	3	3	6	6	3	1	5	2		2	1	2
2								2		1	1	2	1	1		1								
3							1	2	3	2	1	3	1	3	1	1	1	1	1					
4	1							1	2	2	5	4	1	2	6	5	3	2	1	2				
5								1	1	2	3	2	2	3	1	1	4	2	3		3			
6									2				1		1		1							
7							1	2	1		1	2	4	1	2	4	4	2					1	
8									1			1	1		1				1			1		
9							1	1	2		2	1			1		5	9	9	1	2			
10								2	3	4	5	6	7	8	5	4	4	1	1			1		
11										1	2	2		1	1	5	2		1					
12									1		1		1	2	1	2	4	4	1			1		
13						1		1	1				1			1		1	1	2				
14														1			1			2				
15								2	3	1	3	3	3	2	4	6	3	1	6	1	2		1	
16											1		1		1		1	1						
17											1		1				2	2	1					
18								1			1	3	1			1			1					
19									1	2	3	8	2	2	4	1	1			1	1			
20								2	1	1					1	2	1	4	3	2	2		1	
21													1							1				
22										1			1			2	1		2	1	1	1		
23											2				1		1							
24								1							2		1	1	2	2	1			
25										4	4	2	2	4	1	4	2	1	1					
26											2		1	1	1									
27												1	2	2			1	3	1					
28											2						1		1					
29																				1				
30							1		5	1	4	1	3	1	3	1	1	2			1			
31													2	1	2		1		1		1			
32										1	2	2	2	2	4	3	1	3			1			
33							1						2			2	1	3	1	1		2		
34								1			1	1				2					1			
35							1	1		1	3	1	5	3	3	3	1	2	5	3				
36										1	3		1		1			1		1	1			
37																1		1						
38										3			3	3		2	2	3		5	1	1		
39												2					1	1		1		1		
40								1		1		2	5		3	2	1	7	3	3	1	1		
41								1	1	2				2	1		1				1	1		
42											1	1	2	3		1		4	5	3	2	1		
43										1	1	4	5	4	7	1	2			1				
44								1						1		1	1			1				
45										1	4	2		3	1	2		2		3	1	1		
46	1							2	1	4	10	12	7	15	13	10	10	5	12	10	12	5	3	1
47									1	3	6	4	10	8	3	5	4	6	4	9	6	2	1	1
48								1		1	4	3	7	5	5	10	4	2	10	6	4	7	3	
49	1									2	1	4	5	4	2	2	5	6	7	1	6	3	5	
50											1		1	5	4	5	3	5	3	3	3	3	3	
51	1										3	5	7	4	2	3	11	10	6			3	1	1
52	1									2	1	5	5	2	3	1	5	8	5	2	3		2	1
53												4	4	8			3	5	1	2		2	1	5
54											1		5	5	1	3	4	3	2	2	2		2	
55						1						1	2	1	1	4	2	1	1	1	1	1	4	1
56	1						2	1						1	4		5				1	1		1
57	1						1	1						1	1	7		3		1			2	
58	1				1	1	1			1					1	3	1			1			1	1
59	1						3	1	2	1			1			5	6	3	1		1		1	
60					1	1		2	2						2	7	7	4	1	1	1		1	
61	1	2				2	1	7	2		1				2	10	10	13	2	2			1	3
62						1	1	5			1					2	9	15	4	1				
63							4	2	5	1					1		2	7	5					
64	1					2	2	6	4	2	1							4	5	1	1			1
65						2	6	5	6	1	1						1	2	2	2				
66						2	3	2	3			1						1	3		1			
67				1	1		2	4	5	2		1				1				3				
68					3	10	48	60	58	51	36	25	8	16	13	8	10	5	8	3	5	3	3	2

Blocks: Number of Starts in each hour of day   Shaded blocks: No data available

Figure 6.3
MOBILE6 Soak Interval Matrix for Commonwealth of Virginia from 1995 NPTS

Soak Interval	Hour of Day													
	5AM-7AM	7AM-8AM	8AM-9AM	9AM-10AM	10AM-11AM	1AM-12NOO	12NOON-1PM	1PM-4PM	4PM-5PM	5PM-6PM	6PM-7PM	7PM-8PM	8PM-11PM	11PM-5AM
1	190	565	628	460	364	373	388	1280	541	496	344	217	367	117
2	22	61	118	92	96	101	86	257	125	120	90	73	96	14
3	48	116	154	139	142	163	157	435	103	80	57	42	56	20
4	39	149	230	277	252	299	284	855	224	189	123	95	158	24
5	73	182	203	156	152	153	153	475	312	372	281	163	263	56
6	14	28	57	47	50	71	57	202	50	43	27	20	23	3
7	29	81	147	157	203	221	206	663	224	217	156	107	165	31
8	5	23	32	54	55	55	49	153	60	63	55	34	44	13
9	54	137	130	97	114	120	114	327	304	398	288	208	270	36
10	15	51	183	294	303	345	309	940	224	141	101	78	71	31
11	8	41	65	130	113	149	147	378	55	27	19	11	7	8
12	1	7	38	60	76	85	91	253	99	121	68	47	72	7
13	15	32	26	15	26	42	43	101	75	78	71	41	52	15
14		2	30	31	31	45	45	139	65	59	54	32	45	9
15	35	76	163	242	310	389	358	1039	411	389	306	193	321	46
16	8	20	18	24	35	37	42	118	35	39	17	20	27	2
17	3	7	17	29	36	53	53	143	73	62	57	44	58	11
18	6	9	31	61	72	78	74	244	48	45	25	19	24	12
19	4	12	66	177	248	314	279	775	187	84	61	40	56	6
20	20	51	61	49	64	68	67	175	195	251	206	180	217	18
21	2	4	12	12	20	29	23	89	27	14	12	15	14	
22	2	15	29	90	112	122	141	373	103	116	81	87	99	8
23	2	2	9	15	39	29	35	115	45	44	24	18	28	5
24	13	34	48	37	33	34	62	126	173	241	229	178	191	17
25		9	78	147	227	293	302	804	154	72	67	34	51	17
26	2	15	35	52	92	92	133	292	48	14	9	8	11	3
27		4	9	37	47	51	86	159	68	62	62	46	44	4
28	3	16	15	14	16	19	26	70	34	39	47	39	35	7
29		4	9	16	22	28	31	107	47	32	22	22	20	1
30	14	45	95	145	195	209	272	618	235	239	196	144	147	21
31		8	13	26	41	40	67	173	42	63	46	38	48	4
32	4	21	52	112	172	193	280	639	184	81	51	38	45	7
33	8	30	49	56	63	59	70	194	94	166	174	117	126	14
34	5	12	20	57	68	95	124	309	91	73	79	68	67	7
35	13	36	84	129	169	212	287	675	238	228	230	149	206	28
36	2	6	30	49	78	81	110	263	63	50	30	35	33	1
37	4	8	33	19	24	25	41	91	61	54	33	35	48	2
38	14	22	75	102	185	192	247	661	205	195	228	172	167	34
39	2	6	25	39	48	56	81	192	47	51	49	32	43	4
40	10	21	71	124	180	207	259	696	206	204	222	154	247	31
41	6	8	27	50	68	68	105	282	75	84	61	64	74	8
42	4	22	51	28	44	43	53	139	52	186	188	162	202	10
43	2	7	33	109	179	223	238	793	180	50	44	36	42	19
44	2	6	19	24	33	41	42	139	49	77	61	60	75	9
45	8	26	33	88	142	161	165	480	147	170	191	147	179	20
46	21	116	285	565	804	1088	1081	3208	996	1059	1158	1087	1445	171
47	20	45	114	281	467	695	737	2193	729	715	756	787	1394	179
48	16	18	45	137	319	465	499	1549	543	520	549	497	1169	172
49	15	10	21	88	194	384	438	1192	487	495	424	382	1030	199
50	14	11	13	44	127	324	438	959	505	462	299	246	778	208
51	12	7	11	23	66	350	529	838	491	506	283	236	595	217
52	19	10	7	16	50	234	595	710	331	510	198	181	454	191
53	22	19	1	13	18	144	388	625	242	425	218	141	342	171
54	24	21	12	13	22	55	234	656	168	267	218	108	286	152
55	67	22	8	6	14	29	109	511	154	160	188	90	215	124
56	60	35	13	8	7	21	62	505	124	135	144	83	183	137
57	79	40	30	13	7	13	22	574	164	113	108	72	138	115
58	104	76	42	14	5	6	18	549	167	144	93	73	121	96
59	172	138	79	16	9	3	20	511	331	206	97	49	126	128
60	196	213	104	34	18	7	12	710	566	373	126	57	123	217
61	234	266	111	52	31	12	8	909	905	609	141	55	133	296
62	270	282	142	62	23	12	4	332	583	796	173	51	100	157
63	334	324	184	87	42	13	8	141	305	485	207	43	80	117
64	318	340	221	114	67	42	6	52	144	306	208	62	70	88
65	342	426	246	119	81	36	19	39	86	205	204	82	57	85
66	367	411	285	159	87	30	22	37	29	82	147	80	56	76
67	467	461	286	174	95	51	16	29	12	52	73	69	70	82
68	3907	5931	4991	4095	3430	2433	1739	4134	899	799	753	556	761	517

Blocks: Number of starts in each hour of day   Shaded blocks: No data available

Figure 6.4
Condensed Soak Interval Matrix for Whole of United States from 1995 NPTS

Soak Interval	5AM-7AM	7AM-8AM	8AM-9AM	9AM-10AM	10AM-11AM	1AM-12NOO	2NOON-1PM	1PM-4PM	4PM-5PM	5PM-6PM	6PM-7PM	7PM-8PM	8PM-11PM	11PM-5AM
1	1	9	6	7	2	5	3	14	7	9	2	5	6	1
2	1	2		1		1	1	3			1	1	2	
3	1	1	1	1	2	3		3		1	1			
4		3	1	3	3	7	1	4	5	1	2	1		
5		1	3	4	1	2	4	3	5	4	4		1	1
6			2				1	1					2	
7		1	2		7	2	2	6	4	2	1		1	1
8						1				1	1			
9		1				3	1	4	3	3	2	3	4	
10		1	3	2	2	3	7	15	2				1	
11				1	1	3		2	1					
12					1			4	2	2	3		1	
13								1		1	2	1	1	2
14								1				1	1	
15		1			6	5	6	6	3	5	5	3	4	
16					1	1	3	2						
17							1	1	2	3				
18				2	3	3	1			1			1	
19			1		3	3	3	4	1	2	1		1	
20		1	1		1		1	2	3	4	4	3	3	
21							1	1	1					
22			1		1		2	4	2	3	2	2		
23					2				1	1	1			
24							1	2	2	2	3		2	1
25			1	2	7	2	4	8	4	1	1			
26			1		1			2			1			
27					1		1	1	2	1	1			
28					1					1				
29								1		1				
30	1		3	3	2	2	3	6	2	2	1	2		1
31							1		1	1	3		1	
32					2	2	3	6	3	3				
33	1		1		1	1	2	2	1	4	1	2	1	
34				1	1	2		2	1		1			
35	1	1	1	1	4	3	3	9	1		2	1		
36								2		1		1		
37			1						1	1				
38			2	1		2	1	6	3	1	2	3	1	1
39						1	1		1	1	1		1	
40					2	1	2	6	1	2		2	2	
41				2	1		2	1	1	1			2	
42			1	1			1	1	1	3	2	1	3	
43			1	2	2	5	5	3	2		1	2		
44		1									1		1	
45			1		3	1	2	6	1	1	1	3	1	
46		2	2	3	11	9	11	40	13	7	7	11	11	2
47				5	7	7	6	23	4	10	3	6	10	1
48					3	1	11	17	6	2	6	7	14	1
49			1	1		2	4	9	6	7	4	5	10	2
50				1	1	1	4	15	2	3	3	3	10	2
51					2	3	3	6	6	2	4	1	7	
52				1		2	6	10	2	7	2	1	5	2
53	1					2	3	6	3	3	3	2	2	1
54					1		1	7	3	6	3	1	1	1
55	1							8	1	1	2		4	4
56								3	5		2	1	1	
57	1	1						8		2	2		2	1
58	1							5	1		1	3	1	3
59			1					6	6	4			2	
60	1	1	1		1			8	3	4		2	1	3
61	4	2					1	4	7	6	2	2	1	4
62	2	3		2				3	10	7	5			
63	2	4	2	1	1	1				4	4		1	
64	5	5	3	2	2					1	7	1	1	2
65	6	3	1	4		1				2	3	2	1	
66	5	5	3	3	1				1	1	2		1	
67	3	3	4	2	1	2		1			2	3	1	2
68	39	60	59	51	41	45	13	47	18	5	9	5	15	4

Blocks: Number of starts in each hour of day   Shaded blocks: No data available

Figure 6.5
Condensed Soak Interval Matrix for Washington DC MSA from 1995 NPTS

Hour of Day

Soak Interval

	5AM-7AM	7AM-8AM	8AM-9AM	9AM-10AM	10AM-11AM	1AM-12NOO	2NOON-1PM	1PM-4PM	4PM-5PM	5PM-6PM	6PM-7PM	7PM-8PM	8PM-11PM	11PM-5AM
1	1	7	6	7	4	11	4	19	6	3	5	5	4	3
2		2	1	1	2	2	1	3		1	1			
3	1	2	5	2	1	4	2	5	1	1	1			
4		1	3	3	6	7	2	14	5	3	1	2		1
5		1	2	2	5	3	3	8	6	4	3		3	
6			2				1	2	1					
7	1	2	2		2	2	5	11	5	3		1	1	
8			1			1	2	1		1	1		1	
9	2	1	2		3	3		2	5	12	10	3	4	
10		2	3	4	5	7	9	23	5	1	1		1	
11				1	4	3		7	2		1			
12			1		1		3	7	4	4	1		1	
13	1	1	1				1	1	1	1	1	2		1
14				1				1	1		2	3	1	
15		2	3	1	5	5	6	16	5	2	7	1	6	
16					1		2	1	1	2			1	
17					1	2	2	1	2	2	1		1	
18		1			1	3	1	4			1			
19			1	4	7	11	3	11	3			1	3	1
20		2	1	2				4	1	4	4	2	4	
21							1					1		
22				1	1		1	4	4		2	1	2	
23					2			1	1					
24		1				1		3	2	1	2	2	1	
25				5	5	3	7	15	3	1	1		1	
26			1		2	1	2	2						
27					1	1	2	2	1	4	1		1	
28					2				1		1			
29												1		
30	1		6	1	5	3	4	5	3	5		1	1	1
31							3	3	1	1	1		1	
32				2	2	4	4	10	2	3	1		1	
33	1				1		2	2	2	4	1	1	2	
34		1		2	2	1		3	1	1	1		1	
35	1	1		1	7	3	6	12	2	2	7	3	1	
36				1	3		1	2		1		1	1	
37								1	1	1				
38				3			5	11	2	4	1	5	2	1
39						3	1	1	1	1		1	1	
40		1		3		2	5	8	2	7	3	3	4	
41		1	1	2	1			4	1		1		2	
42					1	1	2	5	1	4	6	3	5	
43				2	3	8	6	14	2			1		
44		1			2			2	1	2		1		
45				1	5	3	1	11	1	2	1	3	2	
46		2	1	5	16	15	11	49	14	12	18	14	28	4
47			1	5	11	8	16	27	12	13	6	14	13	2
48		1	1	1	4	5	15	32	6	6	10	7	17	3
49			1	2	1	5	10	16	6	8	8	3	18	1
50					1	1	4	19	3	6	4	5	13	2
51					4	9	7	12	12	12	9	1	7	2
52				2	1	6	5	9	6	10	5	2	8	2
53						4	5	12	4	6	1	4	6	6
54					1		5	10	6	4	2	4	4	2
55	2					1	2	8	2	1	2	1	7	1
56	2	1						5	5	2	1		2	2
57	1	1						10		3	2	1	2	2
58	2			2				4	1	1	1	3	1	4
59	3	2	2	1			1	7	6	5	1		3	1
60	1	3	2		1			10	7	5	1	1	3	1
61	3	9	3		1			16	11	14	2	2	2	6
62	4	5	1	1	1			2	10	18	4	1	1	
63	4	3	5	2		1		1	4	8	5			
64	6	6	5	2	1		1			4	6	2	1	2
65	9	7	9	3	1				1	2	2	2		1
66	6	5	3			1				1	3		1	1
67	3	4	6	3	1	1		1			1	3	1	2
68	65	67	82	78	66	39	17	67	13	8	9	6	15	5

Blocks: Number of starts in each hour of day   Shaded blocks: No data available

Figure 6.6
Condensed Soak Interval Matrix for Commonwealth of Virginia from 1995 NPTS

6.2 Starts Per day

The modeling setup for MOBILE6 is structured to seek starts per day input by vehicle class and vehicle age. MOBILE6 classifies vehicle age into 25 vehicle age groups with 24 separate age groups for vehicles with vehicle ages from 1 to 24 and one vehicle age group for vehicles with vehicle age 25years or more. This input requires the starts per day distribution for 18 vehicle classes (as given under EPA guidance). The 18 vehicle classes are shown in the appendix. Since NPTS data contains travel data only for personal travel, starts per day can be derived only for 3 vehicle classes, Light Duty Gasoline Vehicles (LDGV), Light Duty Gasoline Truck 1 (LDGT1) and Light Duty Gasoline Truck 2 (LDGT2). Hence this data input requires travel data to be filled in 75 cells (for weekday or weekend).

Figure 6.7 shows the starts by vehicle age matrix for whole of United States for weekday and weekend. It is observed that there are no weekend vehicle starts for vehicle age 1 and hence gives zero starts per day per vehicle, which seems to be questionable. Figure 6.8 shows the starts by vehicle age matrix for Washington DC MSA and the shaded blocks show that there are no vehicle trips in that vehicle class for a particular vehicle age group. Hence the use of the starts per day variable derived from NPTS data seems questionable.

Nationwide			
Weekday Starts			
Vehicle age	LDGV	LDGT1	LDGT2
1	14	17	12
2	1130	294	634
3	7148	1368	2936
4	8308	1813	2956
5	8535	1410	2761
6	7843	1340	2144
7	7553	1256	1798
8	7632	1201	1803
9	8870	1591	1738
10	7772	1603	1548
11	7755	1389	1421
12	6870	1338	1006
13	4894	1024	804
14	3696	740	603
15	2162	434	293
16	1290	337	131
17	1044	284	95
18	892	208	68
19	953	352	193
20	754	277	142
21	529	229	45
22	293	135	56
23	200	67	28
24	80	80	36
>=25yrs	767	414	109

Nationwide			
Weekend Starts			
Vehicle age	LDGV	LDGT1	LDGT2
1			
2	411	64	160
3	1985	433	976
4	2561	516	1009
5	2487	380	780
6	2395	358	661
7	2325	404	524
8	1926	312	466
9	2537	421	411
10	2376	336	410
11	1760	365	390
12	1598	343	332
13	1306	181	243
14	1047	169	140
15	585	83	72
16	486	77	25
17	346	93	25
18	254	36	15
19	280	114	48
20	208	63	8
21	111	44	20
22	106	30	10
23	46	20	14
24	33	19	15
>=25yrs	245	114	55

Figure 6.7
MOBILE6 Starts by Vehicle Age Matrix for Nationwide Weekday Starts from 1995 NPTS

Washington			
Weekday Starts			
Vehicle age	LDGV	LDGT1	LDGT2
1			
2	23		16
3	106	6	38
4	98	15	29
5	72	14	15
6	69	16	27
7	80	6	14
8	141	18	11
9	87	21	6
10	81	2	5
11	71		8
12	46	14	17
13	36	8	2
14	29		10
15	17	3	
16	7		
17	6		
18	15		
19	4	2	
20	5		2
21	4		2
22	1	2	
23			
24			
>=25yrs	7		

Washington			
Weekend Starts			
Vehicle age	LDGV	LDGT1	LDGT2
1			
2	4		5
3	25	11	10
4	32		11
5	26	5	4
6	25	5	40
7	48	2	26
8	27		1
9	53		
10	27		15
11	34	2	
12	30	1	7
13	22		4
14	27		
15	6		2
16		5	
17			2
18			
19			
20			
21	2		
22			
23			5
24			
>=25yrs	4		

Figure 6.8
MOBILE6 Starts by Vehicle Age Matrix for Washington DC MSA Weekday Starts from 1995 NPTS

6.3 Recommended Applications

Should the NPTS data sample for the MSA region of interest be inadequate, as a next level of aggregation, soak times for the corresponding census division should be derived or may be soak interval based on the MSA size may also be derived [5]. The next geographic grouping in the hierarchy, census region, should only be considered when both MSA and census division data are found to be inadequate.

Since it was found that Washington DC MSA had inadequate data, the cold soak data from the census division (South Atlantic) to which it belongs or the MSA size (3,000,000 or more) to which it belongs may be used. Similarly if the NPTS data is found to be inadequate for any state, soak times for the census division to which it belongs should be used. National defaults may only be used as a last resort.

7. Sensitivity Analysis of MOBILE6

MOBILE model is used to predict CO, VOC and NO_x emissions from motor vehicles. MOBILE6 reports emission rates in grams or milligrams of pollutant per vehicle mile traveled (g/mi or mg/mi). Emission rates from MOBILE can be combined with estimates of travel activity (total vehicle miles traveled, or VMT), which also change over time, to develop highway vehicle emission inventories expressed in terms of tons per hour, day, month, season, or year. MOBILE6 allows users to calculate and report sub-components of total emissions for some pollutants.

A sensitivity analysis of MOBILE6 is carried out with respect to the travel variables derived from the 1995 NPTS data and the emission factors thus obtained are compared with the MOBILE6 default values.

7.1 MOBILE6 Emissions Classification

MOBILE6 allows users to calculate and report sub-components of total emissions for some pollutants.

- ✍ Composite Emissions
- ✍ Exhaust Emissions
    - ? Start emissions (emissions occurring from the tail pipe when the engine is turned on)
    - ? Running emissions (emissions occurring while a vehicle is driven from the tail pipe)

- ✍ Non-exhaust (often described as "evaporative") HC emissions from gasoline-fueled vehicles include:
    - ? Diurnal emissions (emissions generated by the rise in temperature during the course of a day when the vehicle is not being driven);
    - ? Hot soak emissions (emissions occurring after the end of a vehicle trip, due to the heating of the fuel, fuel lines, and fuel vapors);
    - ? Running losses (emissions occurring while a vehicle is driven, due to the heating of the fuel and fuel lines);
    - ? Resting losses (small but continuous seepage and minor leakage of gasoline vapor through faulty connections, permeable hoses, and other components of the fuel system);
    - ? Refueling emissions (vapors that escape into the atmosphere when incoming liquid fuel displaces vapors in the vehicle fuel tank).

Similarly, MOBILE6 can report emissions by roadway type, time of day, vehicle category, and other characteristics that allow for very detailed modeling of specific local situations. MOBILE6 calculates running exhaust emissions separately from vehicle start emissions.

Based on the MOBILE6 guidance, the default variables were replaced by various travel inputs derived from NPTS data. Various combinations of these variables were given to MOBILE6 and the sensitivity of MOBILE6 to these travel variables was observed. During the sensitivity analysis, input parameters other than those being tested, were based on EPA national default. The calendar year used for modeling was 2003 and the evaluation month was July.

Table 7.1 shows a comparison among the default emission factors, emission factors obtained by changing VMT, starts distribution, cold soak and hot soak distribution (set 1) and the emission factors obtained by changing all the travel variables (set 2) derived from NPTS data. It can be seen that the start emissions are affected mostly. The CO start emissions are increased by nearly 25% for LDGT2 (set 1). The NOx start emissions are affected mostly (42% decrease for LDGV) by changing all the derived vehicle activity inputs. This decrease in the emissions is mainly due to the starts per day input variable (lower than MOBILE6 default input by 50%).

The change can be observed in the thousandth place of the emission factors but may create a large difference in terms of the total emissions when multiplied by the total miles of travel. Table 7.2 shows the emission factors obtained by changing only the starts per day variable and it is observed that the start emissions are effected mostly and the running emissions are not effected which is obvious since the starts per day input is varied. The percent changes are indicated in the table and the negative sign indicates a decrease in the emission factors.

Table 7.1
A summary of the emission factors (g/mi) obtained by replacing the MOBILE6 defaults with NPTS derived inputs

Pollutant Type	LDGV			LDGT1			LDGT2		
	MOBILE6 Default	Set 1	Set 2	MOBILE6 Default	Set 1	Set 2	MOBILE6 Default	Set 1	Set 2
Composite VOC	**0.928**	1.005	0.82	**0.937**	1.029	0.782	**1.192**	1.304	1.036
Composite CO	**10.47**	11.52	9.91	**12.03**	13.48	10.57	**15.98**	17.83	14.62
Composite NOX	**0.734**	0.775	0.694	**0.682**	0.721	0.618	**1.054**	1.108	0.988
VOC Start	**0.204**	0.274	0.152	**0.266**	0.351	0.164	**0.319**	0.423	0.215
VOC Running	**0.204**	0.206	0.206	**0.242**	0.244	0.244	**0.362**	0.365	0.365
VOC Total	**0.408**	0.48	0.358	**0.508**	0.596	0.408	**0.681**	0.788	0.58
CO Start	**2.75**	3.69	2.08	**4.14**	5.52	2.62	**5.21**	6.97	3.76
CO running	**7.71**	7.83	7.83	**7.89**	7.95	7.95	**10.77**	10.87	10.87
CO total	**10.47**	11.52	9.91	**12.03**	13.48	10.57	**15.98**	17.83	14.62
NOX Start	**0.148**	0.186	0.104	**0.156**	0.194	0.091	**0.207**	0.259	0.138
NOX Running	**0.586**	0.589	0.589	**0.526**	0.527	0.527	**0.847**	0.85	0.85
NOX Total	**0.734**	0.775	0.694	**0.682**	0.721	0.618	**1.054**	1.108	0.988
HOT Soak Loss	**0.144**	0.144	0.08	**0.11**	0.11	0.051	**0.123**	0.123	0.063
Running Loss	**0.214**	0.22	0.22	**0.161**	0.165	0.165	**0.196**	0.201	0.201
Set 1 : Emission factors obtained by replacing VMT ,starts distribution, cold and soak and hot soak distributions									
Set 2 : Emission factors obtained by replacing all the derived travel activity inputs									

Figure 7.1 shows the emission factor variations for LDGV for default, Nationwide, Washington DC and Virginia obtained by varying the cold soak distribution. The composite and the start emissions varied but the start emissions are not affected which is obvious since cold soak input affects only the start emissions. Figure 7.2 shows the change in emission factors by varying the cold soak, hot soak, VMT and starts distribution inputs. The start emissions and composite emissions are affected mostly and here is a very minor change in the running emissions. Figures 7.3, 7.4 and 7.5

respectively show the change in emission factors by varying all of the derived variables from NPTS. While deriving these emission factors, the starts per day input derived from NPTS data was used only for the nationwide emission factors and for Washington DC and Virginia the default values were used.

Table 7.2
Comparison of Emission Factors for LDGV by replacing the Starts Per Day Variable

Emissions	Default	NPTS	% Change
Composite VOC	0.928	0.774	-20%
Composite CO	10.47	9.26	-13%
Composite NOX	0.734	0.669	-10%
VOC Start	0.204	0.113	-81%
VOC Running	0.204	0.204	-0%
VOC Total	0.408	0.317	-29%
CO Start	2.75	1.55	-77%
CO running	7.71	7.71	-0%
CO total	10.47	9.26	-13%
NOX Start	0.148	0.083	-78%
NOX Running	0.586	0.586	-0%
NOX Total	0.734	0.669	-10%
HOT Soak Loss	0.144	0.080	-80%
Running Loss	0.214	0.214	-0%

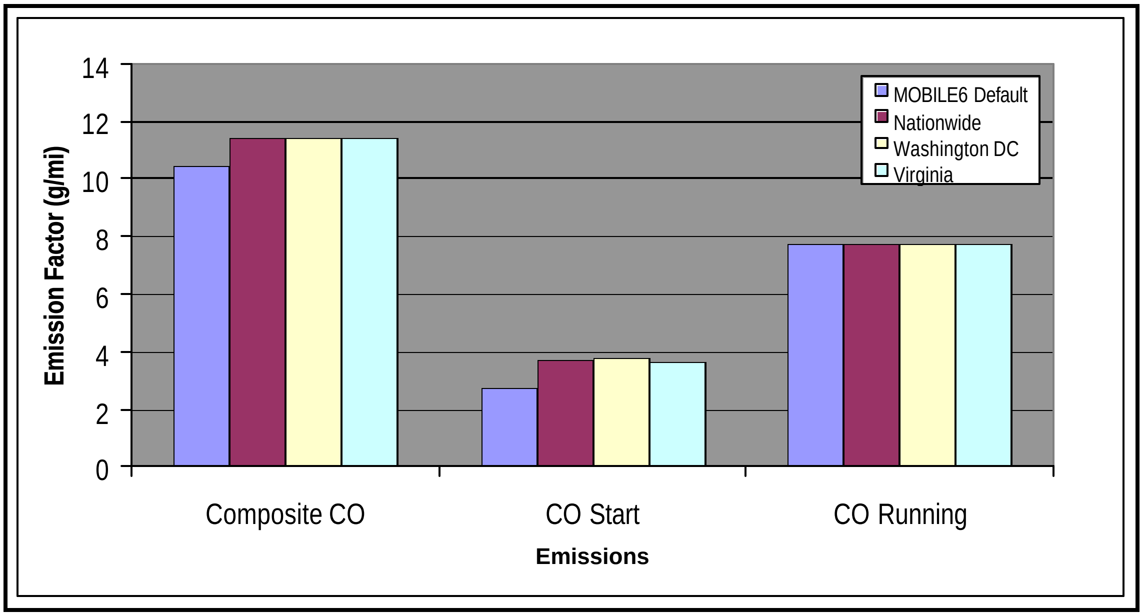


Figure 7.1
Variation of CO Emission Factors by changing the Cold Soak Input

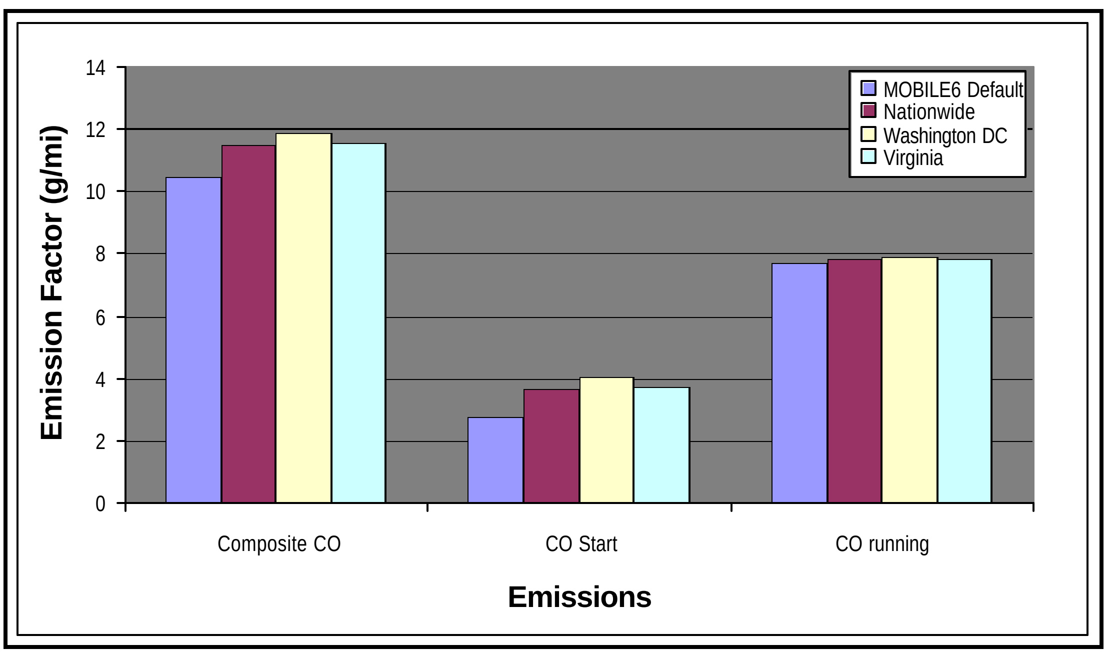


Figure 7.2
Variation of CO Emission Factors by changing Cold Soak, Hot Soak, Start Distribution and VMT Inputs

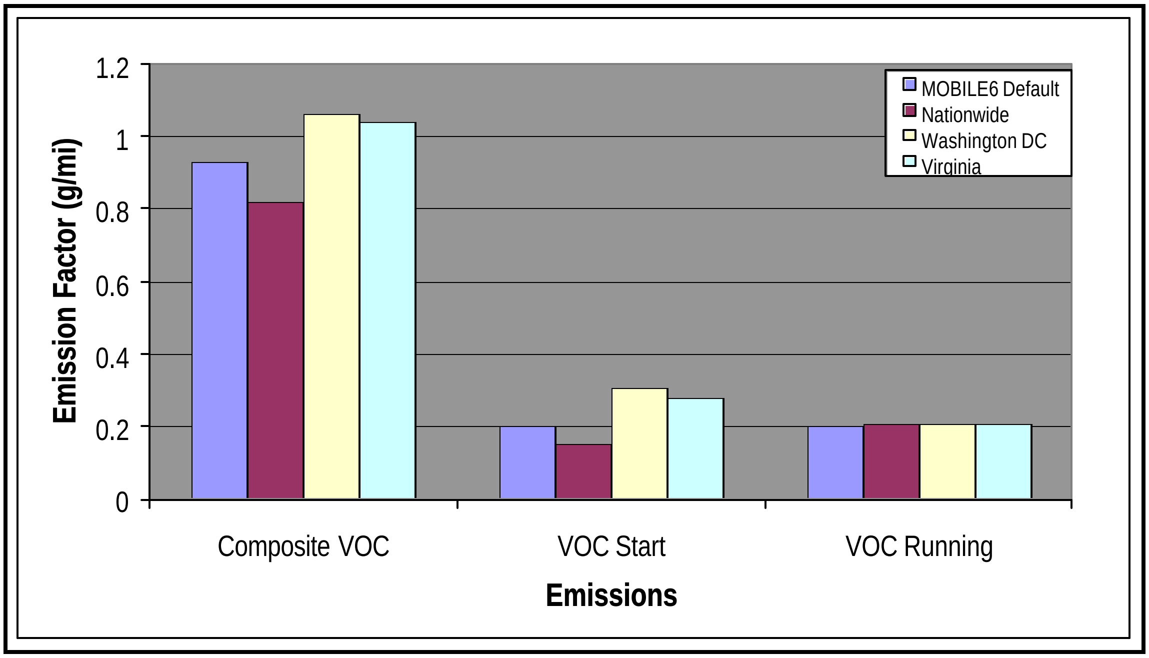


Figure 7.3
Variation of VOC Emission Factors by changing all the Derived Travel Variables

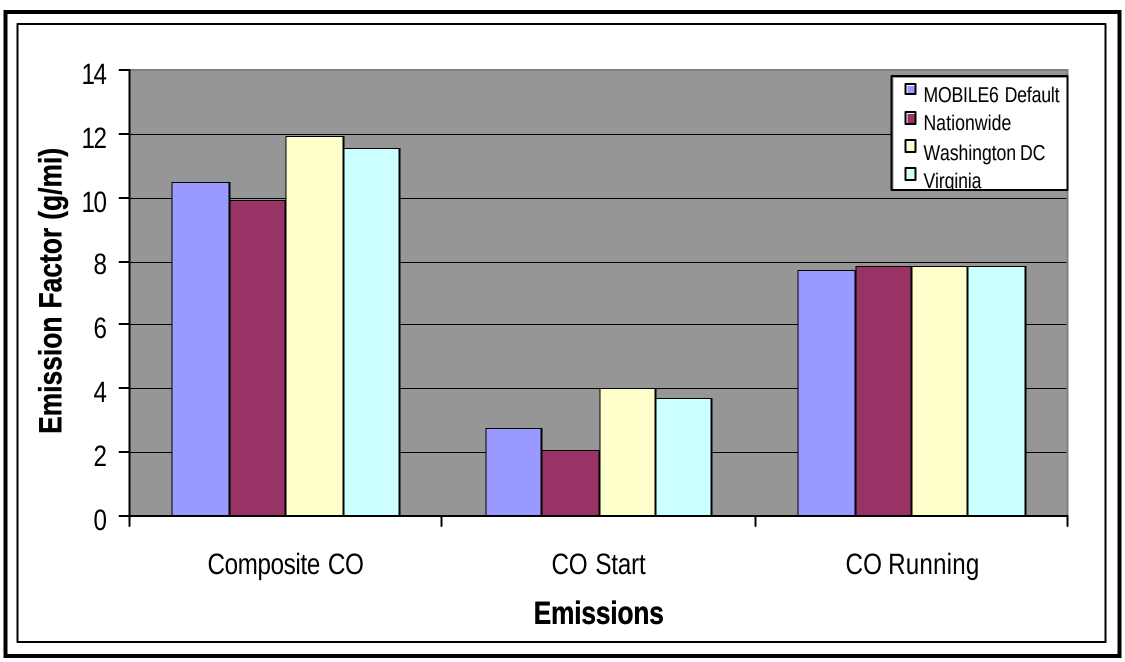


Figure 7.4
Variation of CO Emission Factors by changing all the Derived Travel Variables

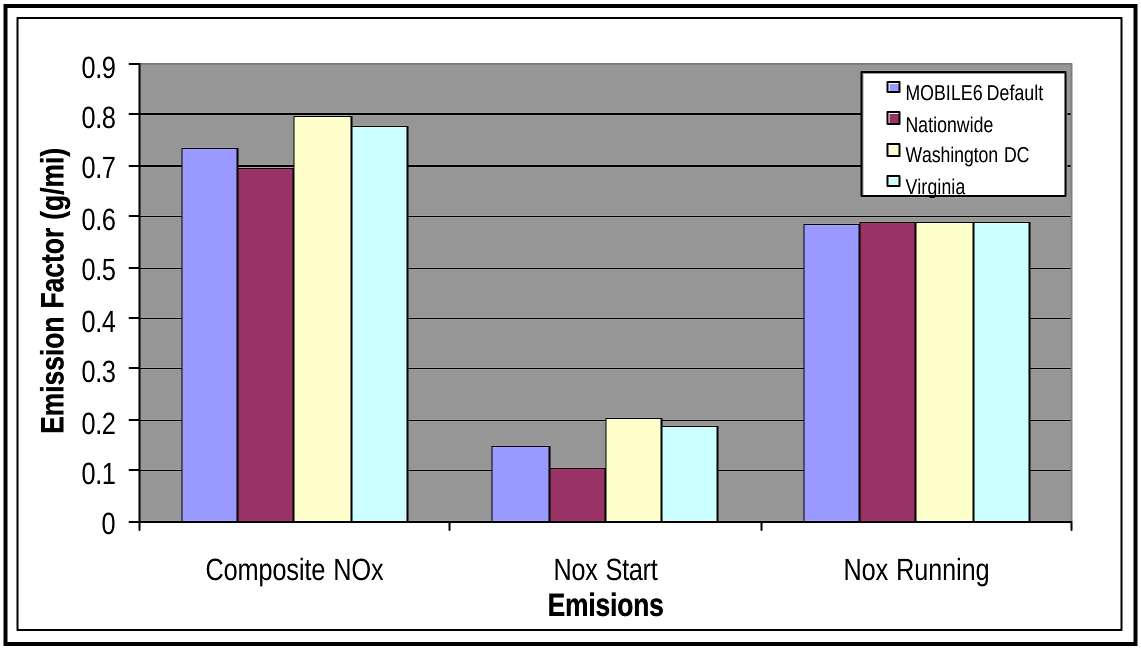


Figure 7.5
Variation of NOx Emission Factors by changing all the Derived Travel Variables

7.2 Statistical analysis for the emission factors

Venigalla et al. [5] have conducted statistical analyses to assess the usefulness of soak period distributions derived from the 1995 NPTS data. The analyses were performed in the form of analysis of variance (ANOVA) for which the responsible variable is the trip soak time and the independent variables tested were time of day, trip purpose and geographic variables such as census region, census division, MSA size and individual MSA. It was observed that all geographic levels had a statistically significant effect on soak times. In relative terms it was found that the classification “Individual MSAs” had more influence than other three geographic categories.

Similar statistical analyses were conducted in this research to determine the following:

1. Whether emission factors obtained with the NPTS input parameters significantly differ from those obtained from MOBILE6 defaults.
2. Whether the above differences vary significantly among various geographies.

In the first case, the analysis was performed in the form of a pair-wise comparison between the emission factors obtained by replacing the MOBILE6 default inputs with the NPTS derived inputs and the MOBILE6 default emission factors. The analysis was performed for the VOC, CO and NOX composite, start and running emissions. The variable for analysis is the percent difference between the MOBILE6 default emission and the emission factors obtained by replacing the default inputs with the NPTS data derived inputs.

The null hypothesis (research hypothesis) is: the percent difference between the default values and the NPTS derived emission factors is not equal to zero. The alternative hypothesis is: the percent difference between the default values and the NPTS derived emission factors is equal to zero. The results of this analysis are summarized in Table 7.6. The p-value indicates the probability of a Type 1 error in which the null hypothesis is rejected when it is true. Hence the low p-value indicates that the null hypothesis holds good and there is statistically significant difference between the default MOBILE6 emission factors and the NPTS derived emission factors.

Table 7.3
Summary of the student's t test for analysis of the emission factors

Emissions	t-statistic	p-value
Composite VOC	133.55	<.0001
Composite CO	157.53	<.0001
Composite NOx	185.7	<.0001
VOC Start	139.83	<.0001
CO Start	122.13	<.0001
NOx Start	155.66	<.0001
VOC Running	24.78	<.0001
CO Running	24.89	<.0001
NOx Running	20.39	<.0001

In the second case, the null hypothesis (research hypothesis) is: the emission factors vary significantly among the various geographic regions. The alternative hypothesis is: the variation is not significant. The analysis was performed in the form of analysis of variance (ANOVA). The response variable for the analysis is the emission factor for Light Duty Gasoline Vehicles (LDGV) class and the independent variables tested are the geographic variables such as the census region, census division and MSA size. There will be only one value for the response variable in each cell, which is the transformed value of the percent difference between the MOBILE6 default emission, and the emission factors obtained by replacing the default inputs with the NPTS data derived inputs. This dependent variable is transformed to stabilize the variance. An appropriate transformation for this case is the arc sine transformation, which is performed as follows

$$Y' = 2\text{arcsin}\text{v}Y$$

Where, Y is the dependent variable

The results of this analysis are summarized in Table 7.4. The p-value indicates the probability of the Type1 error in which the null hypothesis is rejected when it is true. The high p values indicate that the null hypothesis does and hold good and there is statistically no significance that the emission factors varied among the various geographic classifications.

Table 7.4
Summary analysis of variance for the emission factors

Emissions	F-statistic	p-value
Composite VOC	0.81	0.4635
Composite CO	0.55	0.5886
Composite NOx	0.57	0.5771
VOC Start	0.1	0.9070
CO Start	0.18	0.8388
NOx Start	0.22	0.8022

The following observations are recorded based on the statistical analyses and the values shown in tables 7.3 and 7.4.

- The emission factors varied significantly from the MOBILE6 default emission factors. Of the composite, start and running emissions, the start and composite emissions varied significantly.
- In relative terms, among various geographical regions (census division, census region and MSA size), the variation of the emission factors is not statistically significant.

However, the analysis performed is very limited in scope where true variation, if exists, could not have been captured. This can be remedied by conducting a two-factor factorial experiment wherein inputs are simultaneously varied for geographies by hour of day, and trip purpose. Such an experiment is time consuming and requires several repeated execution of MOBILE6 and it was beyond the scope of this study.

8. Conclusion and Recommendations

NPTS data has been studied and analyzed thoroughly to derive the travel variables that are required as inputs to MOBILE6. A thorough examination of the relationship between MOBILE6 input parameters and the relative importance of these parameters in deriving the emission factors have been studied. Each parameter evaluated was varied and the resulting MOBILE6 emissions were compared to emissions determined with default inputs. The following conclusions were drawn based on the observations.

8.1 Conclusions

- Several of the travel related variables could be derived using NPTS data.
- Travel variable inputs vary significantly from MOBILE6 defaults, which are most popularly used for getting the locality specific emission factors.
- MOBILE6 has been found to be sensitive to these inputs, which makes it a worthwhile effort to derive the input variables from NPTS or other survey data.
- Care must be taken to use the inputs derived from NPTS data, as there are data gaps that can be adjusted for by following the suggested recommendations.

8.2 Recommendations

- Local survey data is preferred to NPTS data to derive the locality specific variables.
- Analysis must be based on latest NPTS data (if NPTS must be used)

- ✍ Certain degree of data analysis background is needed to mine survey databases for use in deriving MOBILE6 inputs and hence NPTS data has been found to be ideal for deriving an automated data-mining tool to shield regular MOBILE6 users from the complexities of the analysis of the travel variables. Also, the tool will ensure certain degree of uniformity in practice across the nation.

8.3 Development of TRIMM

The discussion provided in the earlier chapter of this report focused on certain issues with data screening and analysis of travel survey databases. Using the NPTS data for deriving MOBILE6 input files requires certain degree of data analysis skills. Furthermore, uniform data screening techniques have to be adhered to, the failure of which may result in lack of consistency. The data screening and analysis steps described in this research require fairly sophisticated database and information processing skills. Time and personnel resources are other impediments to ubiquitous deployment of the techniques described in this report. A simple solution to these issues is to develop an automated tool that would evaluate locality specific MOBILE6 inputs and extract the pertinent information in the form of MOBILE6 input files.

A database application tool called TRIMM (for Travel Related Inputs Model for MOBILE6) was developed to shield the MOBILE6 modelers from the complexities of the analysis of the travel variables. TRIMM ha been designed to perform several data mining tasks on the NPTS and NHTS data. The purpose of this tool is to derive certain vehicle activity MOBILE6 input files from travel survey data. TRIMM provides the MPBILE6 input files for various geographic regions. These input files can be directly used to run MOBILE6 and get the emission factors. Thus, TRIMM makes the vehicle activity derivation a simple process for an average MOBILE6 user.

8.3.1 TRIMM Features

Travel Related Inputs Model for MOBILE6 (TRIMM) , an automated tool for deriving vehicle activity data input files for MOBILE6 has the following characteristics:

- Can automatically mine three NPTS databases (1990, 1995 , 2000) based and can write files from the database selected.
- Provides the option of choosing as many vehicle activity input files required by the user.
- Also provides the option of choosing the input files for various geographic levels of aggregation (Nationwide, Census Region, Census Division, and Statewide). If these is insufficient data for any of the selected geographic level, TRIMM also provides the option of choosing the next higher geographic aggregation level to the user.
- Provides the files in the form of MOBILE6 input format and these files can be replaced with the default input files.
- Users can compare the variables within the various geographic variables and also with other geographies.
- Users are also provided with an option to compare NPTS based inputs to M6 defaults in the form of tables and charts.

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Appendix A

A.1 A list of MOBILE6 Input Parameters

- Calendar year
- Month (January, July)
- Hourly Temperature
- Altitude (high, low)
- Weekend/weekday
- Fuel characteristics (Reid vapor pressure, sulfur content, oxygenate content, etc.)
- Humidity and solar load
- Registration (age) distribution by vehicle class
- Annual mileage accumulation by vehicle class
- Diesel sales fractions by vehicle class and model year
- Average speed distribution by hour and roadway
- Distribution of vehicle miles traveled by roadway type
- Engine starts per day by vehicle class and distribution by hour
- Engine start soak time distribution by hour
- Trip end distribution by hour
- Average trip length distribution
- Hot soak duration
- Distribution of vehicle miles traveled by vehicle class
- Full, partial, and multiple diurnal distribution by hour
- Inspection and maintenance (I/M) program description
- Anti-tampering inspection program description
- Stage II refueling emissions inspection program description
- Natural gas vehicle fractions
- HC species output
- Particle size cutoff
- Emission factors for PM and HAPs
- Output format specifications and selections

Source: ***http://www.epa.gov/otaq/models/mobile6/r02001.pdf***

A.2 MOBILE6 Pollutant Categories

MOBILE6 Pollutant Categories		
Number	*Abbreviation*	*Description*
1	HC	Hydrocarbons (gaseous)
2	CO	Carbon Monoxide (gaseous)
3	NOx	Oxides of Nitrogen (gaseous)
4	CO_2	Carbon Dioxide (gaseous)
5 thru 6	(reserved)	
7	SO_4	Sulfate Portion of Exhaust Particulate
8	OCARBON	Organic Carbon Portion of Diesel Exhaust Particulate
9	ECARBON	Elemental Carbon Portion of Diesel Exhaust Particulate
10	GASPM	Total Carbon Portion of Gasoline Exhaust Particulate
11	Lead	Lead Portion of Exhaust Particulate
12	SO_2	Sulfur Dioxide (gaseous)
13	NH_3	Ammonia (gaseous)
14	Brake	Brake Wear Particulate
15	Tire	Tire Wear Particulate
16	BENZ	Benzene
17	MTBE	Methyl Tertiary Butyl Ether
18	BUTA	1,3-Butadiene
19	FORM	Formaldehyde
20	ACET	Acetaldehyde
21	ACRO	Acrolein

Source: ***http://www.epa.gov/otaq/models/mobile6/r02001.pdf***

A.3 Vehicle Classes affected by the starts per day command

Vehicle Classes Affected By the STARTS PER DAY Command		
Number	**Abbreviation**	**Description**
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3751-5750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5750 lbs. ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, 5751 lbs. and greater ALVW)
6	HDGV2B	Class 2b Heavy-Duty Gasoline Vehicles (8501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8A	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8B	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1 and 2 (0-6,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

Source: ***http://www.epa.gov/otaq/models/mobile6/r02001.pdf***